THE FORESTER

A PRACTICAL TREATISE ON BRITISH FORESTRY AND ARBORICULTURE FOR LANDOWNERS, LAND AGENTS, AND FORESTERS

BY

JOHN NISBET, D.Œc.

FORMERLY CONSERVATOR OF FORESTS, BURMA
AUTHOR OF
'BURMA UNDER BRITISH RULE,' 'BRITISH FOREST TREES,' 'STUDIES IN FORESTRY,'
'OUR FORESTS AND WOODLANDS,' ETC.
AND EDITOR OF THE
SIXTH EDITION OF 'THE FORESTER,' BY THE LATE JAMES BROWN, LL.D.

IN TWO VOLUMES

VOL. II.

WILLIAM BLACKWOOD AND SONS
EDINBURGH AND LONDON
MCMV

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PROTECTION OF WOODLANDS

BRITISH LITERATURE.

Brown and Nisbet, *The Forester*, 6th edit., 1894 (chaps. viii. and xii.); R. Hess, *Forest Protection* (translated by W. R. Fisher, as vol. iv. of Schlich's *Manual of Forestry*), 1895; Kauschinger and Fürst, *Protection of Woodlands* (translated by J. Nisbet), 1893. Special portions are dealt with in Miss E. Ormerod's *Injurious Insects* and in R. Hartig's *Diseases of Trees* (translated by W. Somerville, and edited by H. Marshall Ward), 1895, while numerous articles on insects and fungi are to be found in the *Trans. Royal Scot. Arbor. Socy.*, and *High. and Agri. Socy. of Scot.*; in the *Jour. Royal Agri. Socy. of Eng.*, *Board of Agriculture*, and *Royal Hort. Socy.*; in the *Gardeners' Chronicle*, &c.

CHAPTER I.

PROTECTION AGAINST MEN AND HUMAN ACTIONS.

THE **Protection of Woodlands** is the oldest branch of Forestry. It teaches how danger of any sort threatening the wellbeing of timber and other woodland crops can best be prevented or remedied. In Britain protection of *forests*, after *afforestation*, took place at first solely for the benefit of the chase; but for over 420 years timber crops have continuously received more or less of legal protection (see vol. i., *Introduction*, chap. i.)

Woodlands require to be protected against injuries caused by men, farm live-stock, game, other animals (vermin), destructive birds, injurious insects, weeds, parasitic plants, and inorganic agencies. And it is perhaps most convenient to deal with this branch of Forestry in the above order.

Legislation.—Individual proprietors would be comparatively powerless to prevent malicious injury occasioned by men unless special protection were given to woodlands by Acts of Parliament. In India, France, Germany, &c., there are special forest laws for protecting woodlands against mischief and more serious acts; but in Britain there is no necessity for this, and human actions affecting proprietary rights in woodlands are controlled by the ordinary civil and criminal law. The legal protection now given in Britain to woods and plantations generally is as follows:—

In 1861 the various statutes dealing with damage to woodlands, trees, and shrubs were consolidated and amended in the *Act . . . relating to Larceny and other similar Offences* (24 & 25 Vic. cap. 96,—sect. 16, referring to "any Forest, Chase, or Purlieu," and sects. 31 to 33 and 35, referring to "trees and woods"), while protection was at the same time given to ornamental trees and shrubs under the Act relating to *Malicious Injuries to Property* (cap. 97, sects. 20 to 22 and 53). Under these it was made felony to steal any tree, shrub, or underwood, or to destroy or maliciously injure the same with intent to steal, if the value be £1 in parks, avenues, or pleasure-grounds, or £5 elsewhere; and even if the value be only over 1s., on a third offence the larceny becomes a felony, and the malicious injury is then punishable with two years' imprisonment with hard labour.

In Continental countries with extensive forests the State goes much further, and enforces rational forest laws for the general welfare. In Bavaria, for example, whenever there is danger of any insect calamity, special orders are enforced for the removal of coniferous timber to over half a mile from the forest, or for barking the logs to prevent attacks of bark-beetles in large numbers.

Boundary marks, necessary to indicate where the ownership of one proprietor ceases and that of another begins, should be erected and maintained for easy recognition by all parties concerned.

There are marked differences between English and Scots law with regard to fencing. In England—

It may be stated as a general rule of law that an owner or occupier of land is not bound to put up or maintain any fence between his own and his neighbour's land, though he must take care that no cattle or anything belonging to him strays or trespasses over the adjoining property. Any obligation to fence can only arise in virtue of a special agreement between the parties. . . . Where two persons are possessed of adjoining fields, though neither is bound to fence as against the other apart from contract, it seems that one might be able to establish a prescriptive right to call on the other to fence. . . . Although, as already stated, the owner or occupier of a field is not strictly bound to fence it, he must abide by the consequences of not doing so. Thus, if land immediately adjoining a highway is unfenced, the owner or occupier cannot complain if cattle stray on to it from the highway, and if they do, he must bear any loss caused thereby. (S. Wright, *The Law relating to Landed Estates*, 1897, pp. 205-209.)

Under Scots law a proprietor can force his neighbour to share expenditure on enclosure.[1] The law is as follows :—

The Act 1661, c. 41, ratified by 1685, c. 39, enables a proprietor to force a conterminous proprietor to concur with him in mutually enclosing their property. And, accordingly, the conterminous heritors must, under this statute, mutually bear the expense of making a march-dyke or proper fence. . . . And in the same manner, fences once made may be kept in repair at the mutual expense of the parties, or, when no longer reparable, may be reconstructed.

Where the march is a rivulet, which is not a sufficient fence, a proper fence may be built upon the spot, if it be practicable. The fence may run along one side of the stream, but if it be desired, the stream ought to run a space within the fence and a space without, that both parties may have the benefit of watering. (Bell's *Dictionary and Digest of the Law of Scotland*, 1890, p. 522.)

Boundary marks usually consist of stone walls, pillars, cairns, earthen mounds, stakes, large trees, hedgerows, green lanes, ditches, &c. Though all proprietary rights are ascertainable legally, and are easily recorded in surveys, yet the different portions of landed properties are usually specially marked off by walls, ring-fences, posts with notice-boards, hedgerows, ditches, and the like.

These different kinds of boundary vary in durability. Ditches fall into disrepair if not kept in proper order, and wooden posts rot and decay, while hedgerows also change with time, so that stone walls or pillars form on the whole the best, although the dearest, boundary marks.

When boundary stones are used for marks at angles, it is best to dress them. Stones rising 3 ft. high and dressed with square heads, on which grooved lines run from the central point to the edge in the direction of the nearest stone on each side, form the best of boundary marks, where woodlands are not enclosed and fenced. Such stones can also bear other marks, such as the initials of the proprietor, or numbers relative to woodland blocks and compartments, &c.

Boundary marks should be properly maintained. Repairs are simple at the outset, but if long delayed they often then cause considerable trouble and expense. A revision should be made once a-year, and any discrepancies noted should be immediately rectified.

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[1] Details about enclosure and fencing will be found in chap. ii.

Where the boundary happens to run through woodlands, a line should be cleared broad enough for each stone to be seen from the next, and such narrow lane should be kept clear of boughs, coppice-shoots, shrubs, &c.

When the boundary stones run the risk of getting damaged by carts, guard-stones should be placed at the sides and in front of them as a protection.

A proprietor is entitled to plant as near to the limit of his land as he likes, but the adjoining proprietor has the right to cut such branches as overhang his land.

For extensive woodland tracts, such as large State forests, a demarcation register should be kept, showing (1) name of each separate block and compartment, (2) number of boundary marks, (3) distance from mark to mark, (4) angle (in degrees) formed at each mark with the next on each side of it, (5) name of owner and nature of land marching with it, (6) points at which the boundary is intersected by roads, paths, streams, &c.

Commonage and Rights of User are practically in British woodlands confined to the Crown forests, which are not the absolute property of the State, but are more or less burdened with rights of commonage. Such rights are of the nature of real property, so far as concerns the compulsory doing of certain acts, or the not doing of certain other acts. In England the rights of commonage, &c., were at one time far more extensive than now; but matters were simplified by the legislation which took place about the end of the eighteenth century (see vol. i., *Introduction*, p. 26).

Throughout most of the Continent of Europe servitudes in woodlands date from early times, when woodland produce was of little money value. They usually originated in agreements between barons and their retainers, or the inhabitants of small neighbouring towns, or in privileges granted in return for special services; or they merely arose from use and custom, unchecked till the market value of the produce made the landowner think it worth while to interfere.

Such rights of user or **servitudes** may sometimes be of greater value than the nominal ownership of the soil, and unless limited they may ultimately extinguish any benefits derivable from possession.

The nature and the effects of servitudes over woodlands have little practical interest for Britain as compared with those in foreign countries with large woodlands, and in our colonies and dependencies—*e.g.*, India in particular. Such relate to *Timber*, for building-trade requirements, fuel, softwoods, dead wood, windfall, stumps, brushwood; *Minor Produce*, grazing, pasturage, pannage, fallen leaves for litter, tapping for resin, collection of mast and fern, turbary; *Other Rights*, such as quarrying, mining, right-of-way, right of transport by land and water.

Such servitudes frequently debar the owner in possession from utilising the land in a reasonable and economic manner for the production of timber, and sometimes even compel him to adopt an unreasonable system of management, or mismanagement. It is seldom that extensive rights of user can be continued without a great deal of friction between the landowners and those possessing the rights of user. The worst case of this in Britain is in the New Forest, some details concerning which have already been given in vol. i., *Introduction*, chap. i.[1] The Forest of Dean is also, however, burdened with heavy rights, which were thus described in the Report of the Select Committee of 1874:—

The Forest, as defined under the Act of 1831, comprised about 24,000 acres, which may be divided in this way: First of all, there are freehold lands of the Crown not subject to any rights of common at all; the Crown's private property, I may so say, freed from

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[1] Fuller details will be found in the article on *Forestry and the New Forest*, in the *Victoria County History of Hampshire*, vol. ii., 1903.

all rights of commoners, extends to between 600 and 700 acres; land which the Crown is entitled to keep enclosed for the growth of timber, under Acts passed in the reigns of Charles II. and George III., as against the rights of commoners and all other persons, with the exception of rights of free miners underneath the surface, amounts to 11,000 acres. Land of which the freehold is in the Crown, subject to claims of commoners, amounts to about 7500 acres; and the land belonging to individuals within the limits I have mentioned amounts to about 4800 acres,—those quantities together making about 24,000 acres.

As to the whole of that quantity, the title is subject to the right of free miners. Of the 4800 acres belonging to individuals, about 1640 acres consist of detached lands which have been sold by the Crown since 1788,—they are entirely detached from the main body of the forest; and a further part of the 4800 acres belonging to individuals consists of 2100 acres which are encroachments on the part belonging to the Crown, but which, under the provisions of an Act of Parliament, have been made the property of individuals.

The extinction or expropriation of such rights of user in forests is purely a matter for legislation. But so far as the protection of woodlands is concerned, proper control must be kept over those exercising rights of user. For example, if right of commonage exist over a certain acreage annually for grazing, turbary, &c., the forester must see that its exercise is strictly confined to portions of the woods declared open for the current year.

Theft and Mischief.—Any illegal act committed in woodlands is treated as a "forest offence" in countries having special forest laws (*e.g.*, India, Germany, France, &c.), but in Great Britain and Ireland it merely constitutes a "misdemeanour" under common law.

Such "offences" and "misdemeanours" vary greatly in character and degree. They may be acts of commission or of omission. They may amount to theft, punishable as larceny under the criminal law, or they may include malicious injury, similarly punishable. Or damage may be caused by negligence and want of reasonable precautions, in which case the owner must apply to the civil courts for satisfaction.

Injuries caused by malice or revenge range from petty damage up to incendiarism, often resulting in great loss. Even though the damage may happen to be slight, the intention to inflict injury is in the eye of the law a much graver offence than damage caused by want of reasonable precautions.

The statute law of the United Kingdom, passed in 1861, referring to damage to woodlands, trees, and shrubs, has already been sketched above.

The poorer classes of the rural population no more regard as theft the purloining of firewood from woodlands than do the well-to-do classes consider the smuggling of small quantities of lace, cigars, &c. for personal use, or the omission to state one's full income to the assessors of income-tax, to be a criminal act. It is the same in all countries, civilised or uncivilised. Thus in Germany, only in Saxony and Wurtemberg is the purloining of forest produce ranked as theft when the quantity stolen is of considerable value. Purloining of wood for fuel is of course most frequent during severe years, while the removal of grass takes place mostly during hot dry summers. As constant supervision of large woodlands is difficult even during day-time, the purloining of produce by night can easily take place from time to time without much risk of detection, especially if supervision be slack and the habits and movements of the foresters and woodmen have been watched.

So far as purloining of dead windfall branches for fuel, or surreptitious removal of dry poles, or cutting grass herbage on green lanes, are concerned, the growth of the timber crop is not thereby affected, and the loss hardly affects the amount of income obtainable. But the cutting out of dominant poles damages the crop, and removing large quantities of dead leaves from the soil for use as litter tends indirectly to reduce its productivity.

Carelessness is often the cause of injury to young growth, especially when standards are being barked in copsewoods or are being removed from areas regenerated naturally. And when timber is being dragged or carted out, damage to young poles and trees is often due to sheer carelessness.

Trespass does no harm to woodlands, though it disturbs game. Notice-boards stating that "Trespassers will be prosecuted according to law" are really nonsensical, because the only remedy is a civil action and a suit for damages to the extent to which actual damage of property can be proved. Any trespasser can be turned off the property, and just sufficient force as is necessary may be used to eject him if he refuses to go; but the trespass is not in itself a criminal act.

Foresters and woodreeves should be properly instructed as to what action they are to take with regard to different kinds of misdemeanours. Inspections should not be made with fixed regularity, as pilfering is kept in check when bad characters are never sure at what part of the woods the forester or one of his men may make his appearance.

Fires not only do very serious damage to young plantations and pole-woods, but often necessitate the premature felling of older crops over extensive areas. Further damage is also indirectly done by exposing the soil to the exhausting action of sun and wind. On good soil a rank growth of weeds and of coarse grasses soon springs up, while poor sandy soil becomes parched and arid. Even when the damage does not seem sufficient to necessitate the clearance of the crop, whether mature or immature, the trees are often so much disturbed in growth as to become infested with noxious insects, which find a favourable breeding-place in trees, poles, and young plantations thrown into a sickly condition after being scorched.

Fires may either occur as *ground-fires* passing over the surface-soil and burning the dead leaves and twigs lying on the ground, or else as *conflagrations* spreading among the crowns of the trees. A true *soil-fire*, where peaty land becomes ignited and the fire spreads in the peat, is rare.

Ground-fire is by far the most common form. Here the fire, beginning among dry grass or dead leaves, spreads quickly, consuming these and any other dry weeds lying on the ground. In old crops of trees with thick bark, where such dead and dry soil-covering is usually scantier than in younger woods, the damage done is seldom serious; but in young crops the plants are generally killed, and even in pole-woods the scorching of the bark often leads to sickening and death.

Conflagrations.—When once started where the soil is littered with dry dead foliage, a ground-fire soon gains in intensity and power, and in coniferous woods there is always the danger that it may develop into a *conflagration*, spreading among the crowns of the poles or trees forming the crop. And when once a conflagration has thus established itself, it may spread by wind to older crops, and leave little behind save charred stems.

Fires are mostly due to incendiarism, either to hide other offences or from malice. Next to that comes negligence, and after that sparks from railway engines,—this last being a constant danger where railway lines traverse conifer woods. Accidental fires are most often due to imprudence or negligence, such as failing to extinguish thoroughly any fire lighted by woodmen or other workmen employed in the woodlands. Such operations as burning gorse and heather for soil-preparation, or burning bark and twigs to destroy insects trapped in them, and charcoal-making, may easily cause a fire unless conducted with care to the very end.

Cigar-ends, or ash from tobacco-pipes, or still glowing matches, if thrown away without being thoroughly extinguished, may easily start a fire, as is proved by fires being frequent near pathways on holidays. Lightning is also sometimes, though seldom, the cause of a fire.

According to the present state of the law, railway companies are not liable for damage caused by fire arising from the sparks emitted by locomotives on railways which pass through woodlands, while owners of traction engines going along roads are liable for similar damage. The present non-liability of railway companies for damage done by sparks from their engines is based upon a judicial decision in 1894.[1]

The extent of the damage done by fire depends in Britain chiefly on the nature of the soil and situation, because this mainly determines the nature of the soil-covering and the kind of timber crops. Poor sandy soil covered with dry heather and coarse grasses, which become as dry as tinder in summer, is more exposed to danger from fire than fresh soil with strong growth of rank grass and herbage. And, as a rule, poor soil is usually planted with conifers, which is just the kind of crop most exposed to danger in any case, and that in which a widespread conflagration is most to be feared.

Heathery stretches planted with Scots Pine are more exposed to danger from fire than any other timber crop. Here both soil and soil-covering are usually dry, while the timber crop itself is resinous and inflammable when once fire has broken out. Young seedling growth suffers most from ground-fire when dry parched-up weeds cover the soil. Thickets and young pole-woods are most exposed to conflagrations, but the danger decreases as the crops grow older. Fires are most likely to spread in large compact woods and plantations, where also it is most difficult to extinguish them.

April and August are generally, throughout most parts of Britain, the most dangerous months for fire. During the former the dead grass and weeds are often dried by wind, and during the latter they are parched by heat; and in either case fires are easily started, and spread rapidly. Continuous drought of course increases the risk of fire, and strong winds increase the chance of a ground-fire becoming a conflagration.

[1] A *Railway-Engine Sparks Bill* was introduced into the House of Commons on 3rd March 1905.

Continental experience shows that in Central and Northern Europe danger is greatest during March, April, and May, when the last year's dead grass has been dried by continuous east winds, and when more men are at work in the woods than at other seasons, engaged in felling and extracting timber and fuel, grubbing stumps, sowing, planting, thinning, &c. From June till October the danger gradually diminishes, and during the snowy months of November to February fires are of extremely rare occurrence.

Prevention of Fire.—It is very necessary that all workmen employed in burning heath for soil-preparation, burning turf for manuring nurseries, or bark for destroying insects, &c., should be thoroughly impressed with the importance of exercising great caution in the use of fire. And they should be supervised as well as possible, to see that proper care is taken by them. Green lanes should be kept free of long grass, and woodland paths clear of inflammable matter.

Where railway lines pass through woodlands, ditches or naked strips of ground should run parallel to them on each side, and should be planted with wide belts of broad-leaved trees (*e.g.*, Birch or Robinia in Scots Pine tracts), whose non-inflammable foliage would intercept the sparks, while below these belts of trees the ground should be kept free of inflammable material to a breadth of about 20 yards by sweeping with stable-brooms or scrub-besoms.[1] If it is not desired to incur even that slight annual expense, then the Birch and Robinia should be underplanted with Sweet-Chestnut, or whatever else will grow as underwood, and kept as thick as possible. And such coppice must be separated from the woods behind by at least a good broad road kept free of inflammable material.

In extensive Scots Pine woods on dry sandy tracts, where there is always danger from fire, the whole area should be divided into moderate-sized compartments by narrow rides kept free of inflammable matter. Such rides are usually sufficient to stop a ground-fire; and in case of a conflagration they are convenient points for beginning operations to check the spread of the fire into other portions of the woods. These rides should run at right angles to the direction of the prevailing winds, or generally from N. to S. (with local deviations to N.E. and S.W., or N.W. to S.E. as required), and should be planted with a wide belt, or at any rate a fringe, of some broad-leaved tree, to assist in stopping a conflagration. For such protective belts Birch is the most suitable tree on poor sandy soil; but if Oak can grow, it also answers well if treated as coppice.

Continental Note.—In the Scots Pine woods on the North German plain lofty wooden watch-towers are erected, and cow-horns are blown from these as soon as any suspicious smoke is seen; and whenever a fire is discovered the church bells are rung continuously, and a red flag is run up to the top of the spire to make known the fact generally and call the population together to take measures for extinguishing the fire.

That the work of fire-protecting exposed forests can be successfully achieved is evident from the official statistics for the Prussian State forests during 1903. These aggregate 6,498,000 acres, by far the largest portion of which consist of Scots Pine and Spruce. Yet there were only 7 fires of any size, affecting a total area of 77½ acres, of which 65 acres were destroyed or badly damaged, and 12½ acres only slightly damaged. Of these 7 fires, 2 occurred in March, 4 in June, and 1 in July. The largest, which only destroyed 25 acres, was due to negligence, but the causes of the other 6 are unknown.

[1] A more elaborate method, in use in parts of the Scots Pine tracts of Northern Germany, is described in the *Trans. Roy. Scot. Arbor. Socy.*, vol. xvii., part ii., 1904, pp. 198-205.

Extinction of Fire.—A ground-fire may often easily be extinguished, if seen in time; but when once it has spread far, this becomes more and more difficult. Hence not a moment should be lost in trying to put out any fire discovered in or near the woods.

On being informed that a fire has broken out in extensive woodlands, any forester or woodman should at once collect as many men as possible, with axes, hoes, spades, and besoms, and go to where the fire is; and mounted messengers should, if possible, be sent to the nearest villages for assistance. On arriving where the fire is, the head man of the party should immediately dispose of the workmen in the way he thinks most likely to prevent the fire spreading. If it is still only a small ground-fire, it can often be put out by beating the burning line with green boughs cut from trees or with flat shovels, or by sweeping back the fire to where it has already passed. If the wind is at all strong, one must, on account of the smoke and heat, begin work at the flanks of the line of fire and work along these towards the centre; but when the air is still, or there is merely a slight breeze, work may be begun simultaneously at different points along the running edge of flame.

If there is a strong and steady breeze, and the fire has already established itself and made considerable headway, it is best to go ahead of the line of flame and thoroughly clear of all inflammable material a strip several yards wide, in order to check its progress. But this can only be successful if the line be cleared far enough ahead of the fire to let the removal of *débris* be completed before the line of flame reaches the cleared line; and this of course entails a sacrifice of part of the crop in order to save the rest. This measure is all the more effective if a counter fire can be started along the inside of the cleared line, so as to eat its way along the ground and meet the approaching fire. This decreases the danger of sparks being carried across the cleared line. Compartment boundaries, cart-tracks, and old paths form good lines to work from as a base, because they can be easily and quickly found and cleared. While such a line is being cleared, the work of extinguishing along the edges of the line of fire should also be vigorously carried on.

When the ground-fire is already so strong as to be likely to carry over the cleared line by means of sparks, counter-firing becomes necessary—*i.e.*, setting fire to the inner edge of the cleared line, and burning against wind, to meet the fire it is intended to check. Caution is necessary in starting such a counter-fire. The new line of fire should be sufficiently well guarded to ensure that, in place of burning against wind, it does not burn in the opposite direction and start a new fire. When once well started, however, the line of counter-fire soon eats its way towards the approaching line of original fire, as the heated air is drawn towards the main line of fire, and thus tends to attract the new line of fire towards it.

In coppices any extensive ground-fire may develop into a conflagration if it spreads to thickets and pole-woods. Extinction is then far more difficult, especially when high wind blows the smoke, flames, and heat forward. If the conflagration then extends to extensive Conifer woods, it may assume proportions that can only be checked by some such natural circumstance as a broad stretch of unplanted clearance or a belt of broad-leaved trees, or the fire may burn right through to the other side of the woods.

Broad fire-protection belts, well planted with broad-leaved trees, are the best natural means of checking conflagrations, and these should always be provided when very extensive conifer woods are formed in localities exposed to risk from fire. The path or line used as a base can be broadened, if necessary, by rapidly clearing away the trees along the outside edge. But the success of this work, as well as the rapid clearance of inflammable matter from the ground to work against a ground-fire, depend on operations being taken in hand far enough ahead of the fire to enable them to be completed before this can reach the newly cleared line. Poles and trees felled should be lopped, and the branches removed to the far side of the woods, to obviate risk of their catching fire from sparks.

When a conflagration has obtained a firm hold on thickets and young pole-woods, the leaf-canopy should be well interrupted by firing the woods along the edge of one of the interior lines, caution being of course exercised to prevent the fire spreading into woods lying behind that. But in older crops there is less danger of that sort, and the main object then is to check the ground-fire.

Fires found in the inside of hollow stems, such as may be caused by picnic parties, or smoking out bees, &c., may be put out by filling the hollow with sods of turf and earth, thus cutting off the supply of oxygen. If this cannot be done, the tree should be felled and the fire put out with earth.

Soil-Fire which may have broken out in a peat-moor can only be extinguished by digging trenches deep enough to reach the mineral soil and isolate the burning part.

When once a fire has been extinguished in a wood, watchmen should be left in charge, especially when there is any strong breeze, to see that it does not break out again. On warm nights in August a good watch should be kept all night long. Earth should be thrown on all smoking and smouldering stems which glow in the dark, and the watch should be kept till all danger is past.

Remedying Damage from Fire. — Young conifer plantations that are badly damaged usually need to be cleared and replanted; but young crops of broad-leaved trees, having greater natural recuperative power, can quite well reproduce themselves if coppiced. Among the latter, Beech is the least hardy against fire. Owing to its smooth thin bark, even a slight ground-fire injures it. The woodland crops least liable to damage are old woods, especially of thick-barked trees like Oak or Pine. When the foliage in old woods looks sickly and unhealthy after a ground-fire, or trees die off here and there, it is often necessary to clear the crop. This is especially the case in conifer woods, to obviate danger from noxious insects. After any serious fire in conifer woods, the forester and his woodmen should pay special attention to noting anything like an increase in the number of injurious insects. Attention should in particular be paid to species which breed in the roots and the lower parts of the stems of poles and trees.

CHAPTER II.

PROTECTION AGAINST FARM LIVE-STOCK, GAME, AND THE LARGER KINDS OF VERMIN.

I. **Farm Live-Stock**, consisting of cattle, horses, sheep, goats, and swine, cause damage in woods by nibbling buds, leaves, and young shoots; by gnawing and stripping bark; by injuring roots with their hard hoofs and horny feet; by bending back young growth and saplings; by dislodging soil on slopes; by stamping down damp, heavy clay soil, and loosening light sandy soil; and by breaking down the sides of drains.

The damage varies greatly, according to the kind and number of animals; but in general these may be classed in the following order: *goats*, *horses*, *sheep*, *cattle*, and *swine*. *Sheep* and *cattle* are, however, by far the most important in Britain.

1. **Goats**, fortunately seldom to be reckoned among the live-stock on British farms, are the most injurious, because, even when grass and other herbage is plentiful, they prefer to graze on leaves, buds, and young shoots. By standing on their hind-legs, they can reach up to the crowns of big sturdy saplings. Many of the mountain forests in Southern Europe have been almost totally destroyed through the unrestricted grazing of herds of goats, which devastated the seedling crops, raised by natural regeneration of old woods. There seems to be something poisonous about their bite, which is far more injurious and lasting in its effects than that of other animals.

2. **Horses** usually prefer the short grass along the sides of roads to the ranker grass growing inside the woods; but they are fond of young foliage and succulent shoots, which they can strip to a considerable height. Young horses are also fond of gnawing the bark. Their great weight and their iron-shod hoofs cause a good deal of damage to young seedlings, and to shallow superficial roots.

The English forests were at one time overrun with horses, and especially the New Forest (Hants). An Act, known as the *Drift of Forests*, had to be passed in 1540, which ordered that the forests, heaths, chases, and waste grounds should be driven once a-year, on St Michael's Day or within fifteen days after it, for ascertaining that the forests were not burdened by too many horses and cattle owned by those possessing common rights, and for killing weakly mares and foals.

3. **Sheep**, besides feeding on grass, are, like goats, fond of nibbling young leaves and shoots, and often do considerable damage when frequently grazed in any one wood, their tread tending to break up loose sandy soil only thinly overgrown with grass or weeds.

4. **Cattle**, on the other hand, which have always in Britain been grazed in large numbers in the forests and woodlands, prefer feeding on grass and other herbage, and only browse on leaves and twigs when that is scanty. But where they do feed on leaves and young succulent shoots, they bend down strong saplings under their chests to reach the foliage; and where common grazing lands are planted, they rub themselves against and damage the poles. From their weight they loosen and dislodge soil on hill-slopes, and they damage young growth with their hard horny feet, often tearing out plants along with the tufts of earth held by their roots. Where there is a very strong growth of grass in young pole-woods, however, the grazing of cattle may be of use in checking this.

Young cattle, horses, sheep, or goats do more damage than old beasts. Even where grass and herbage are plentiful, they nibble young timber crops, partly from wantonness and partly to assist operations when changing their teeth. If cattle in thin condition are grazed in woods after being poorly fed in winter, they do much damage to the young plantations, as they greedily devour all they can.

5. **Swine** were driven into the English woods from time immemorial for pannage, and in Saxon times the value of woods was estimated by the pannage afforded. But the herding of swine for pannage in the woods, formerly so important, has, like the grazing there of sheep and cattle, lost much of its early importance. In most places it is now quite a thing of the past, partly owing to the more extensive potato cultivation, and partly to the gradual clearance of the old Oak and Beech woods. Swine eat acorns and Beech-nuts greedily, and also the cotyledons of Oak and Beech seedlings; and while wallowing and snouting in the ground after grubs and mast, they root up many small plants and damage the roots of large ones. On grazing land they rub themselves against and damage young trees.

On the Continent it has been found that irregular and unchecked herding of swine can be very injurious to forests, but that the damage can easily be minimised if the herds be limited in number, and pannage be only permitted under proper supervision. In many cases swine can be of great use in woodlands. In soil-preparation for seed-fellings of Beech and for covering the mast, for example, the wallowing of swine can be very useful, while it also helps to destroy injurious insects, whose larvæ and chrysalids are eagerly devoured when found hibernating in the soil.

Damage may be prevented or reduced to a minimum if herds of swine are confined to old woods, where the tree-roots are not likely to be injured, and if there is always a swineherd in charge. If, as is usual at mast time, they are to be left all night in the woods, they should be penned at night.

In the natural regeneration of Beech-woods in Germany, the herding of swine in ordinary mast years ceases when the fall of the nuts becomes general; but in good seed years it still goes on in the enclosures undergoing regeneration, to have the benefit of their breaking up the ground by snouting and working the seed into the soil with their feet. But they are only driven in there after feeding elsewhere, so that they are unable to devour much mast before beginning to wallow and snout in the ground. If herding begins before the acorns and beech-nuts fall, or if the herds are too large, there is, of course, all the more risk of damage being done to the roots of seedlings already on the ground.

6. **The extent of the damage** caused by farm live-stock varies mainly according to the kind of animal grazed; but of course it is also dependent on various other circumstances, such as the nature and age of the timber-crop, the soil and situation, the number of the animals grazed, and the time and manner of their being herded in the woods.

Different kinds of trees suffer to a different extent through grazing. Grazing animals usually prefer the foliage of broad-leaved trees to that of conifers, and only browse on the latter in the absence of the former. But the damage done to conifers is generally by far the more serious, because they are not endowed with anything like such recuperative power as broad-leaved trees in repairing damage. The different conifers vary considerably, however, in this respect. Scots Pine, if badly bitten while young, usually remains more or less stunted, while Silver Fir soon recovers. The shallow roots of Spruce are more apt to be cut and barked by the hoofs of cattle than deep-rooting Pine and Larch. All conifers, however, are in so far more damaged by grazing, that injuries to bark or shoots enable parasitic fungi to effect an entrance; and the destruction caused by them, and by injurious insects, is far greater than in young broad-leaved crops.

Grazing animals prefer the leaves and young shoots of Beech, Ash, Elm, Oak, Maple, Sycamore, Hornbeam, and other hardwoods to those of Willows, Aspen, Poplars generally, and other softwoods; while Lime, Birch, and Alder they seldom touch. Among conifers they prefer the young succulent shoots of Silver Fir, Douglas Fir, Spruce, Larch, and Weymouth Pine to the longer and harder sprays of Scots, Austrian, and Corsican Pine. Horses and sheep usually prefer young Oak foliage to any other; while sheep graze readily on Scots Pine and Birch on poor heathery tracts, and are glad to have any such change of diet.

The younger the crop injured, the greater is generally the damage done. Young seedling crops and plantations suffer most, whereas the damage done in old crops is often confined to surface-wounds on shallow roots by horny-footed cattle. When there is a rank growth of grass the damage done by cattle and sheep is usually very slight, and grazing may then sometimes be beneficial in checking the growth of the grass and treading it under foot. Thus, on the Continent, cattle and sheep are sometimes driven in when the young crop seems likely to be damaged by rank growth of grass and weeds.

The moister and the more fertile the soil, the ranker is the growth of grass, and the less danger is there of the herds grazing on the plants, while the recuperative power of the latter is always stronger than on dry or poor land. On steep slopes there is constant risk of the soil being dislodged, and at the same time the animals grazed are much more likely to feed on the crowns of the plants growing below them than is the case on level or gently sloping ground.

Stool-shoots in coppice-woods soon outgrow the reach of cattle, and they also possess a strong reproductive power, quickly repairing any damage done even when the falls are deliberately grazed over. Goats, however, poison the shoots with their bite, and should never be allowed inside any young wood. In young coppices, even where there is a strong growth of grass, more or less damage is always done by treading down and breaking young shoots. In coppice with standards there is always more danger than in simple coppices, because the young stores are very liable to damage.

When herds are grazed in woods early in spring, before the grass has come up freely, or are kept there till late in autumn, when the grass hardens and dries, or if they have been driven in in too large numbers, or have been allowed to graze too long in any one part of the area, more damage is of course done than would otherwise be the case. During wet weather cattle prefer young foliage to grass, probably because it retains less moisture and dries more quickly.

7. **Protection against damage.**—In Britain protection against grazing, and at the same time against deer and ground-game, is secured by **Fencing** (see pp. 22-37).

On the Continent of Europe, however, and in countries like India, grazing in woodlands is still a matter of importance; and in many of these countries the action of proprietors of woodlands is limited by rules such as the following, framed under Forest Acts, and having the force of law:—

1. *The closing of Falls bearing Young Crops.*—How long the protective time should last is of course dependent on the species of crop, the conditions of its growth, and the nature of the grazing; but in any case protection must at least be given until the young woods have outgrown the reach of the cattle. The protected areas are usually distinguished by some well-known mark or visible sign, like wisps of straw bound to poles stuck in the ground, or by means of boards with the notice "*Grazing forbidden.*"

2. *Adequate Supervision.*—Grazing should only be permitted under the supervision of a herdsman, with one or two lads under him in the case of large herds. In some localities it is prescribed that all the cattle, or at any rate the majority of the animals, must be provided with bells attached to their necks, so that cases of straying away from the herd, or getting lost in grassy plantations, may the more easily be prevented or discovered.

3. *Prohibition of Grazing during the Night.*—As supervision is impossible during the night-time, grazing should neither be allowed before sunrise nor after sundown.

4. *Grazing herds should not be driven into the woods too soon in spring,* nor should they consist of a more numerous head of animals than is likely to be amply provided with fodder from the area, while, at the same time, there should be a regular and adequate change in the localities grazed over. Too long-continued grazing in autumn, after the grass has begun to dry up and wither, should also be avoided.

5. *Grazing paths, green lanes, or drives* should be kept clear where large herds are in the habit of being led out and back; and where they pass through young woods, these green lanes should either have ditches at each side, or else be fenced off with poles. This latter method should, at the same time, be adopted to protect, as well as possible, young woodland growth where it marches with the land that is being grazed over.

6. When put out on grazing land, *saplings should be protected* by being bound round with thorns, or by means of three poles inserted triangularly, and secured so as to keep off the animals from the stem.

7. Where injuries are to be feared from the treading and tramping of the cattle, the intervals between grazing should be longer, as also on steep slopes during damp weather favouring the loosening and dislodgment of the soil.

It may, however, be remarked that, even on the Continent, woodland grazing has now lost much of the importance it once had agriculturally. The acknowledged superiority of stall-feeding, the increase in the number of, and the improvement in, the meadows, and the cultivation of feeding-stuffs, have in many localities almost caused woodland grazing to be a thing of the past. It is only in mountainous districts that it is still of some importance, where the rearing of cattle is extensively engaged in, and where there is usually a dearth of meadow-land; but there the freshness of the soil on the one hand, and the atmospheric humidity on the other, combine to produce a strong growth of grass within the forests. In such places woodland grazing is still carried on to a considerable extent, and very often without the enforcement of any of the above-mentioned protective precautions; for whilst the rich growth of grass and the usual crops of conifers tend to minimise the damage done, the injury to the forest is of much less importance from a national-economic point of view than the maintenance of the cattle-rearing industry. (*Protection of Woodlands*, 1893, p. 87.)

II. **Damage by Game.**—In British rural economy more attention is generally given to game-preserving than to Forestry, even in parts of the country specially suitable for growing timber for profit. In many such places, however, there can be no doubt that a higher rental is received from shooting-tenants than is otherwise obtainable. Game-preserving, as customary on most large estates in Britain, is incompatible with profitable Forestry; and where rabbits are allowed to abound, it is almost impossible that woodlands can ever show anything but *a dead loss, properly chargeable to the game account.* On many estates thinning operations are prohibited from being carried out at the proper time, for fear of disturbing the game, although there is no real necessity for any such extreme prohibition of work in the plantations.

There is only one form of British sport which is really of some advantage to the woodlands, and that is the preservation of foxes, which help to keep down rabbits and hares. Otherwise, all forms of game-preservation tend to disturb the balance of nature (*e.g.*, shooting of vermin by gamekeepers), and of course result in more damage being done than would else be the case.

It very often happens that after enclosures are made and planted the stems of the young Oak, Ash, Maple, Hazel, &c., have their bark gnawed, and the tops are eaten off Larch, Pine, and Spruce. This is more especially the case in winter, when snow lies on the ground. Although the forester may point this out, his complaints are seldom of much use, because the gamekeeper protests that there are very few hares or rabbits; but even a few inside a large enclosure very soon multiply, and do a great amount of damage. If ground-game, in particular, were kept down more than at present, planting operations would cost less, and their results would be much more satisfactory and profitable.

In England hares and rabbits, as well as heath or moor game, are protected by the Game laws, though no close time is fixed. In Scotland the same applies to deer, hares, and rabbits. In Ireland there is a statutory close time for deer and hares.

Sport and **Forestry** are not necessarily antagonistic; on the contrary, they are closely related, and may easily be combined with profit. There is

Fig. 100.

Damage caused by Deer and Rodents.

a. Hornbeam gnawed by *Field-mice.*
b. Beech frayed by *Deer.*
c. Ash and Beech gnawed by *Rabbits.*
d. Spruce gnawed by *Squirrels.*

less *shooting*, it is true; but there is much better *sport*, in the true sense of the term, in the large forests of Continental Europe than is anywhere obtainable in Britain. The wild boar, the red-deer, and the roebuck shooting, enjoyable in Continental woodlands, is in all essential points (except the mere size of the bag) a far more sportsmanlike amusement than the shooting of very artificially preserved game in most parts of Britain. And the antlers of stags are far heavier and handsomer in woodlands than when the **deer-forests** consist only of heathery wastes. When there are extensive woodlands for game to roam about and feed in, the evils that are so marked in small woods and plantations become greatly diminished, while the sport offered is at the same time of a higher class. Existing **deer-forests** in the Highlands of Scotland might, therefore, quite easily be planted without any danger of ruining the sport.

Red-deer and roe-deer, hares and rabbits, and feathered game, all injure woodlands to a greater or less extent. The nature and extent of the damage of course varies greatly, according to the kind of game, and it can always easily be kept in check by reducing the head maintained.[1]

1. **Red-Deer** (*Cervus elaphus*) damage woods by biting off buds and young shoots, by gnawing the bark of poles in winter, and by stripping the bark in spring and summer. The nibbling of buds and shoots kills young plants at once, and when often repeated it cripples and stunts older plants, and interferes greatly with their future growth. In Oak- and Beech-woods they eat a good many acorns and beech-nuts, and soon become clever at finding and turning up seed sown for artificial reproduction; while they are fond of browsing on the young seed-leaves in Beech-woods undergoing natural regeneration. The saplings or poles used as "fraying-stocks," when rubbing the velvet from their antlers in July and August, or when they "fray" at the time of rutting in September and October, are more or less stripped of their bark and often killed outright (Fig. 100 *b*). Oak, Ash, Maple, Sycamore, and Beech are the kinds of trees which deer prefer to gnaw, while softwoods are naturally preferred as fraying-stocks, preference being given to those of such a size as to bend slightly under the pressure applied to them. The gnawing takes place horizontally, the deer turning their heads sideways and nibbling the whole of one side of the bark on poles up to a good size, so long as the rind is soft and sappy. Red-deer also tread down and damage young Oak, Beech, &c., that have been sown in strips or bands, often following the horizontal lines sown on hillsides, and doing a lot of damage when a herd of deer has thus made a run for any length of time.

The greatest damage done by red-deer, however, is when they strip the bark of poles and trees in woods. They chiefly attack young, smooth-barked, broad-leaved, and coniferous poles, especially Spruce. In winter the hungry deer both gnaw and peel the bark at about the height of their head, or higher if much snow is on the ground, and the gnawed stems then show plain

[1] What may be considered "a reasonable head of game" varies according to circumstances. In Continental woodlands it may be taken as on the average about one red-deer, or two fallow-deer, or four roe-deer, for every 150 acres of woods.

horizontal marks of teeth, with narrow lines of bark and cambium between. But far more injurious is the bark-stripping in spring and summer while the sap is in flow. The bark is then usually bitten through somewhat low down, and the deer moves back, holding on firmly with its teeth until a strip of rind from 2 or 3 to 6 ft. long tears off. Sometimes the lower end bitten through is 4 to 6 in. broad and more than half the circumference of the stem in breadth, but the strip gradually becomes narrower and more wedge-shaped until it finally comes away from the stem, often at a considerable height, when it is eaten by the deer. Gnawing and stripping in winter are no doubt often done to obtain some tonic when hay-feeding is general. But as both this and also the spring and summer stripping are chiefly done by the stags, it may possibly have some connection with the setting of their antlers. The barking of poles in summer is very much more destructive than the slighter injuries inflicted by gnawing in winter. As soon as the poles begin to form thick corky bark, deer cease their peeling.

Spruce-woods from 20 to 40 years old are specially liable to injury, then 15- to 20-year-old Beech, Silver Fir, Weymouth Pine, and Oak so long as the bark is smooth. Larch, Ash, Elm, Maple, and Sycamore are less liable to be attacked; and Scots Pine, Birch, and Alder are damaged least of all. Among conifers, Silver Fir makes the best recovery, while Scots Pine usually remains stunted after being nibbled. Young poles with a smooth rind are always attacked soonest, and the danger ends when thick rough bark is formed. The danger is greatest about the time of the first thinning of a plantation, and clean, well-grown, dominant poles are more likely to be damaged than poles still rough with twigs. Crops of poor growth are therefore to some extent protected by their numerous twigs and branches and their coarse bark. Stripping chiefly occurs in deer-parks or in enclosures where the deer are fenced in to keep them from the fields. Where a large head of game has poor natural grazing in winter, and has to be fed on hay, the damage is much greater than when a moderate head of deer can roam about in the open. In mountainous tracts, where there is more varied grazing, damage is usually comparatively slight.

Damaged poles often rot far up into the stem, and are liable to breakage from wind, snow, or ice. Even when this does not happen, the lower end of the stem is often useless for timber up to 15 or 20 ft. high.

Continental Notes.—Damage by deer was first mentioned in German forest literature about the middle of last century with reference to the Spruce forests of the Harz Mountains. But it has now gradually become of more importance, and in many localities, especially in deer-parks, it has assumed such proportions as very materially to reduce the outturn from Spruce-woods, which suffer most in this way. Bark-peeling in winter is probably in most cases due to want of sufficient nourishment or of variety in food; and in this latter case it may be diminished by laying down numerous salt-licks in convenient spots. Summer-stripping, however, is probably due to the daintiness of the deer in quest of either the sugar or the tannic properties contained in the rind. But it may perhaps be merely a continuation of the practice begun during the winter, or may simply arise from wantonness. Occasional stripping may easily develop into a habit, soon imitated by other animals in the herd; and this can only be put an end to by shooting those deer found stripping.

Reuss's investigations led him to the following conclusions—(1) that the modern method of Forestry in Germany, resulting in the formation of densely canopied, equal-aged crops in deer-parks, throughout which softwoods and shrubs become gradually suppressed, tends to an artificial and altogether unnatural method of rearing large game, because bark-stripping seldom occurs unless the deer are confined within a ring-fence; (2) that the usual monotonous feeding with hay is the principal cause of their stripping the bark, in order to provide themselves with the tannic acid necessary to stimulate the secretion of certain requisites (*e.g.*, for the formation of antlers and the process of digestion); and (3) that a movement from the feeding-trough to the peeling of bark has now almost become instinctive. (*Protection of Woodlands*, p. 96.)

Prevention of damage.—If profit is expected from the woods, it is of course essential that the number of deer should be kept within reasonable limits, and that whenever necessary during hard winter weather they should be supplied with hay, potatoes, turnips, maize, acorns, beech-nuts, and horse-chestnuts. Meadows and open spaces are required for large herds, and softwoods, Chestnuts and Horse-chestnuts, and other mast-bearing trees, should be sprinkled throughout the timber-crops. But **Enclosure** and **Fencing** are always necessary to protect plantations and natural regenerations until they outgrow the risk of being browsed on. If only of small area, these can be defiled by hanging up here and there along the edge and in the interior linen cloths that have been dipped in crude petroleum, assafœtida, bullock's blood and urine, or any similar strong-smelling substance. For park-trees one of the simplest and most effective of such applications (also useful for protection against hares and rabbits) consists of cow-dung and soot in equal proportions, thinned with water so that it can be applied like paint to the base of the stem. In Bavaria a mixture of 4 parts fresh cow-dung and 1 part coal-tar reduced with urine to the consistency of thick paint is applied with a brush or wooden spud, or with the gloved hand, to the leading shoots of conifers. But a cleaner mixture of coal-tar and petroleum (in the proportion of 8 to 1) is equally effective. This can be applied best and most cheaply with a Büttner's *double brush*, consisting of something like 2 miniature blacking-brushes on long stalks joined with a C-spring. The leading-shoot is thus held between the two brushes as in a clip, and the shoot and buds are coated by drawing the brushes upwards. A coating of slaked lime also answers, but tar alone is unsuitable, as it prevents the buds opening. Such protective measures have to be repeated each autumn, but the cost is usually only about 2s. to 2s. 6d. an acre.

Binding rough twigs round the dominating stems at the first time of thinning prevents bark-stripping. A bundle is made of fairly long twigs laid one over the other round the stem, with points downwards and thick ends reaching up to about 6 ft. above ground, and is tied firmly in two places with thin strong wire. This costs from about 10s. to 12s. 6d. per 1000 poles, and remains effective for eight to ten years. It only needs to be repeated once before the poles outgrow danger of being stripped.

The best way of preventing damage from treading plants set in horizontal lines on hillsides is to put short pole-stakes about 4½ ft. long slantingly into the ground every 20 or 30 yards, as this usually makes the deer change their run.

Nurseries have of course to be fenced to a sufficient height.

Continental Notes.—In woods where deer abound acorns and beech-nuts are sown in spring in place of autumn, especially if the sowing has to be made in strips on prepared soil. Red-deer (and wild pigs also) soon discover autumn-sown seed, and are almost sure to eat it all up during the winter. Blanks among young growth are beaten up with sturdy transplants of quick-growing species; and in some places (*e.g.*, the Harz Mountains) Spruce is planted in wisps of three to five seedlings, as it has been found that the middle plant has then a certain amount of protection. Introducing subordinate species in small patches is preferable to merely planting them singly, wherever there is any danger of their being nibbled.

In place of coating the leaders as above described, small, thin, 4-pointed, crown-shaped tin **bud-protectors** have also recently been used in Germany for fixing round the leader just below the top bud-cluster, so that the 4 sharp tin points protrude above the buds. Although these tin crowns only cost about 1s. 3d. per 1000 (weighing about 2¼ lb.), this method costs at least 2 to 3 times as much as coating the leaders, and it has no special advantages to recommend it.

The great woodlands in which red-deer are preserved in Germany are carefully fenced in with a wooden fence (called a **Gitter**) about 7 ft. high, formed of wooden spars, set close together to a height of about 3 or 3½ ft., and then wide apart above that. Many of such deer-parks comprise thousands of acres of woods within the fence.

2. **Fallow-Deer** (*Dama vulgaris*) bite and nibble plants, eat acorns and beech-nuts, and rub the bark off fraying-stocks when cleaning their antlers in August and September, and when rutting. But they rarely strip the bark with their teeth even in deer-parks where there is a large head of game, and in the open woods they do not peel the bark from poles or trees at all.

Prevention of damage.—As for red-deer (except as regards bark-stripping).

3. **Roe-Deer** (*Cervus capreolus*) also bite the buds and shoots of trees, and eat acorns and beech-nuts; but they never strip the bark for food. The bucks damage many a young sapling, however, when fraying the velvet from their horns in April and May, and when rutting in July and August. As fraying-stocks, roebucks prefer Larch, Silver Fir, Weymouth Pine, Acacia, &c., intermixed among other species, or planted along green lanes at the edge of compartments. Unless roe-deer are kept down, special measures have to be taken to protect such interspersed species against the bucks.

Prevention of damage.—The preventive measures are in general the same as for red-deer, except as regards bark-peeling and feeding with hay, &c. In place of this, softwoods (especially Aspen) and Silver Fir may be felled as browse-wood during hard winter weather. Larch, Weymouth Pine, &c., interspersed among other trees, can be protected from the bucks by tying rough branches round their base. Small pieces of newspaper about 4 inches square tied with thread or rushes below the top bud-cluster of the leading shoot of plants, about 2 to 2½ ft. high, will protect them from being eaten in winter.

Unless nurseries are protected with a high fence, roe-deer often leap over during winter to feed on the young plants. Beds can be protected by laying poles over them, or hanging feathers, dead rats, broken looking-glass, &c., on strings.

At Scone (Perthshire) it was found (and actually seen in the spring of 1900) that roe-deer can climb over fence-steps about 5½ ft. high, leading over a fence of wire-netting, for protection against rabbits, topped with two strands of barbed wire. From the foot-prints I saw at the foot of the steps on both sides, it was clear that some roe-deer had frequently visited the plantation by this means.

4. **Ground-Game.**—Both hares and rabbits can prove very destructive in nurseries and young plantations. They both gnaw the bark of trees and bite completely through young saplings and coppice-shoots up to about ¾ of an inch in diameter; and they can commit a vast amount of destruction in young plantations of all sorts. But they are seldom found together, as hares usually avoid places infested by rabbits. **Hares** do far less damage in Britain than rabbits, because they are much fewer in number, and are far more easily kept down than the very prolific burrowing rabbit. **Rabbits** sometimes absolutely

clear large patches of young coppice-growth during the year after the fall, and make natural regeneration in Beech-woods impossible without wire-fencing. In fact, so bad has damage from rabbits now become in nearly every part of Great Britain and Ireland, that it is impossible to raise young plantations without careful and expensive wire-fencing. But even if a landowner goes to much trouble and expense in trying to exterminate rabbits (an extremely difficult operation in light loamy or sandy soil, or in rocky places), his woods are soon likely to be overrun from adjoining estates.

It is easy to distinguish between damage done by hares and that caused by rabbits on young stems which show the feet-marks. The indentations made by hares are longer, broader, and fewer in number than those made by rabbits, which are shorter, narrower, and generally consist of two to six more or less parallel grooves, larger, broader, and less numerous than the finely-chiselled indentations left by mice and voles.

Hares (*Lepus timidus*) chiefly gnaw Beech, Elm, Ash, Maple, Sycamore, Hazel, and Robinia (as well as fruit-trees, especially apples, in orchards), but the damage they do is not concentrated like that of rabbits.

On the Scottish moors, however, the **blue hare** (*L. variabilis*) is often driven by hunger to attack young plantations, which need to be protected by wire-netting. While snow lies on the ground, these hares run round the netting trying to find a gap, till their footprints often form quite a beaten track.

Rabbits (*Lepus cuniculus*) attack almost anything, except large, thick-barked Oak (Fig. 100 *c*). They often ruin Hazel- and Ash-coppice near where they burrow, sometimes effecting an almost entire clearance while snow lies on the ground in winter. They do a vast amount of damage in all sorts of young plantations (see remarks in vol. i., *Introduction*, p. 28), during the first six or seven years after planting; and in most parts it is mere waste of time, land, and money to try and grow young timber-crops without careful and expensive wire-netting of each plantation. Wire-netting is, however, worse than useless unless the area enclosed is absolutely cleared of rabbits and the mesh of the netting is small enough (1 inch is now required near the ground in many cases) to keep out very young rabbits. If once these get inside an enclosed plantation, this forms a warren for them, and they very soon do a great deal of damage. The only kinds of trees they do not seem to care about are old thick-barked Oak among the broad-leaved species, and Corsican Pine among conifers. In mixed conifer plantations the latter is usually attacked to a far less extent than Larch, Douglas Fir, Spruce, or Scots Pine. In underwoods the common Rhododendron (*Rh. ponticum*) is about the only shrub they do not eat.

In Britain, so far as growing timber for profit is concerned, rabbits are by far the worst and most destructive kind of **Vermin**, and one of the most difficult to exterminate. Unfortunately they are not (as yet) included as vermin in the conditions attaching to gun-licences.

Protection against Ground Game.—Fencing with wire-netting is the only way of protecting nurseries and plantations of any considerable extent. Hares and rabbits may, it is true, be prevented from gnawing the bark and soft shoots of young trees by frequently coating the latter with a mixture of cow-dung and soot in equal proportions, made thin enough with water to admit of its being applied to the trees with a brush. This coating, which does no harm, should be applied from the ground-level as far up as the animals can reach. But this measure, of course, like the use of tree-guards, is only practicable where the number of ornamental or park trees to be protected is limited.

Broad-leaved saplings that have been gnawed can be cut back and made to spring from the stool; but young conifers are usually damaged beyond any hope of recovery. Fruit-trees in orchards, young park-trees, and exotic species scattered experimentally in the woods, can be protected by binding thorns or rough brushwood round the stems to a height of about 2½ ft. Rabbits may be trapped, poisoned, ferreted, or shot, but it is often very difficult to exterminate them. Foxes, stoats, and weasels are among their natural enemies.

To be rabbit-proof, wire-fencing must now, in some places, have a 1-inch mesh for the first 18 inches (besides 6 inches being bent outwards underground), and a 1¼-inch or 1½-inch mesh for 2 ft. above that; and, in addition to being bent outwards underground for 6 inches at lower end, it must either be bent outwards at the top, or else the posts should lean slightly outwards to prevent the rabbits climbing up. If set upright, and the wire be not bent over, rabbits can climb up and get into the plantation, as they have now in many localities (*e.g.*, Scone, in Perthshire) developed climbing-power since close-meshed wire-fencing was introduced.

Enclosure and **Fencing**[1] are necessary to protect young woods and plantations against damage from farm live-stock and game. In Britain it is customary to fence all land previous to planting. Apparently the onus of protecting his woodlands has always, since before the days of the *Statutes of Enclosure* (1482) and the *Statute of Woods* (1543), rested on the landowner; whereas on the Continent, and wherever timber-growing forms a great national industry, the owner of cattle, deer, &c., is liable for damage committed by his animals.

The vast forests of continental Europe are not fenced in, except in the case of large deer-parks (which are surrounded with a *Gitter*, or 7 ft. high fence of spars of wood or strands of wire to confine the deer and wild boar); and there is no reason, from a sylvicultural point of view, why enclosure should take place. The sole object of the fences round deer-parks is not to keep cattle out, but to keep deer in; and the shelter afforded to the edge of the wood by a dyke can be provided much more cheaply, and just as effectively, by planting Sycamore, Elm, White and Common Spruce, Douglas Fir, Silver Fir, Mountain Pine, Beech, &c., thickly along the edge of the wood, and allowing them to grow up with as dense an outer covering of foliage as they are capable of producing. This can be stimulated, when necessary, by lopping the tops to induce greater density of branchlets, twigs, and foliage. In France and Germany it is only found necessary to fence nurseries, though there is usually a good head of game kept up; but foxes, stoats, &c., keep down ground-game there.

Wire Fences[2] are the cheapest and most generally suitable for enclosing plantations. Of course they give no shelter; but in every other respect they

[1] The most detailed works on fencing are Hunt's *Boundaries and Fences*, 4th edit., 1896, and Vernon's *Estate Fences; their Choice, Construction, and Cost*, 1899. Chapter xii. of the former contains the laws about boundary trees.

[2] As *hedges* are usually more or less ornamental, details concerning them have been given under *Arboriculture* (in vol. i., Part III., chap. vii., p. 493).

are preferable, being effective, cheaper, more durable, and more easily kept in order and repaired than any other. The efficacy of a fence is increased if it be set along the top of a mound thrown up by digging a ditch along the outside; but this, of course, also increases the cost considerably.

Wire Fences[1] may be strained on wooden posts, or erected on iron straining-posts with intermediate standards made entirely of iron. But they all consist of four main parts (Fig. 102)—(1) *straining-pillars*, (2) *stobs* or *intermediate standards*, (3) *stays* or *struts*, and (4) *wires*.

1. **Straining-Posts** are for keeping the horizontal wires at full stretch. They may be of squared wood (7 to 7½ ft. long and about 6 in. square), fixed into the ground with soles or struts, or of cast- or wrought-iron batted into large stones, wooden blocks, or cast-iron blocks, firmly fixed deep in the ground, and supported by stays (about 5 ft. long, by 6 by 4 in. for wooden straining-posts). If the line of fence be straight, straining-pillars are generally placed from 80 to 100, or sometimes up to 200 yards apart; but in lines with curves or angles, intermediate straining-posts with stays are required. At present the cost of 4 ft. iron straining-pillars varies from about 20s. to 30s. according to strength.

2. **Standards** may be of squared wood (6 ft., by 3 by 3 to 4 by 3 in., and pointed at lower end), or of wrought-iron, and are placed from 6 to 18 ft. apart, according to the nature of the ground, the size of the posts, &c. It used to be customary to place stobs 6 ft. apart, no matter for what purpose the fence was required. This often led to quite unnecessary expense. For horses and cattle, stobs are only needed every 12 to 18 ft., if the fence runs fairly straight, and consists of three plain wires topped with two rows of 4-point barbed wire. For a sheep-fence, however, an additional wire is required below, and then (with stobs 18 ft. apart) short wooden *droppers* are needed at 6 ft. apart. But they only cost about 1½d., while stobs cost about 6d. each. Iron standards cost more (about 1s. 3d. or 1s. 4d. each), but the outlay on maintenance is practically *nil*. Standards keep the horizontal wires at regular distances, and support the whole fence. Wooden standards are either driven into the ground or sunk into holes in the same way as posts in a paling-fence. Iron standards are either batted into stones or are fitted with self-fixing feet for driving into the ground. Stays or struts are also required to support the standards at curves and angles, but are then made lighter than those for supporting straining-pillars.

3. **Stays** or **Struts**, made of sawn wood (about 5 ft. long, and 3 by 3 to 4 by 3 in.) or of wrought-iron, prevent the straining-pillars from being drawn off the perpendicular by the tension of the wires. Iron stays are made double for straining-pillars, and single for standards. They are batted into stones, or have flat "self-fixing" blocks attached.

4. **Wires** are placed parallel, and at suitable distances from each other. They are passed through holes bored in iron standards, or are fixed with staples to wooden ones, and are kept at proper tension by the straining-pillars.

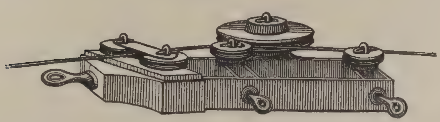
Wire fences should only be made of the best galvanised wire. There are two kinds of steel wire, *drawn* and *rolled*. The latter is the cheaper, because drawing requires a better quality of metal and more manipulation. Fencing-wire is sold under various trade names. *Bright Wire* is cold-drawn, and very hard. If the fence is desired to resist pressure without yielding, this kind should be used. It is difficult to knot, and therefore requires experienced workmen to erect the fence. *Annealed Wire* is also cold-drawn, but is afterwards annealed and softened. This renders it more pliable and easier to knot. It can therefore be more easily used by inexperienced workmen. Both of these qualities cost

[1] It is not necessary to give here many details concerning wire-fencing, iron-posts, and gates, &c. Prices fluctuate from time to time, and the fullest information as to cost, manner of construction, &c., are easily obtainable in the illustrated catalogues of such firms as the following: Messrs Bayliss, Jones, & Bayliss, Wolverhampton; Messrs Boulton & Paul, Norwich; Messrs Hill & Smith, Brierley Hill, Staffordshire; Messrs A. & J. Main & Co., Glasgow; Messrs Ransom, Sims, & Jeffries, Ipswich; and many other good firms.

at present about 10s. per cwt. *Black Wire* is rolled, and is not sold in such long lengths as the two preceding. It is soft, and not elastic; but it knots easily, and is therefore used where a cheap fence is wanted for a few years. *Galvanised Wire* of any of the above qualities costs about 1s. 6d. per cwt. extra. *Galvanised Strand-* or *Rope-Wire* is stronger than the smooth wire, but is considerably dearer. It does not rust, and therefore needs no painting or oiling.

There are eight sizes of wire (Nos. 1 to 8), but those chiefly used in fencing are Nos. 6, 7, and 8, of which about 393, 467, and 566 yards respectively go to the cwt. No. 8 galvanised steel wire is, on the whole, the most useful and economical kind for woodland fencing, with upper rows of galvanised 4-barb steel wire, with thickset barbs 3 inches apart (488 yards per cwt., and requiring 4 cwt. per mile; present cost about 15s. per cwt.)

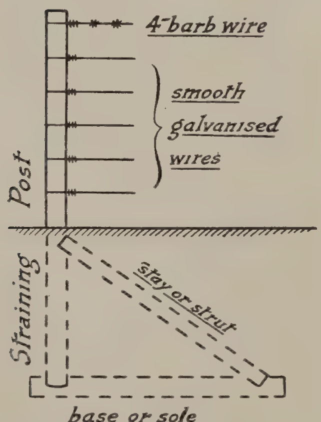
Fig. 101.



The wire, as received from the manufacturers, is generally in bundles, and requires to be passed through a *wire-straightening machine* (Fig. 101), or an *uncoiling tube*. By passing the wire through either of these, it is made straight and ready for use. Some kinds of wire, however, uncoil fairly straight, and need no special manipulation.

Fences have often in the past been made with far larger posts, and therefore at a greater cost, than there is any real necessity for. A post-and-wire fence to resist horses, cattle, and sheep should be about 3 ft. 9 in. to 4 ft. high, and should have six strands of wire; and it is more effective if the top strand consists of barb-wire (Fig. 102). Such a fence (with well creosoted posts) will ordinarily last for from eighteen to twenty-four years, and should cost very little to maintain. If, however, the fence is only required against sheep, as in plantations formed on rough mountain heather tracts, a 3 to 3½ ft. fence, with four to five wires, is sufficient; and it is more effective if the third and the top wires are barbed.

Fig. 102.



A 7-foot Straining-post at end of a six-wired fence, 4 feet high, against farm live-stock.

Erecting the Straining-Posts.—The exact line of fence being fixed on, **straining-posts** made of good Oak, Larch, or creosoted timber should be set at the required distances, according to the nature of the ground. These main posts, at corners and important points, should be about 6 in. square and 7 to 7½ ft. long, made square above and below, and should be set in the ground from 3 to 3½ ft. (according to its nature), and to project about 3 ft. 9 in. to 4 ft. above it.

Of course their durability is very much greater when the posts have been thoroughly dried and then impregnated with creosote, naphthalin, or other antiseptic substance. Small holes should be bored through all these main posts where the wires are to go, and the height to which they are to be put in the ground should be well marked. Other pieces of Oak, Larch, &c. (about 5 ft. by 6 in. by 4 in.), are needed as an underground sole or base for the post to rest on, in a prepared notch about 2 in. deep, and leaving about 6 in. of a heel at the end. The lower end of the post is fixed in this notch, and secured by driving two large nails through the post into the sole. An Oak, Larch, &c., strut of suitable length is then fixed in another notch made near the other end of the sole, while the top of the strut rests in a groove notched about 1 in. deep into the post near the ground surface. This underground stay or strut should be about 5 ft. long and 3 by 3 in. to 4 by 3 in., according to the size of the post. It supports the post against the strain of the wire, and as it is not seen above ground, it does not affect the look of the fence. The mortising and tenoning of the posts and struts can best take place in the workshop before carting them to the land to be fenced.

Pits having been dug in the ground for the posts, the first post should be erected where the fence begins, and should be so set that the strut lies exactly in the line of the fence, so as to offer the maximum resistance to the strain of the wires. As the hard ground, or at any rate the lower part, usually requires picking, the pits should be made as near the exact dimensions of the post and strut as possible. In this work the **foot-pick** (Fig. 103) is preferable to the common hand-pick for loosening the hard subsoil. The **horizontal spade** (Fig. 104) is also very useful for removing soil within 18 in. below the surface.

Fig. 103.

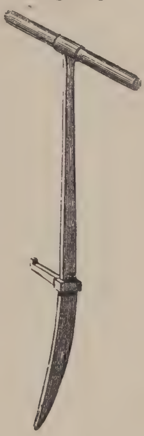


Fig. 104.

The straining-post is put upright into the pit after the base of this has been properly levelled. When the **plumb-line** shows that it is placed upright, two wedge-shaped keys or pieces of Oak, Larch, &c., about 18 in. long, should be driven obliquely and well home into the ground at each end of the sole (Fig. 102). The pit should then be refilled gradually, each layer of 3 or 4 in. being well beaten down with a heavy iron-shod **rammer** about 4½ ft. long.

After the first straining-post has been erected, the subsequent posts are put up in similar manner at about 80 to 100 yards apart, according to the nature of the ground. The only difference is that the position of the underground stay or strut should always be such as will best help the post to resist the strain due to the tension of the wire. In a straight line of fence the struts should therefore be in the line itself; while at every angle they should occupy the middle of the interior angle. But wherever the ground falls away at all suddenly, it is then necessary to have either two underground stays (a double wooden stay), or else one underground wooden stay and an iron stay above ground in addition to it, on account of the much greater strain then thrown on the post.

Erecting the Intermediate Standards.—The intermediate uprights or standards are next erected at 12 to 18 ft. apart. These should also be of Oak, Larch, &c., 6 ft. long by 3 by 3 to 4 by 3 in., and sharp-pointed at lower end for driving into the ground. Their position should be carefully fixed, so that the strands of wire may rest on the inside of the posts and uprights, and not on the outside, as the wires would then be less able to resist pressure of cattle.

Fig. 105.

Holes are sometimes dug for the intermediate uprights, but they stand firmer if rammed into the ground with a heavy mallet. Much depends, however, on the nature of the soil, as it is sometimes almost impossible to drive in a post owing to gravel and boulders.

When the posts are being driven in with the mallet, an iron cap is fixed over their heads to prevent splintering. This **cap** (fig. 105) is of the same shape and size as the top of the post, on which it should fit rather tightly. In driving home the posts, one man lays hold of the top of each with this cap, and can give the post the proper direction if it should happen not to go in straight: it is therefore also called the **post-guide.** An iron-bound cap of tough wood (like Hornbeam) is often used instead of this implement, and does not fray or damage the tops of the posts.

As each standard is put in position, the height at which each strand of wire is to be fixed should be marked with a carpenter's pencil, and sharp-pointed galvanised 1½-inch *staples* (5s. per 1000) should be nailed on at the required heights to run the wire through (if smooth wire be used). The wires may then be run through the holes of the first pillar, and through each of the staples in the posts; and it is best to begin with the top wire. One end of the wire is fastened to the end post and brought half round it, then twisted with the **turn-key** (Fig. 106) round the wire inside of the post. Should a join in the wire at any time be necessary between two straining-posts, this is done by forming an eye or loop on the end of one wire with **clams** (Fig. 107); and while one man holds the wire thus, another twists the end round with the turn-key. The other wire is then passed through this eye and treated in the same way, thus completing the joint or knot (Fig. 108).

Fig. 106.

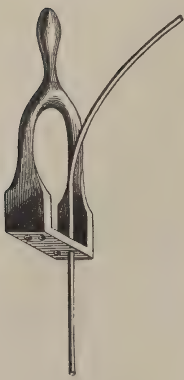


Fig. 107.

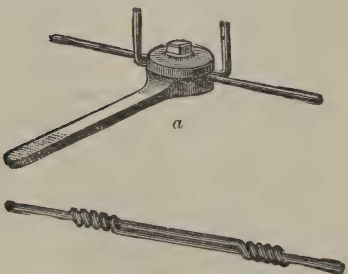
Fig. 109 shows another way of knotting smooth wire. The ends are laid inside the **knotting-tongs**, and secured by a bolt and cap. When the ends have been properly set up, as at *a*, a twist is applied, and the knot is tied as shown in *b*; and as the knot is formed complete, no ends require to be trimmed off.

When the wire is brought up to the second straining-post, it is cut a foot beyond it to leave enough for finishing. The wire should be passed through the upper hole corresponding to that on the first straining-post, then pulled taut by a **straining-machine** and securely tied round the post.

Fig. 108.

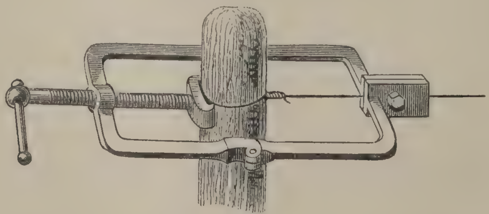
There are several kinds of **Straining-machines.** The common *straining-screw* (Fig. 110) holds the wire by a jointed **vice**, opened or closed at pleasure by a nut worked with a screw-key. The wire passed through the upper hole of the post can then be held by the vice and screwed up tight before being fastened with the turn-key in front of the post.

Fig. 109.



Wire-knotting tool.

Fig. 110.



Figs. 111, 112 show other useful forms of straining-screws. The end (*a*) of that shown in Fig. 111 being placed against the post, the wire is passed through the opening and fixed to the vice (*b*) by a screw-bolt and nut, and then tightened up by turning the handle (*c*), when the wire can be keyed up and fixed round the post in the usual way. The "Victoria Straining-machine" (Fig. 112) consists of a powerful screw capable of straining 300 yards of wire. It weighs 6 to 6½ lb., and is strong and practical.

Instead of tying the wire round the *second* post in the way above described, **screwed eye-bolts** may be used (Fig. 113). The wire is attached to this through an eye upon one end (*a*), and passing the bolt through a hole in the post, a **nut** (*b*) and washer (*c*) are put upon it outside. The wire is then tightened by screwing up the nut, and the washer prevents this cutting into the post. It is then easy to tighten the wire in summer when it expands from heat, and to loosen it in winter when it contracts with cold. When it is *tied* at both ends, this is more difficult and troublesome. Screwed eye-bolts for wooden posts are generally 15 in. long (costing 6s. per dozen). Cast-iron **winder-brackets** (Fig. 114), worked with a simple lever, are largely used,

Fig. 111.

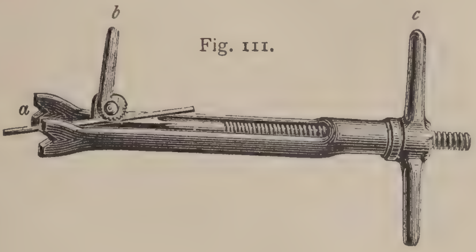
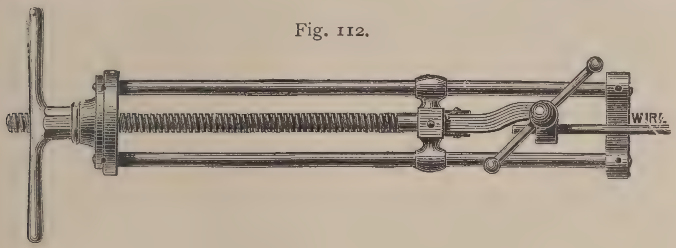


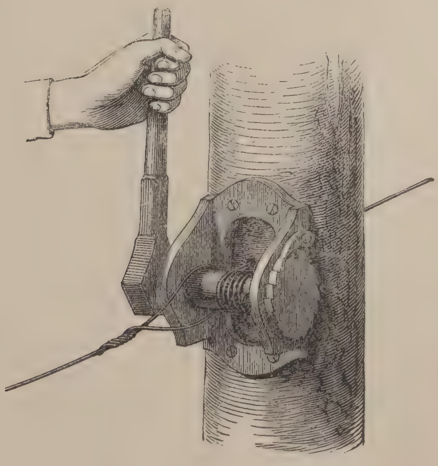
Fig. 112.



and form very convenient straining-machines. They are simpler and more powerful than screwed eye-bolts, and they enable the wires to be tightened or slackened at any time with very little trouble.

Fig. 113.

Fig. 114.



The upper wire of the fence having been fixed, all the others are also fixed in similar manner, care being of course taken to keep the distance between the wires closer near the bottom than at the top. In general, where the fence is to keep out sheep or lambs, the distance between the two lowest wires should be 5 in., while that between the two uppermost may be 10 in.

Fences of this description made for deer are usually about 6 ft. high, and have 10 wires, while 5 or 6 are generally sufficient for sheep and cattle. But in erecting a wire fence above 4 ft., it is necessary to have the extra strength of an iron stay put to the straining-posts above ground, as well as a wooden one underneath. These extra stays are sunk into stones and batted with lead or cement; and the stone should not be less than an 18-in. cube, sunk about 3 in. under the surface.

The higher the fence, the deeper the post should also be sunk in the ground. In a 6-ft. fence the sole of the ground-stay should be 4 ft. below ground. The staples should never be driven home in the uprights, but should leave room for the wire to move freely in them, else it will be impossible to tighten or loosen the wires. As soon as the fence is completed, the posts should receive a coat of coal-tar, and the wires will also require painting or tarring, unless galvanised wire be used, as is most economical.

The cost of Wire Fences with Wooden Posts varies of course according to the height of the fence, and the size and number of the wires used; but the larger the area to be fenced, the smaller is the cost per acre for fencing. If plantations were made in squares, the cost would only increase twofold while the enclosed area extended fourfold. Thus, if only light fencing were required at an average cost of 6d. per running yard, the actual cost per acre would vary as follows *in plantations formed in squares*:—

Area in acres . .	1	4	16	64	256	1024	4096
Yards of fence .	280	560	1120	2240	4480	8960	17,920
Cost of fencing .	£7	£14	£28	£56	£112	£224	£448
Average cost per acre	140s.	70s.	35s.	17s. 6d.	8s. 9d.	4s. 4½d.	2s. 2¼d.

But plantations are seldom formed in squares or in any regular figure, so that the acreage enclosed never of itself conveys any definite idea as to the number of yards of fencing actually needed. This can only be ascertained by measurement on a map, or on the ground. The difference in cost is often, however, very considerable. For example, 1 square mile of plantation (640 acres) *in a square* needs 4 miles or 7040 yards of fencing, and at 6d. a-yard costs £176, or 5s 6d. an acre; but the same area *as a rectangle twice as long as it is broad* needs 5 miles or 8800 yards of fencing, amounting to £220, or 6s. 10½d. per acre; while if *thrice as long as broad* it needs 6⅔ miles or 11,733 yards of fencing, costing £293, or 9s. 1⅞d. per acre. It is therefore economical to make plantations as large, square, and compact as possible.

Such a fence against cattle as has been above described—3 ft. 9 in. to 4 ft. high, with 6 wires (5 smooth, and the top wire barbed)—usually comes to from 10d. to 1s. per running yard, whereas a lighter fence, against sheep only, can usually be put up at a cost of 6d. to 8d. per running yard.

Of course, if a plantation formed one year be extended during the following, or the next two or three years, so that part of the fence can be lifted and placed along the edge of the plantation added, so as to leave only a comparatively small portion to be erected as an entirely new fence, the cost per acre of the whole becomes very much reduced. Thus, say about 250 acres are planted in a square for four years in succession, the first 250 acres would cost, at 6d. a running yard, 8s. 9d. per acre, the 500 acres probably about 6s. 9d. to 7s. per acre, the 750 about 6s. 3d., and the 1000 acres, when completed, about 5s. 9d. per acre as the total cost of the whole four years' fencing, only part of the fence being moved and the original enclosure increased by 250 acres each year.

If wire-netting is required as a special protection against rabbits (as is unfortunately only too often the case), this of course necessitates considerable further expense (see p. 21). A 50-yard roll of strong galvanised wire-netting with 1 in. mesh and 4 ft. broad now costs about 22s. 6d., while the same length of mixed mesh, $1\frac{1}{4}$ in. for 2 ft. and $1\frac{1}{2}$ in. for the top 2 ft., costs 22s. 3d., so that there is only an extremely small saving by using the mixed mesh. It is therefore best to use only the 1-inch mesh where rabbits are dangerous. The *additional cost* of providing and fixing strong small-mesh rabbit-proof wire-netting of 4 ft. breadth, bending it outwards underground for 6 in. at lower side to prevent burrowing, and making it also bend over somewhat at the top to prevent rabbits climbing over, comes to about 7d. a running yard. This brings up the total cost to about 1s. 6d. a-yard for *cattle-and-rabbit* fencing, and 1s. $1\frac{1}{2}$d. to 1s. 3d. a-yard for *sheep-and-rabbit* fencing.

Where rabbits are not abundant, or where they have not yet become accustomed to contend against wire-netting, fencing *against ground game alone* can often be done at a very much cheaper rate than the above. A 48 in. wire-net fixed to a No. 6 wire or a barbed wire, with stakes 9-12 ft. apart, usually costs altogether about 8d. a-yard.

The following fence, which I have successfully erected on a very large scale, worked out at 6d. to 7d. a lineal yard. . . . The fence was for the exclusion of ground game only, and consisted of wooden uprights (Larch) 2 in. by 2 in. by 4 ft. 6 in. (creosoted), set 12 ft. apart, one top wire-netting, $1\frac{1}{4}$ in. mesh, No. 17 gauge, 42 in. wide. This allowed of a 3-ft. fence with 6 in. turned and covered by a sod. The netting at top was tied by a thin wire. It was found best to open the trench for receiving the netting by spade, as the furrow ploughed was too erratic (Curtis, in *Jour. Roy. Agric. Socy. Engl.*, vol. 64, 1903).

Iron Straining-Pillars last longer than wooden posts, are more easily erected, and look neater; and the wires can be very easily tightened or slackened with a key or other winding apparatus.

But they are more expensive, wrought-iron terminals of 4 ft. high and $1\frac{1}{2}$ in. square (with stay and self-fixing bases) for 6 wires costing about 22s. 6d. to 25s. each, and the double-winder uprights (with self-fixing bases) about 18s. or 18s. 6d. each, while strong angle-posts with double bases cost about 35s. each. It is not necessary to give any detailed description of them here, as the illustrations in any manufacturer's catalogue are self-intelligible.

For batting Iron Standards into Stone, *lead* is still largely used; but the standards loosen if the hole be not well filled. Good *cement* is cheaper, and it does not injure the iron as the sulphur in lead sometimes does. Cement sets quickly, is hard, and is just about as good a material as can be had for this purpose. Straining-pillars should generally be sunk 5 in., stays or struts 4 in., and standards 3 in. into the stones; but such details depend greatly upon the kind of stone and the size of the posts.

Barb-wire, introduced from America, is (especially the four-barb kind, thickly set at 3 in. apart) unequalled for efficacy as a fence. Although costing about 50 per cent more than smooth galvanised wire, it is not necessarily dearer, as three strands are usually sufficient to keep out farm-stock. It is dangerous in a hunting country (unless a wooden rail or bar be put all along the top), and is a cruel fence till horses, cattle, and sheep, whose skin is lacerated in a painful manner by the barbs, find out that it is best to give it a wide berth. It can be fixed to wooden or iron straining-posts, with wooden or iron intermediates, the straining-posts being the same as those already described.

A top strand of barb-wire, or a top strand and also a second line in the middle of the fence, can be used with effect in an ordinary wire fence. The wire is

Fig. 115.

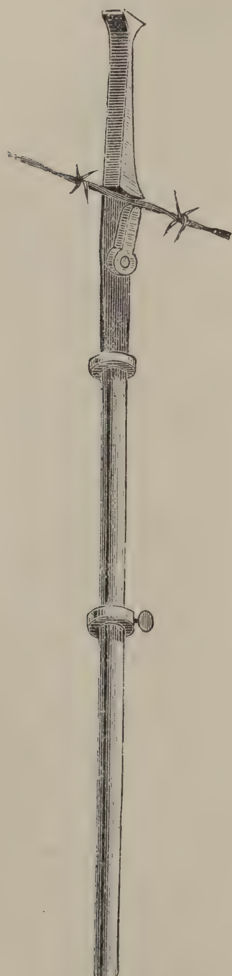


Fig. 116.

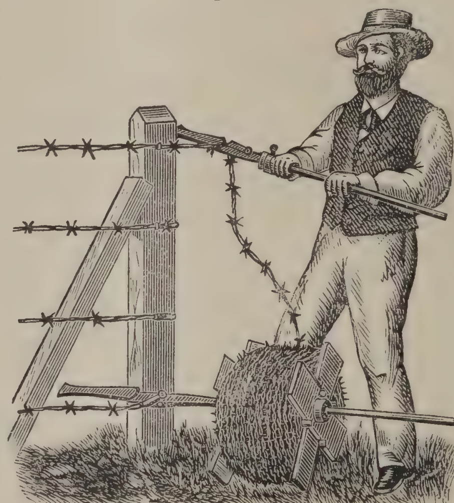
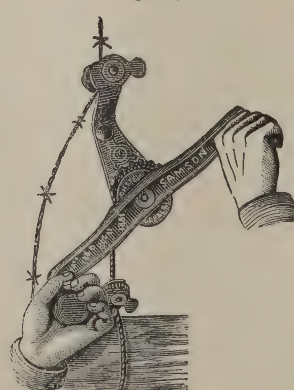


Fig. 117.

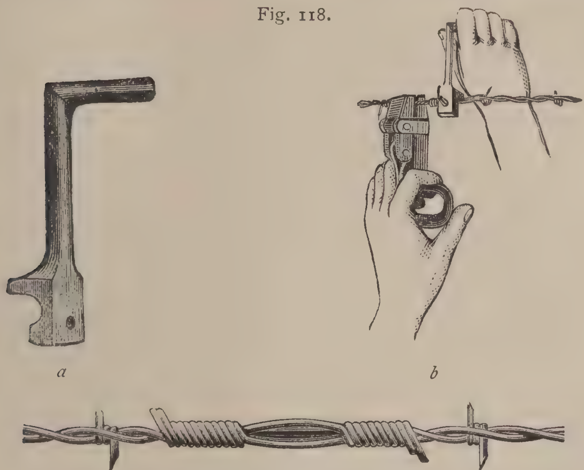


supplied in reels of ½ or 1 cwt. (488 yds. per cwt. for four barbs 3 in. apart), and can be fixed with ordinary staples.

In fixing barb-wire on wooden straining-posts and uprights, the end of a reel should be secured to the first (terminal) post at the mark for the highest strand, and then the wire should be unrolled along the entire length of the proposed fence, and should be raised to its proper place and stapled lightly on each upright as far as the next corner-post. Then the strainer is applied to pull the wire taut, the *lever strainer* being used for short lengths and the *winding strainer* for longer lengths (Figs. 115, 116, and 117), and the wire is stapled firmly to the two main posts and to each intermediate post. When wire has to be joined between posts, it is spliced as shown in Fig. 118.

The cheapest and best iron-fencing of this class is that known as the **Corrimony** fence, which was introduced in 1873 from New Zealand by Mr Ogilvy of Corrimony, Inverness-

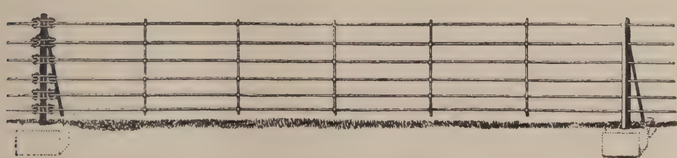
Fig. 118.



a. The Splicer. *b. Pincers and Splicer in action.* *c. The Joint when compteted.*

shire (Fig. 119). The main difference between Corrimony and ordinary strained wire fencing consists in the wrought-iron winding straining-pillars and solid resisting pillars, placed alternately about 200 or 220 yards apart (or eight to nine to the mile), and either batted on stones or else fixed by means of patent earth-plates. Iron standards with stays

Fig. 119.



a. Corrimony Fencing batted on stone.

b. Corrimony Fencing fixed with iron earth-plates.

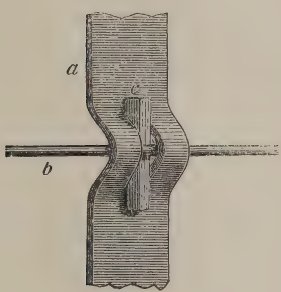
attached are placed about 18 yards apart, with **droppers** or intermediate uprights placed 6 ft. apart. The wires are threaded through the standards, while the droppers hang on the wires without touching the ground. They are made very light, and are fixed to the wires with iron staples, holdfast clips, or wedge-pins (Fig 120). In this kind of fence both straining-pillars and standards must be securely fixed in the ground, as they are so far apart. The droppers give no stability, but merely keep the wires at proper distances apart, and they are not fixed until after the wires have been strained.

The Corrimony fence answers well both for parks and for hilly outlying districts where cattle and sheep are grazed. At present a fence of this sort, 3½ ft. high and 1 ft. 9 in. below ground, with five to eight wires and a top line of barb-wire, costs about 1s. a-yard; while a fence 4 ft. high and 2 ft. below ground, with six strands No. 8 wire and one of barb-wire, costs about 1s. 3d. a-yard or more, according to local circumstances.

The Maintenance of Fences consists in coating the ironwork (except galvanised iron wires) once every two years with black varnish (costing about 1s. 8d. a gallon), in tightening the wires when they expand in summer and in slackening them when they are likely to contract in winter. If this be left undone, the wire may break during hard frosty weather or may become too loose in summer. But a good fence made with good wire should not give much trouble, either with regard to straining or breakage.

Dry-Stone Dykes were formerly extensively erected in most of the high inland districts throughout Great Britain and Ireland, where stones are plentiful and cheap. They shelter young plantations for the first year or two, and also cattle in the adjoining field; but they are now much more expensive than post-and-wire fencing. They are therefore seldom used as fences for new plantations nowadays, because even if the land is stony, and Oak and Larch wood is scarce or dear, creosoted wood is cheaper, or iron posts can still be used at a less cost than erecting a stone wall.

Fig. 120.



a. Part of dropper.
b. Wire.
c. Wedge-pin.

The dry-stone wall used to be built from 3 ft. 9 in. to 5 and even 5½ ft. high, without lime or mortar, and was always apt to break down under pressure from cattle. But if the top- or cope-stones are bedded in lime, this keeps the wall more firm and compact.

In supervising the building of dry-stone dykes, the main thing is to see that the body of the wall is firmly packed with the smaller stones, and that no open spaces are left. When anything seems suspicious, pressure applied with the foot about half-way up on one side should cause the wall to bulge out a little on the opposite side; but if this does not happen, then the wall cannot be well packed.

Cost.—Even when labour was much cheaper and more easily obtainable than is now the case in waste-land tracts and poor mountain-pastures, the cost of dry-stone dykes 3 ft. 9 in. high used to be 1s. per running yard.

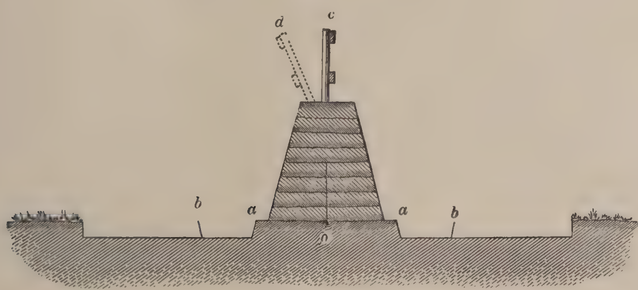
"A double-faced 3 ft. 9 in. dyke requires 1 ton of stones for 1 square yard of its face, so that 36 tons of stone are required for 1 rood of 30 yards long.

"The expense of quarrying that quantity of stones may be about 10s. the rood; the carriage of them at a reasonable distance beyond 1 mile is also 10s.; and the building commonly undertaken, when the stones are good, at 10s. also;—so that such a dyke costs 30s. the 30 yards, or 1s. for 1 yard in length, or £6, 9s. 6d. per cubic rood, or 3s. 7d. per cubic yard. The best way to contract for the erection of stone-dykes is by the rood of 36 cubic yards, when every temptation on the part of the builder to lessen the breadth, and make the heart of the dyke hollow, is removed."—Macdonald's edition of Stephens's *Book of the Farm*, 1893, Div. V., p. 231.

Dykes or **Mounds** are still sometimes erected in high-lying parts, where stones are not easily obtainable, and where it is not advisable to plant hedges. Their place has also, however, been to a great extent taken by wire-fencing round recent plantations, owing to want of labour and its increasing cost in thinly populated tracts.

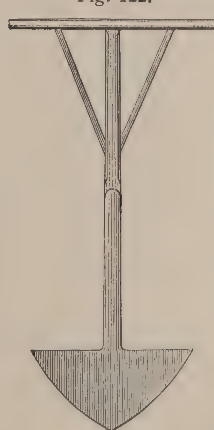
The line of a turf-dyke (Fig. 121) having been laid off by a set of pins, 18 in. are marked off from the centre (*o*) to one side (*a*), and the hemp-line is stretched tightly to its full length, fixed also at 18 in. from the centre on the same side of the fence, pinned down, and then edged off with a sharp, half-worn spade. The man stands on the run of the dyke with his face to the field, so that the edge (*a*) may slope outwards to correspond with the upward slope of the dyke, when formed. In the same manner the other side of the ground-level foundation is also cut and edged at 18 in. from the centre on the opposite side, so that the foundation (*a* to *a*) is 3 ft. wide. A sod 15 in. broad at top

Fig. 121.



is then measured and edged off from *a* to *b* on each side along the whole length of the first line on each side of the foundation. The operator faces the line of the dyke when cutting the inner edges (*b b*), so that when cut, turned upside down, and laid alongside each other on the foundation, the two sods will appear thus , and be at once ready for use in building up the sloping dyke. A second man then follows with a **turf-spade** (Fig. 122) and cuts the turf right across, into convenient lengths of about 18 in. all along the line; and as he cuts it into lengths, *proceeding backwards*, he turns the sod, grassy side uppermost, by a twist of the spade. As each sod is turned up, a third man lays the sods on the base of the dyke, care being taken to lay the first course of turf 3 in. within the outer edge (*a*), on each side, which is left as a supporting margin. The men then set the sods properly to form the lower layer of the mound. As soon as the sods are placed, the joins between their edges should be well filled by packing with earth, after which the upturned sods are firmed and levelled before putting on the next layer. The work is thus continued throughout, one man edging off the turf-sods with a line to an exact measurement corresponding to the decreasing width of the dyke as it gets built up, so that each higher layer of turf gets narrower than that last laid on; while the second man cross-cuts the turf into convenient lengths, and turns up the sods for the third man to place on the dyke. The lower layers of sods are placed grassy side downwards, but it is best to place the upper turf with the grassy side upwards. The sods are taken equally from each side, to save time and to heighten the fence equally on both sides.

Fig. 122.



The thickness of the sods depends on the soil. If light and sandy, the less soil that is lifted the better, as sand soon moulders down. In light sandy soil the sods should not be thicker than 3 in.; but on heavy soil they may well be 4 or 5 in. thick. In general the turf should be just of the thickness that appears to contain plenty of the fibrous grass-roots.

In Fig. 121 the first four layers of turf consist of two sods in one breadth. This obviates too great a breadth of sod, as work would be difficult if the turf were put on whole.

Turf-dykes are generally made about 36 in. broad at base, and tapering regularly to about 14 in. at top. As they subside a few inches after being put up, they should be made about 6 in. higher than ultimately required; but the largest allowance for shrinkage is required for soft mossy turf.

Where the surface-soil is covered with rank grass or weeds, these should be cut close with a scythe before lifting the turf; and if the sods are damp and spongy, about one-quarter of the height must be allowed for shrinkage. Unless the dyke be made high, a paling or wire-fence should be put along the top, but not until after the mound has settled fairly. If the mound skirts the edge of a wood, and is meant to protect it only, the paling or wire-fence may slope outwards, as at *d*; but if the mound is only a field-fence, then the paling should be upright, as at *c*. For this purpose it is sufficient to run one or two strands of barb-wire along standards placed 10 to 15 yards apart, or 8 to 10 yards on curves. The old custom of erecting a stout paling (as shown here in Fig. 121, after Brown), and putting stobs 6 ft. apart, was quite unnecessary.

Turf-mounds require more supervision, and cost more to maintain, than other fences. Wire-fencing is more durable and convenient, and does not usually cost much more.

Wooden Palings have now, for plantation fencing, been almost entirely superseded by wire-fencing. **Post-and-Rails** are the most generally useful of all wooden palings, consisting of strong posts or uprights, about 3 to 4 in. square, driven into the ground at 6 to 12 ft. apart, upon which posts and bars are nailed horizontally at regular distances from, and parallel to, each other.

For a 4-ft. paling, posts of 5½ to 6 ft. will be required, according to the nature of the ground. The posts should be pointed at lower end for ramming in easily, and the horizontal rails are usually 18 ft. long and 4 in. broad by 1 in. thick (Larch or creosoted wood). The posts and the horizontal rails (three or four bars, as the case may be) are laid all along the line at the required distances upon one side of the line of fence. The tools required are a garden-line, a No. 3 **paling hammer** with claws (Fig. 123), a bag of nails of two sizes (held in separate compartments), and an iron 12 lb. **post-mallet** (Fig. 124). For hard difficult ground, a **borer** (Fig. 125) may also be necessary, consisting of a heavy *shod* or pointed piece of iron (*a*), about 12 in. long and 3 in. top diameter, hollowed to receive the handle (*b*), about 4 ft. long.

Fig. 123.

Fig. 124.

Fig. 125.

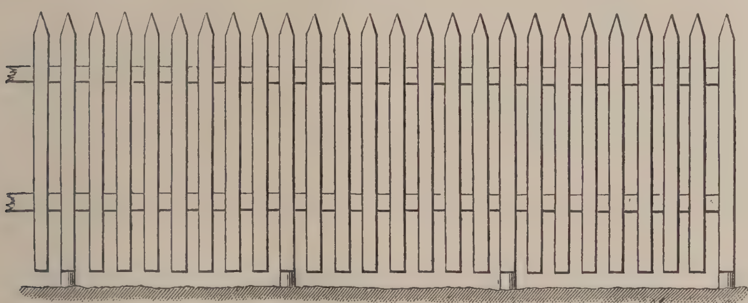
Where the soil is comparatively light, well-pointed posts may be driven home with a heavy iron-bound wooden mallet or an iron sledge-hammer; but to avoid splintering of the head, it should be protected with an iron-bound cap of tough wood like Hornbeam. Two men are of course requisite for driving home the fence-posts in this manner.

The garden-line should be stretched along the run of the fence, and pinned down about 2 in. to one side, so that the posts may be put in a straight line. The post is then driven in by the mallet to the required depth. If the rails are of unequal lengths, it is best to lay a single bar along the ground beside the line, and allowing an overlap of 4 to 5 in. for each joint, and to put in a post at the joining of the rails, without regard to exact distances. One post having been erected at each joining of the rails, the others must be erected between these at as nearly equal distances as practicable. The posts having been driven in as far as the line stretches, they should be examined to see that they are both level on the top and regular on the side view. A post here and there may require beating down if too high, or beating to the side if a little out of the line. When the posts are all properly adjusted, two men place a rail along the top to form the upper bar. The rail should be nailed on, projecting about 2 in. beyond the second post, to provide for a splice there. The second bar in continuation of this first should be nailed on about 2 in. behind the post to provide the other part of the splice, and so on all along the line of posts put in. When the whole line of top-bar is in position, the overlapping parts are sawn across, properly spliced thus , and firmly nailed to the post. And in the same way the second, third, and fourth bars are fixed at distances about 9 or 10, 7, and 6 in. below that immediately above it. In putting on the second, third, and fourth bars, it is not so necessary to have their joints made upon the posts as in the case of the upper bar. They may be joined in the middle, or wherever the ends happen to meet, as the under bars are not so heavily pressed on by cattle.

In like manner the whole fence is put up, one line-length after another. Two good workmen will, in moderately soft soil, put up from 25 to 30 roods a-day.

Upright or Spar Fences are more of an ornamental character (Fig. 126), and are now too expensive for enclosing plantations. There is nothing in their erection that calls for special explanation. The height of paling required mainly determines the size of the posts, horizontal bars, and upright spars; and the latter should always be nailed to the bars on the side which is most in view.

Fig. 126.



The "Peignon" Fencing, consisting of split Chestnut bound together with galvanised smooth or barb-wire in rolls of $5\frac{1}{2}$ yards, and now largely imported from the South of France, is convenient for merely temporary purposes. But it is also considerably dearer than ordinary wire-fencing, and is therefore of no use for enclosing large plantations.

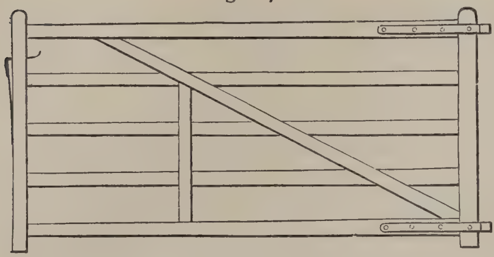
Fence-Gates have generally to be made and erected by the forester.[1] **Wooden Gates** are usually made of Oak, Larch, or creosoted Pine, &c. Whatever wood is used should be well seasoned to prevent twisting from heat; and creosoting or naphthalining of course increases the durability.

A type of gate formerly very much favoured is shown in Fig. 127. The posts are 5 ft. high, the back one being $4\frac{1}{2}$ by $2\frac{1}{2}$ in., and the front post $3\frac{1}{2}$ by 2 in. The top and bottom horizontal bars are about 9 ft. long between the posts, and tapering from 4 in. at back to $3\frac{1}{4}$ in. at the front, and $2\frac{1}{2}$ in. thick, while the three intermediate bars are the same breadth but only $1\frac{1}{2}$ in. thick. The diagonal bar, reaching from the heel of the gate to within 18 in. of the end of the top bar, is 3 by $2\frac{1}{2}$ in. like the top and bottom bars; while the upright support is 3 by $2\frac{1}{2}$ in. like the intermediates, and reaches from the bottom bar to the diagonal at its junction with the second bar from the top. The gate has double hinges which

[1] When wire-netting is placed round fencing, hares can easily be kept out by continuing the netting on the gates; but as regards rabbits the matter is different, for the netting cannot then be put 4 or 5 in. underground.

clamp the joints of the top and bottom bars and strengthen the back part. By having the gate heavier near its centre of gravity, the hinges, the maximum of stability is given. Such a gate costs about 25s. to 30s. ; but a very similar though lighter gate, made of Larch and fitted with self-fastening locks (as used on the Murthly estate, and shown at the Highland and Agricultural Society's Show at Perth, Forestry branch, 1904), can be made for the same price ; while at Scone a 5-barred gate (about 12 ft. long) with posts made of undressed Oak costs 20s.

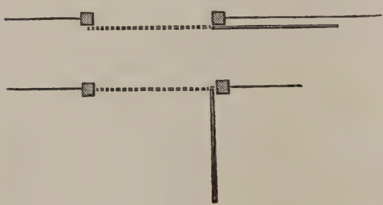
Fig. 127.



For general plantation purposes, however, a very much lighter and less expensive kind of gate is quite sufficient. The heavier and more expensive gates need only be used where more or less constant traffic is likely to throw a lot of strain on the hinges.

A very cheap gate, extensively used on the Raith estate (Fifeshire), and found to answer well, is made of creosoted Scots Pine rails, 3½ in. broad by 1¼ in. thick. The gate has four 10-ft. bars firmly nailed to Scots Pine ends, with two angular pieces for supports, and two pieces of double rail to support the hinge-plates. The ends are 3 ft. 9 in. high, and, along with the angular pieces, project 3 in. above the top bar. A strand of barb-wire is firmly stretched across the ends to prevent stock rubbing or leaning against the gate. It can be made and mounted for about 12s. It is easily supported on its own hinges, and may be hung on a post of 8 in. diameter (Macdonald, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvii. part ii., 1904, p. 453).

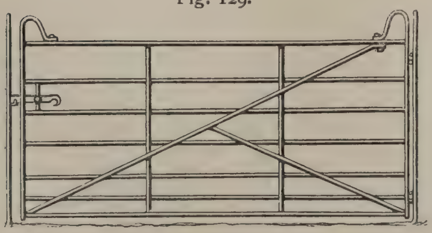
Fig. 128.



In hanging plantation gates, it is better to fix the pin of the hinge at the outer corner of the post, and not in the middle of the post in the centre of the run of the fence. In the former case the gate can be opened back to the fence, whereas in the latter it can only be opened for little more than a right angle, owing to the gate-bars meeting the corner of the post (see Fig. 128).

Wooden gates require to be painted or well coated with tar at time of erection, and once every three years after, to preserve them. Creosoted wood takes tar better than paint, or rubbing them over with crude petroleum is equally good.

Fig. 129.

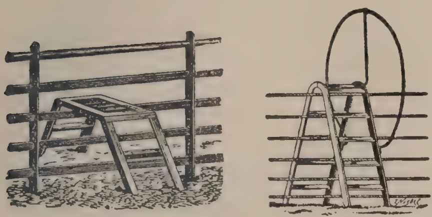


Iron Gates, wrought or cast, look lighter, and are more durable than wooden gates ; but they are more expensive (Fig. 129). Iron gates 9 ft. wide by 4 to 4½ ft. high vary at present from 21s. 6d. to £3 each, without posts. It is often preferable to hang them on wooden rather than on iron posts, as the former are cheaper and less liable to damage from cart-wheels.

Wickets are convenient on the edges of plantations ; but **Fence-Steps**, made of wood or iron (Fig. 130), are sometimes preferred.

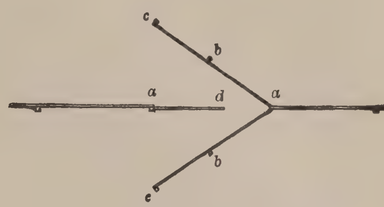
The **angular wicket** (Fig. 131) is simple and effective, both as fence and gate. The gap in the fence (*a a*) may be about 4 ft. wide, and the angle (*c a c*) about 3 ft. wide from

Fig. 130.



Wooden fence-steps. *Iron fence-steps.*

Fig. 131.



Angular wicket-gate.

b to *b*. A small post should be put at each extremity (*c*), and another at *b* on each side, where the wicket (*a d*, hung on a hinge at *a*) hits the rail as it folds to either side in opening or shutting. Iron wickets are also obtainable, as seen in any manufacturer's catalogue.

III. **The smaller Rodents** or **Vermin** (**squirrels, mice**, and **voles**) often do a very great deal of damage in woods, and especially in young plantations and nurseries during the winter months. They not only devour large quantities of seed and eat the buds of young plants, but they also peel the bark. It is, of course, during hard winters that they do most damage by peeling, while the plants attacked often also get frost-bitten at the gnawed parts. In ordinary years the total damage done by squirrels throughout the British Isles is perhaps greater than that done by voles, and it is certainly far more than most people seem to imagine ; but whenever a plague of voles occurs, owing to the balance of nature being temporarily disturbed, the local damage sometimes becomes so great that whole plantations are destroyed.

Sometimes it is difficult to determine, on first inspection, whether the damage is due to squirrels, mice, or voles, unless they have actually been seen at work. The main points for guidance then are (1) the season of the year, and (2) the position and appearance of the part gnawed. The marks left by squirrels are usually fainter than those of mice and voles.

If large trees are barked near their base, it is almost certain to be due to rabbits (or hares, if plentiful, in which case the marks of the incisors are much larger). But in young plantations, up to about fifteen or twenty years old, in which the bark on the young trees is still fairly soft, the base of stems may be gnawed either by rabbits or by mice and voles. Here, again, the difference in the size of the marks left by the incisors gives a fairly good clue as to whether the damage has been done by rabbits, or by mice or voles. Apart from the difference in the actual size of the marks, those made by the rabbits are fewer in number, and are more generally horizontal than the far closer and smaller marks left by mice and voles. But while the long-tailed field-mouse (*Mus silvaticus*) gnaws only at the roots and within 2 in. or 3 in. above the ground, and the damage done by rabbits is confined to within 12 in. or 15 in. above ground, the voles (the genus *Arvicola*, characterised by their short tail and legs, broad head, and small ears hidden in fur) gnaw both near the ground and, except the water-rat (*A. amphibius*), for a very considerable way up the tree, owing to their being able to climb.

Of the three species of these climbing land-voles, the true **field-mouse** (*A. arvalis*) is a poor climber, while the common **field-vole** (*A. agrestis*) climbs better, but the **bank-vole** (*A. glareolus*) is by far the best climber of the three. When voles swarm in woods during the winter, the two first-named do much damage by devouring seed and mast, and by gnawing the rind of saplings and poles near the ground and taking the bark off the foot of young trees as far up the stem as 8 in. or 10 in., while the bank-vole often climbs to a considerable height to reach the soft bark. When plantations have been gnawed at about 11 ft. to 12 ft. above the ground, the injury may, therefore, have been caused either by bank-voles or by squirrels, the voles climbing by means of the little branches. But the voles do their damage mostly during winter, whereas the peeling and ringing of trees by squirrels mainly takes place in spring and summer. Here again, however, the incisor-marks left by squirrels (though often very indefinite, even under a strong pocket-lens, until the specimens have become old and dry) are much larger and wider apart, and are more regularly perpendicular than those made by the bank-vole. And the marks generally extend from about 6 in. to 8 in. or 10 in. above some horizontal branch, where the squirrel seats himself conveniently and proceeds to gnaw away the soft bark and the cambium nearly or entirely around the stem, in which latter case the top of the tree dies off above the girdled ring (see also p. 40).

1. **Squirrels** (*Sciurus vulgaris*), when numerous, can do very serious damage to pole- and young tree-woods of Scots Pine, Larch, and other Conifers. They feed on many kinds of tree-seeds, especially acorns, horse-chestnuts, hazel- and beech-nuts, and also pick cones to pieces to get the seeds of conifers. They often eat the cotyledons of young seedling Beech, and root up young Oak seedlings from the ground. They also devour the terminal and the flowering-buds of Conifers, and sometimes do very severe damage to conifer plantations by biting off the top-shoots and trying to eat the buds, and by gnawing the bark in large patches (Fig. 100 *d*, p. 17).

The two old parent Douglas Firs at Scone have to be specially boarded round with a close wooden paling about 6 ft. high, capped with bent zinc, to prevent squirrels climbing over and getting to the trees. Before this was done, they destroyed all the cones before these could ripen. At Scone they also devour enormous numbers of acorns, beech-nuts, &c.

Squirrels are particularly fond of the flowering-buds of all Conifers, but especially of Spruce. From about the end of January till the middle of March they bite off the thin twigs on which these are situated, eat out the buds, and then let the sprays drop to the ground. Such cast sprays about 3 to 4 in. long are often found lying in large numbers under old Spruce-trees. They also devour great numbers of flowering-buds of Oak, Maple, Sycamore, and Beech. Where squirrels are numerous, seed-production is therefore poor.

Squirrels also in spring and early summer (May to July) peel the soft sappy bark from 10- or 12-, to 30- or 40-year-old Conifers, and to a much less extent also from broad-leaved trees. Besides biting off small patches of rind or gnawing a spiral screw going three to five times round the stem, they often completely girdle the crowns of older trees while sucking or licking the sap. And when stems are girdled, the crown above that of course dies and gets broken off in a gale. Sometimes Scots Pine plantations of about twelve years old are badly ringed, 4 to 5 ft. being stripped of bark.

Bark-peeling near the top of the stem is the most serious damage done by the squirrel, and when this is noticed there can be no question that squirrels require shooting down. As squirrels take to bark-peeling when the sap is in full flow, and chiefly during a hot dry summer, a change to wet weather may stop the damage naturally; but mischief like this soon becomes a habit.

In 1901 a young 14-year-old Larch plantation, near Blairgowrie (Perthshire), was attacked at about 11 ft. from the ground, a considerable number of the trees being damaged; and young Larches planted in March 1902 were destroyed at the same time. As voles were said to be swarming in the locality, it was at first thought that the damage was due to the bank-vole, but squirrels were subsequently seen at work during August. There were always a few squirrels about the residence, and as two large Beech-trees seeded profusely in 1900, the squirrels increased greatly in number, and took to damaging the Larch during the drought of 1901.

Squirrels were, in 1903, the cause of an action for damages, heard before Mr Justice Ridley at the Devon Assizes. Some time ago the Duke of Somerset let certain sporting rights on his Devonshire estates to a temporary tenant, with the special stipulation that squirrels should be kept down. It was contended that squirrels had been allowed to increase, with the result that 6000 Larch-trees had been injured. The jury awarded the Duke £200 damages.

In the south-east of Ireland, in the majority of cases, squirrels only attack Scots Pine and not Larch; and they only seem to peel the bark of trees in 30- to 40-year-old plantations when there is a bad seed-year. When there are plenty of cones, they do not need to peel. Seated on a whorl of small branches, they gnaw off the bark all the way round the pole, and in consequence of this the whole crown of the tree dies, and then gets broken off during a storm, while the lower part of the stem becomes rotten and of no use as timber.

In Scotland great damage was done a few years ago in large plantations near Fochabers (Morayshire); and in one Perthshire nursery, out of 60,000 seedling Firs, more than 50 per cent were damaged by squirrels.

Besides the damage done in nurseries, young plantations, and older woods, the squirrel eats the eggs and robs the nests of useful birds, in addition to levying toll in gardens (walnuts, strawberries, &c.) It is only fair, however, to say that the squirrel can sometimes be of use, as in the following case:—

A third enemy of the Pine-beetle (*Hylesinus piniperda*), and also a useful assistant in destroying large numbers of weevils and beetles in the grub stage, is the squirrel, by whom we were frequently guided to standing Fir-trees, which, though they had green tops, were infested with grubs of beetles and weevils. The squirrel found the grubs in the upper part of the trees, where the bark was not over one-fourth of an inch in thickness, and where they pass through the pupal stage, buried between the bark and the wood. Where the bark is over a quarter of an inch in thickness, the grubs of both beetles and weevils, when full fed, retire into it, and there the squirrel cannot get at them. I think that the squirrels would not feed on grubs unless they were short of other food; and in support of this opinion I may say that from 1895 to 1899, when I observed them eating grubs, Scots Fir cones were not to be found in this district. (J. Clark, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvi. part ii., 1900, p. 276.)

The good they occasionally do in the above way, and also by feeding on the larvæ of saw-flies, is small as compared with the damage they often cause.

Protection against Squirrels.—Squirrels may be trapped, but shooting them is the best way of keeping them in check. The best time is while nesting in spring (May), when a charge of snipe-shot will destroy the mother and her brood. Where this is not permitted, a raid may be made on squirrels in February, after the shooting season has ended and before the game-birds begin to lay.

2. **Mice and Voles** also often do a good deal of damage by eating seed in the woods, and by gnawing plants in nurseries and young plantations. Their attacks are often hard to combat, and sometimes this can only be effected when nature herself helps to restore the proper balance (by increase of natural enemies, or by epidemic disease).

Mice and voles are always found in woods adjoining fields. The wood-mouse lives in the woods, but the voles in summer infest the fields, and in winter live in the woodlands. They are both very prolific, and increase enormously in number during a mild winter followed by a dry spring and summer. But hard frost without snow, violent rain, rain followed by frost, and continuous cold damp weather often kill off excessive swarms in a short time. They require the protection afforded by dense seedling growth, grasses, weeds, and fallen leaves; and any such shelter favours their breeding. They are therefore fond of young plantations with a strong growth of grass, providing them with shelter and food. They seldom stay long in old woods after they have devoured the mast, unless the soil is thickly covered with fallen leaves. A layer of twigs or dead foliage spread over seed-beds is of itself enough to attract them.

Mice and voles chiefly devour acorns, beech-mast, and hazel-nuts, then Chestnuts, Lime, and Hornbeam seed, while they care less for the seed of other broad-leaved trees, and for conifer seeds least of all. Pine, Larch, and Spruce seed are sometimes eaten, but the more oily kinds, like Silver Fir seed, are protected by their turpentine. Autumn sowings of acorns and beech-mast are often destroyed during the winter, especially if sown in strips. Considerable damage is also sometimes done in seed-beds in nurseries.

They gnaw the young and tender bark of Beech, Oak, Ash, Hornbeam, and most other trees (Silver Fir, however, only exceptionally, and Acacia and Sweet-Chestnut hardly at all). But the various species of mice and voles have different tastes in this matter, and they also gnaw plants at different heights above the ground (see p. 38). Some begin to gnaw close to the ground, others only a little way above that, and others again only after climbing a good height up the tree. In nurseries, whole rows of one- and two-year-old Spruce are sometimes eaten through in seed-beds; while plants in plantations may either be bitten through, or gnawed partly or entirely round the stem, according to their age and size. As the young trees grow larger and the bark thickens, the danger of their being gnawed decreases.

The true Mouse (*Mus*) has a pointed muzzle, large ears, and a naked tail as long as its body. **The Wood-mouse** (*M. silvaticus*) mostly devours seeds, and only occasionally gnaws the bark.

The Vole (*Arvicola*) has a broad head with small ears hidden in fur, short legs, and a short hairy tail. Several species do damage in woodlands (Fig. 100 *a*, p. 17). **The true Field-mouse** (*A. arvalis*), which migrates from the fields to the woods in autumn, devours seed and gnaws the bark of saplings and poles near the ground. It is not a good climber. **The Common Field-vole** (*A. agrestis*) does similar damage, but often higher up, as it is a better climber. **The Red or Bank-vole** (*A. glareolus*), which does damage chiefly by gnawing, often climbs to a height of 10 or 12 ft. to reach the soft bark. **The Water-rat** (*A. amphibius*), the largest species, always lives below the ground and gnaws roots. It never occurs in large numbers.

The voles are further distinguished from the true mice by having back teeth, with flat crowns and transverse ridges of enamel, adapted for grinding the vegetable matter on which they feed, whereas in true mice the molars are covered with points or tubercles suitable for an omnivorous diet.

The **Field-vole** may at all seasons be found at all elevations, from the sea-level to near the summits of our highest hills, but most frequently in low-lying moist grass-land and damp young plantations. In such spots they live in communities, forming numerous burrows at a great depth, each pair having their own dwelling in which they bring up their young and deposit their store of winter food. All around, their tortuous runs are to be seen. The field-vole usually produces three or four litters a-year, each consisting of from four to eight young ; but in some seasons it breeds from February to November, and produces litters containing as many as ten young. Its diet consists chiefly of grass-roots and the tender bark of trees and shrubs, but in time of scarcity it becomes omnivorous, devouring insects, and even its own kind.

The **Bank-vole** (*A. glareolus*) is brownish-red, with a pure white breast, belly, and feet ; the ears are longer than in the field-vole, coming well above the fur. It varies from 3½ to 4 in. in length, and its tail reaches 1⅝ in. It is not difficult to catch in traps baited with cheese. It is found chiefly in and around woods, especially in sheltered banks, ivy-clad tree-stumps, and exposed roots in banks. It climbs to the height of 10 ft. or more, and eats out the terminal and lateral buds of trees, thus causing misshapen stems.

The **Water-vole or Water-rat** (*A. amphibius*) devours the stems of grain, grasses, &c., growing near water, and barks the exposed roots and base of stems of shrubs and trees, especially Oak, Ash, Sycamore, and Laurel. The water-vole also damages the banks of rivers, canals, and dykes. It lives along the edge of streams or ponds, or in damp meadows, and tunnels long underground passages.

Prevention and Extermination.—Damage by mice and voles is most likely to be obviated by protecting mice-devouring birds and animals, such as owls, buzzards, crows, ravens, sea-gulls, kestrels, rooks, hedgehogs, weasels, stoats, porcupines, martens, badgers, and foxes—so far as this may be permissible in the interest of sport. The removal of all grass and scrub that can be used as litter, and the maintenance of thick canopy to prevent the growth of weeds, lessen the chance of breeding-places being formed. If swine are herded in the woods, they snout in the ground, eat the mice, and disturb their nests and runs. Grazing cattle is also useful in keeping down grass, disturbing the mice, and destroying many runs and nests.

As mice are often troublesome in nurseries, it is best to form these only at a considerable distance from where fields border on woods. Such nurseries should also be encircled with deep ditches having nearly perpendicular walls, and pots full of water should be let into the sole of the trenches at suitable distances.

Every now and again—when the balance of nature has been temporarily disturbed by gamekeepers having been over-zealous in shooting owls, buzzards, and kestrels—mice and voles multiply into enormous numbers with such marvellous rapidity (and especially during dry mild seasons) as to become a plague, and to inflict very serious damage on the woodlands. Much useful and interesting information regarding their ravages was obtained when the committee was appointed to report on the plague of field-voles in Scotland, 1893.—One of the worst of the attacks known to have occurred in British woodlands was that in the Forest of Dean, in Gloucestershire, in 1813-14. Great numbers of Hollies and of five-year-old Oaks and Chestnuts were barked near the ground, while the voles gnawed the bark at 3 ft. to 4 ft. up. Cats were first of all employed, but proved next to useless as an exterminative measure. Then an endeavour was made to clear away the furze, fern, rough grass, &c., but this was soon abandoned as too expensive. Poisons were next tried, without proving very effectual; while traps of various sorts worked well, but were also expensive. Finally holes or trenches were dug, 18 in. to 20 in. wide at bottom, 2 ft. long, $1\frac{1}{2}$ ft. deep, and 9 in. wide at the top, up the inward sloping sides of which the mice and voles could not climb out again after once they had fallen into the pits. Where the mice were numerous, the lines of trenches were dug about 20 yards apart; otherwise they were 30 yards apart. About 30,000 were thus caught throughout the course of one autumn, and it was calculated that during the three or four months of their visitation upwards of 200,000 were killed, partly by the pits, partly by natural enemies, and latterly also by the mice preying on each other.

At Rannoch, in Perthshire, early in the winter of 1863-64, mice attacked about 140 acres of mixed plantations of eight and fifteen years of age, consisting of Scots Pine and Larch, intermixed with Oak, Ash, Sycamore, Elm, Beech, and Sweet-Chestnut; but on this occasion only the Scots Pine suffered. Sir Robert Menzies thus described the attacks, and the means used in suppressing them:—

> Early in the winter of 1863-64 the mice attacked the Scots Firs in both plantations simultaneously, eating away the bark, and sometimes the wood all round, as high as they could reach, which, assisted by the heather and long grass, was from 6 in. to 1 ft. The Scots Firs only were attacked, and it was difficult to distinguish those that were injured from those that had escaped in the long grass, which concealed the gnawed places,—in this respect showing distinctly the difference between the work of mice and that of rabbits, the latter being visible at once.

They were got rid of in spring by poisoning them with phosphorus paste added to oatmeal laid in drain-tiles scattered throughout the plantations. As food became scarce the mice ate the bodies of the poisoned ones, and were in their turn also poisoned.

From 1864 to 1867 voles did a good deal of damage in the Drumlanrig plantations (chiefly Oak and Ash) on the Buccleuch estate, but they were finally got rid of by means of digging pits. There were subsequent attacks in 1875, 1876, and 1891-92, which were remedied in the same way. So long, however, as mice and voles can get their proper natural food, such as grass and herbage, they are not likely to attack trees. Thus, in 1877, Sir Robert Menzies wrote concerning mice:—

> I have a plantation at present in Ardlarich, in Rannoch, planted in 1871, that is swarming with them quite as numerously as the former ones (attacked in 1863-64), and not a tree has yet been touched (1877) because the grass is still plentiful; but should that fail, the tiles are all ready for them.

In the plague of voles in the south of Scotland, in 1891-92, woodlands suffered here and there, but only to a comparatively small total extent. The chief instance cited before the committee was a plantation of 3 to 4 acres at Suar, which was entirely destroyed, and had to be burned. The only means of preventing plagues of mice and voles is to protect owls of every sort, buzzards, kestrels, and the smaller sea-gulls, which all, as well as foxes, stoats, and weasels, prey on these small rodents. But when once the balance of nature has been disturbed so far as to induce a plague of this sort, then the best practical remedies are that practised by Sir Robert Menzies at Rannoch in 1863, and that recommended by the committee in 1893 to the following effect—

> Where plantations of limited extent are attacked, pit-falls wider at the bottom than at the top, and about 18 in. deep, should be dug. The voles fall into them and cannot escape, and the ground is soon cleared of them in this way.

Even if such a plague were left entirely unchecked, nature would in course of time restore the normal balance and put an end to the abnormal conditions. As in the case of great attacks by injurious insects, it has also been found that plagues of mice and voles never continue for more than three years, by which time epidemic diseases break out and restore the balance by violent measures.

Continental Notes.—In German nurseries, surrounding seed-beds in autumn with a 4 to 8 in. band of tarred paper, held upright by short wooden pegs stuck in the ground, has proved of great use. Smearing the bark of stems of the more valuable species of trees with common tar, or with the patent tar or glue used for grease-ringing against some kinds of caterpillars (see p. 67), has there also proved effective against gnawing.

Where mice are numerous, acorns or beech-nuts are stored throughout the winter, and not sown till spring. Laying tanning-bark and Spruce twigs over the seed-beds, and sprinkling finely-chopped Juniper twigs over the acorns before they are covered with soil, have also proved effective. Digging steep-walled ditches along the edge of fields, from which voles are likely to come in autumn, has likewise been more or less successful.

In Beech-woods specially exposed to danger, young seedling growth can often be protected by cutting and spreading on the ground young stool-shoots, advance growth of softwoods or other trees, and small branches of the standards when felled. The mice gnaw such material found on the ground before attacking upright plants, and at the same time they are fond of the buds on the Beech twigs. If such branch-wood is heaped together throughout young crops specially exposed to danger, the mice collect there in large numbers, and can then be most easily poisoned with wheat soaked in a solution of strychnine or phosphorus, and laid in drain-pipes here and there near the heaps.

Efforts to annihilate large swarms of mice are only feasible for protecting nurseries. Poisoning is then found best, for trapping seldom gives suitable results for the time and trouble required. Grains of wheat, meal, flour, or bread pills soaked in, or specially prepared with, phosphorus, arsenic, or strychnine, are laid in the mice-holes, or in drain-pipes to protect them from damp. Unfortunately, however, mice poisoned with phosphorus or arsenic are generally impelled by thirst to seek water and die away from their holes, and when they are eaten by useful birds (like crows, buzzards, and owls) and other animals (like weasels), these are poisoned too. If precipitated carbonated barium be kneaded with meal or flour, made into pieces the size of a bean, and dropped into the holes, it produces immediate paralysis of the mice which eat them.

Broad-leaved saplings much damaged by gnawing should be coppiced early in spring, so as to flush new shoots from the stool.

3. **The Hazel or Garden Dormouse** (*Myoxus avellanarius*) is frequent in coppice, where it eats the hazel-nuts. But it eats other tree-seeds too, and also gnaws the bark in corkscrew-like spirals. It chiefly gnaws Beech, Silver Fir, and Larch ; and in years when tree-mice are numerous, very perceptible damage can be done. They have to be caught in traps, as their small size and nocturnal habits make it difficult to shoot them.

CHAPTER III.

PROTECTION AGAINST DESTRUCTIVE BIRDS.

THOUGH on the whole usually much slighter than the injuries caused by insect enemies, or even in many cases by deer and ground-game, the damage done to woodlands and nurseries by birds is occasionally by no means inconsiderable. But at the same time many species of carnivorous birds are of decided utility by feeding on small ground-vermin and insects; others are to a certain extent beneficial with regard to one portion of their food, though often also injurious as regards the rest of their feeding; whilst others again must be reckoned decidedly injurious.

A. **With regard to Ground-Vermin.**—Among the birds that may be classed as undoubtedly useful in keeping down the number of mice and voles are the Buzzards, and more particularly the Common Buzzard (*Buteo vulgaris*); the Kestrel, Wind-hover, or Stannel Hawk (*Tinnunculus alaudarius*); the Owls, especially the White or Barn Owl (*Strix flammea*), the Long-eared Owl (*Otus vulgaris*), the Short-eared Owl (*O. brachyotus*), the Tawny Owl (*Syrnium aluco*), and the Little Owl (*Noctua*), which only visits us occasionally; the Rook (*Corvus frugilegus*), during the autumn in particular, the Common or Carrion Crow (*C. corone*), the Hooded Crow (*C. cornix*), the Jackdaw (*Monedula turrium*), and some of the Hawks (*Strigiceps*).

These birds all do exceedingly useful work in maintaining the due balance of nature. Even though the Rooks and Crows and Jackdaws often scratch up seed from the nursery-beds during the late autumn and the winter, yet the amount of good they do in helping to keep down any inordinate increase in the number of prolific voles and mice, most decidedly entitles them to have their offences condoned. In killing Kestrels by mistake for Sparrow-hawks the farmer destroys one of his best friends, and thereby actually protects voles.

In addition to the above, many other birds of prey likewise aid in keeping down ground-vermin; but as they also possess very distinct hankerings after young game-birds and insectivorous singing-birds, the damage they do on these accounts places them beyond the pale of the forester's protection.

For details about the Kestrel, the Short-eared Owl, and the Barn Owl, see Board of Agriculture Leaflets Nos. 40, 42, and 51.

B. **With regard to Injurious Insects.**—When we come to consider the classes of insectivorous birds most deserving protection, a much larger number presents fair claims for preservation by every means in our power.

It includes, again, many of those already entitled to our protection for their aid in restricting the abnormal multiplication of mice and voles, so that such have a twofold claim to our favourable attention.

I. **Decidedly useful Birds.**—The birds of greatest utility in checking the numerical increase of injurious insects are the Cuckoo (*Cuculus canorus*), which feeds principally on hairy caterpillars that are avoided by most other birds; the Starling (*Sturnus vulgaris*), the Tits (*Paridæ*), the Creepers (*Certhidæ*), the Swallows, Martins, and Swifts (*Hirundines*), the Warblers (*Sylviæ*), the Nightingales (*Lusciniæ*), the Wrens (*Troglodytes*), the Accentor or Common Hedge-sparrow (*Accentor modularis*), our summer visitor the Redstart (*Ruticilla phœnicura*), the Robin or Redbreast (*Erythacus*), the Whitethroat (*Curruca cinerea*), the Stonechat (*Saxicola*), Flycatchers (*Musicapinæ*), Wagtails (*Motacillinæ*), the Titlark or Meadow-pipit (*Anthus pratensis*), and the Nut-hatch (*Sitta europæa*). All the Owls, except the Eagle Owl or Great-eared Owl (*Bubo maximus*), a rare bird, do good by feeding on grubs, though here again the Long-eared Owl (*Otus vulgaris*) and the Tawny Owl (*Syrnium aluco*) render best service in this respect, while the Fern-owl, Goat-sucker, or Nightjar (*Caprimulgus europæus*) feeds on night insects (cockchafers and moths). Of the sea-birds which come inland for breeding purposes, gulls generally, and the Brown- or Black-headed Gull (*Larus ridibundus*) in particular, give most aid in preventing any undue increase among noxious insects.

All of these birds deserve protection. Though many of them levy toll on orchards, yet attempts to diminish their numbers must result in favouring the increase of insect pests, and thereby lead to very much worse results in the long-run, because the latter are endowed with enormously prolific power.

Many have declared the Cuckoo to be perhaps more of a nuisance than a blessing; but during a plague of the Processionary Moth or Oak-spinner (*Cnethocampa processionea*) in Germany, Prof. Altum found no less than ninety-seven caterpillars, of about one-third of their full growth, in the stomach and intestines of a Cuckoo.[1]

The Starling is, along with the useful Hedge-warbler or Hedge-sparrow (*Accentor modularis*), one of the victims of the Cuckoo's attentions during the breeding-time. In order to protect its eggs and its young, however, against Cuckoos, wild cats, and other enemies, very useful aid is given to its protection by hanging up wooden nesting-boxes in the branches of trees (p. 64). It is marvellous how quickly the birds respond to this attention; and as the entrance-holes are too small to admit the Cuckoo, and the nesting-place is deep enough below that to be beyond the reach of a cat's paw, an effective measure for their increase can be adopted at slight cost, as the boxes cost little, and last for many years. Two other birds, close relatives of the Cuckoo, but of rather rare occurrence in England, the Roller (*Coracias garrula*) and the Hoopoe (*Upupa epops*), also deserve protection whenever they come as fleeting guests, for they too are exceedingly useful in feeding on caterpillars.

The whole family of the Tits or Titmice (*Paridæ*) are worthy of all the protec-

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[1] During the plague of Black Arches (*Liparis monacha*) in Bavaria in 1889-91, the Starlings flocked in thousands to the forests attacked in order to feed on the caterpillars, whilst the complaints of the market-gardeners were loud at these useful birds having for the time being forsaken their gardens, even although their guardianship has to be paid for by a tithe of cherries.

tion which we can bestow on them, as they wage a most successful warfare against our insect enemies. The Great Titmouse (*P. major*), the Blue Tit or "Billy-biter" (*P. cæruleus*), the Long-tailed Tit (*P. caudatus*), the Black Tit (*P. ater*), and the Crested Titmouse (*P. cristatus*) are more particularly the species which render best service in placing limits to the rapid numerical increase of insects. In young plantations and in nurseries the Wrens are continually inspecting the youngest shoots of conifers, and thus free them from ova and grubs of many sorts; whilst the Chiff-chaff (*Sylvia rufa*), a more common visitor in the south of England than in the colder and less hospitable north, immediately on its arrival in spring pays special attention to the leaf-rolling caterpillars that infest the young foliage and tender early buds of trees, as well as to the various forms of *Aphidæ* which the nurseryman and the gardener include within the comprehensive and elastic term "blight." Belonging to the *Passeres* or Sparrow tribe, mention may also be made of an occasional summer visitor, infrequent even in England, and rare indeed in Scotland, the Golden Oriole (*Oriolus galbula*), which feeds for the most part on insects, although the temptation offered by the fruit in orchards is apt to tempt it away from the woods, particularly when the luscious cherries are ripening.

Many other birds are of partial use in devouring insects, whilst they undeniably commit a certain amount of damage to crops of various kinds or to young game-birds: others, again, do on the whole more harm than good. These may therefore be roughly divided into (II.) such as are more useful than injurious, and (III.) those that are more injurious than useful, and may be considered before the class of birds (IV.) that are undoubtedly destructive.

For details, see Board of Agriculture Leaflets Nos. 43 (*Titmice*), 45 (*Starling*), 50 (*Water Wagtails*), 54 (*Flycatchers*), and 55 (*Swallows and Martins*).

II. **Species that are on the whole more Useful than Injurious.**—In this class several sections of the *Passeres* or Sparrows must be included, even although they mainly subsist on corn and grain as their staple food, and only attack insects in an irregular and spasmodic manner. Local circumstances to a certain extent determine whether or not they are entitled to be classed as useful on the whole; and where careful, unprejudiced observation seems to point to their doing more harm than good, then there can be no justification for affording them unlimited protection, as in the case of all the kinds of birds that have been included among the *very useful species* already enumerated. To this class of limited utility in respect to the suppression of insect enemies belong certain of the Finches (*Fringillidæ*), Larks (*Alaudidæ*), Woodpeckers (*Picidæ*), Thrushes and Blackbirds (*Turdidæ*), the Jackdaws, Rooks, and Crows (*Corvidæ*), the Common Buzzard (*Buteo vulgaris*), the Kestrel or Stannel Hawk (*Tinnunculus alaudarius*), the Peewit, Lapwing or Green Plover (*Vanellus cristatus*), and the Snipe (*Gallinago*). Of the birds of passage, the Honey Buzzard (*Pernis apivorus*) devours large numbers of the larvæ of wasps and other injurious insects, as well as those of bees unfortunately, while the Woodcock (*Scolopax*), which passes the winter with us, issues forth at night from the thickets in which it spends the day, and feeds on the worms and insects to be found on low-lying wet lands.

For details about the Plover, see Board of Agriculture Leaflet No. 44.

The Finches form a very large family of small and interesting birds, including many of our sweetest songsters. From the conical construction of their beaks, it is evident that they have been gifted by nature with special facility for feeding on hard seeds like peas and grain. Of those that may be classed as useful rather than destructive, the Bullfinch (*Pyrrhula rubricilla*), the Goldfinch or Thistlefinch (*F. carduelis*), the Lintie or Common Linnet (*F. cannabina*), and the Greenfinch or Green Linnet (*F. chloris*) are all well-known frequenters of our fields, gardens, nurseries, and orchards, where they feed partly on insects and partly on seeds; whilst the Siskin (*F. spinus*), an autumn visitor merely, is a comparatively rare bird in England, though it is less infrequent in Scotland, where it occasionally stays to breed. The other Finches are generally more destructive than useful.

The two principal species of our British Larks are the Skylark (*Alauda arvensis*) and the rarer and smaller Woodlark (*A. arborea*), the latter of which derives its name from the fact of its often singing whilst perched on trees, a power that is denied to the former. Both species, however, nest on the ground, and both are on the whole deserving of protection.

The Woodpeckers form a class about which a good deal of misinformation is current. It was formerly supposed that they hollowed out holes in the stems of trees only when these were infested by noxious insects. But closer observations have shown that in many cases they peck holes in perfectly sound stems, and that the insects they hunt after are frequently *Cerambycidæ*, of little sylvicultural consequence compared with the injurious *Scolytidæ* they often neglect under the bark.

There can be no doubt that Woodpeckers often consume during the winter months a fairly large quantity of the seed of trees (especially of Spruce and Pine, which they extract from the cones, and of shell-fruits), and can individually do a deal of damage at times by pecking holes in ornamental trees occupying isolated positions (especially after they have been feeding in coniferous woods and have their beaks rendered uncomfortable by resin), as well as by picking the rind off sturdy transplants and young trees of smooth-barked species, and by girdling young trees of all sorts during May and June for some purpose not yet accurately determinable. But the total damage is confined within narrow limits from the fact that all the species of Woodpeckers are to be found at work singly in the woods, and not in flocks. Thus, when injuries on sound avenue or ornamental trees begin to occasion uneasiness, the shooting-off of an individual bird usually puts an end to the mischief. And on the other hand, it is equally certain that during the spring and summer months they feed to a very large extent, mainly in fact, on insects which they either pick out from the ground (as in the case of cockchafer grubs, mole-crickets, earthworms), or from the branches and bark of trees (as in the case of many caterpillars and chrysalides), or from the cambium and the interior of the stem (as in the case of many bark-weevils, beetles, wood-wasps, &c.), for the extraction of which their long, pointed tongue is specially adapted by being furnished with hook-like hairs or barbs pointing backwards. Nor is the least part of their utility attributable to the fact that the chambers they thus hollow out with their strong beaks, when hunting after grubs and beetles in the interior of the stems of large trees, are utilised as nesting-holes or breeding-places by Woodpeckers themselves, as well as by a considerable number of other very useful insectivorous birds, like Starlings and Tits, which would in more open nests be exposed to the undesirable attentions of cuckoos, wild cats, and other enemies.

The most common of this family of birds in Britain is the Green Woodpecker, Woodspite, or Yaffle (*Picus viridis*). The Wryneck (*Yunx torquilla*), a small species, is a not infrequent summer visitor in the warmer southern counties of England; while the Great Spotted Woodpecker or Woodpie (*Dendrocopus major*), the largest species, and at the same time that which does most damage, is only occasionally to be found in England. It usually takes up its haunts in the stillness of large woods.

Among the *Turdidæ*, three species are common in Britain at all times of the year, the largest being the Missel-thrush or Stormcock (*Turdus viscivorus*), which is somewhat bigger than either the Throstle or Mavis (*T. musicus*), or the Blackbird (*T. merula*). These are all three sweet songsters, and the first named is one of the few birds whose notes ring through the woodlands late in winter, when even the Throstle has become silent, and many of the other singing-birds have long since flown to warmer lands. To make up for their temporary silence, however, the Mavis and the Blackbird not only do a considerable amount of good by clearing young plantations, nurseries, and gardens of earthworms, snails, cockchafer grubs, and other insects, but also assist in the distribution and reproduction of many kinds of useful trees and shrubs on whose berries they feed during the winter months. That the first-named thus likewise assists in the spread of mistletoe is a misfortune, though certainly not one of any serious extent, as in orchards near large towns it may even be desirable for the old-fashioned Christmas rites. Were it not that all the Thrushes have such a weakness for every kind of garden-fruit, but more especially for cherries and raspberries, they would be well worthy of a place among the birds of unquestionable utility. The Ring-ouzel (*T. torquatus*), a summer visitor to the British Isles, is also useful. The Redwing (*T. iliacus*) and the Fieldfare (*T. pilaris*), both winter visitors, feed on slugs and insects as well as on hedge-fruits and the seeds of forest-trees ; but they are not of such utility as the other Thrushes, for they are absent when insects are most numerous in spring and summer. Thrushes are also specially useful in killing snails (see p. 52).

Of the Crows, the Jackdaw, the Common or Carrion Crow, the Hooded Crow, the Rook, and the Chough (*Fregilus graculus*) all make up for their assaults on gardens and nurseries by waging war against cockchafer grubs, daddy-long-legs, wireworms, and similar insects, as well as grasshoppers and beetles, that are injurious both in the corn-fields and the market-gardens and nurseries. They seem fondest of a very mixed diet, embracing grubs, potatoes, corn, orchard fruits, full-grown insects, and even an occasional chicken or tender duckling in the case of Rooks and Crows.

III. **Species that are on the whole rather more Injurious than Useful.**—Besides certain Finches (which will be presently referred to), the Common or House Sparrow (*Passer domesticus*) does rather more harm than good in fields, gardens, and nurseries, owing to the fact of its feeding so often in large flocks, and not singly or in small flights merely.[1]

The Shrikes or Butcher-birds (*Laninæ*) live upon insects, frogs, mice, and small birds, many of these latter being species of considerable utility. The Great Grey Shrike (*Lanius excubitor*) is a much less frequent bird in England than the small red-backed species (*L. collurio*), which is the more useful of the two,—or rather, which does less harm than the former as regards killing insectivorous birds, as well as voles, &c.

To this category belong also the Magpie (*Pica caudata*), the now rare Raven (*Corvus corax*), and the equally rare Eagle Owl or Great-eared Owl (*Bubo maximus*), and nearly all the birds of prey included among Eagles, Falcons, and Hawks (*Falconidæ*). Of the latter, the Sparrow-hawk (*Nisus communis*) is common in Britain, while the larger Goshawk (*Astur palumbarius*), a more characteristic dweller in the woods, and one whose protection would be entirely at variance with game-preserving, is comparatively rare. The Merlin (*Hypotriorchis æsalon*), indeed, the vicious dwarf among the falcons, feeds to a far greater extent on thrushes, larks, starlings, tits, wagtails, and the like than on mice and voles, and is therefore indirectly a dangerous enemy of woodlands and gardens by destroying various more useful species.

[1] For details, see Board of Agriculture Leaflet No. 84 (*The House-Sparrow*).

IV. **Decidedly Injurious Birds**—*i.e.*, those which certainly do very appreciable damage in woods and nurseries. The birds which fall under the heading of directly injurious species may be conveniently divided into four main classes—(1) Grouse, (2) Pigeons, (3) Jays, and (4) Finches.

1. **Grouse** (*Tetraonidæ*).—The game-birds coming under this category are all of the Grouse family (*Tetraonidæ*), and include the Capercaillie or Cock-of-the-wood (*Tetrao urogallus*), not now a common bird even in the wildest parts of Scotland, the Blackcock (*T. tetrix*), and the Red Grouse (*Lagopus scoticus*).

The **Capercaillie** is only to be found occasionally in secluded mountainous tracts, where conifers form the ruling woodland crops. During the winter and spring it takes up its quarters in the neighbourhood of temporary nurseries or young plantations, and feeds on the buds and the foliage of the youngest shoots. As the birds keep very much to one feeding-ground circumscribed by narrow limits, the results of their destructiveness are more apparent than if they were spread over a larger area. When snow covers the ground, so that just the tips of the leading-shoots of young seedlings appear above it, they bite them off as cleanly as if they had been cut through with shears. Spruce and Silver Fir appear to offer this bird more toothsome attractions than the Scots Pine, the ordinary tree of our Highland tracts. When the advent of warmer days in spring awakens insects and worms to renewed activity, the cock-of-the-wood varies his diet to a certain extent, and feeds partially on these pests of the nurseries.

Where there are *Capercaillie*, conifer seed-beds can easily be protected by a light wooden framework, or by stretching wires along and across the beds, or by putting down rough branching top-ends and branches on the ground to interfere with the movement to and fro of the birds.

The **Blackcock** and the **Common Red Grouse** of Britain are both inhabitants of the heathery moors and the hill-slopes covered with heath, whortleberry, cranberry, and similar wild growth. When the supplies of food offered by these plants and by berry-bearing shrubs and trees like the Rowan or Mountain-Ash in autumn and early winter become exhausted, the birds are naturally forced to attack plantations or nurseries formed in the vicinity of their haunts. As they feed for the most part on the ground, their attentions are mainly confined to the needles of the lower branches, the loss of which is of no great consequence to the plant. Very often, however, they are forced to pick the buds of conifers and broad-leaved trees in order to obtain a sufficiency of food, and when thus driven by hunger they show little choice in the matter, taking Larch, Spruce, Silver Fir, Pines, Birch, Alder, Ash, Mountain-Ash, and Hazel indiscriminately, wherever they are within easy reach. They are fond of the male catkins of Birch, Alder, and Hazel in the early spring.—**Moor-fowl** or **Ptarmigan** often also damage young Scots Pine by picking out the buds of the leading-shoots.

In comparison with the damage done to plantations by hares, more especially by the blue hare (*Lepus variabilis*, p. 21) so common throughout the Highlands of Scotland, the injuries caused by grouse are comparatively slight, and call for no special measures of protection, which in any case it would be difficult to provide. So, too, the damage that may be done here and there to seed-beds by **Pheasants** is not generally very serious, although they can devour a good many acorns.

2. **Pigeons** (*Columbidæ*).—The Culvers or Pigeons include the Wood-pigeon or Cushat (*Columba palumbus*), also called the Ring-dove from the dark ringlet edged with white which encircles its neck, the Wood-dove or Stock-dove (*C. œnas*), and the Turtle-dove (*Turtur auritus*). The two former

remain all the year in England, but the last-named is merely a summer visitor, coming in May and migrating again to warmer lands about September.

The Wood-pigeon is principally to be found in coniferous woods, where it consumes a large quantity of ripe seed, as well as buds, and the catkins of different kinds of trees at the time of flowering. Where numerous, they often do a good deal of damage by breaking the brittle leading-shoots of Douglas Fir, Silver Fir, and Spruce, by settling on them in spring and summer.—The Stock-dove takes up its quarters more frequently in mixed woods, where broad-leaved species of trees predominate, than in those stocked mainly with conifers, and it feeds to a large extent on the buds, flowers, and fruits of the former.—The Turtle-dove usually takes up its abode in small patches of woodland occurring scattered here and there among fields and meadows, and feeds principally among the latter. During the spring-time all three species are wont to assemble in flocks, when they can do no small amount of damage to the sowings in fields and nurseries. And in the autumn, when the acorns and beech-nuts have ripened, the two larger kinds of pigeons love to feed off the mast, without, however, doing much damage of any really serious nature from a sylvicultural point of view.

The best preventive measure is to dip the seed in red-lead before sowing: 1 lb. of red-lead, costing about 6d., will coat at least 6 lb. of seed.

3. **Jays** (*Corvidæ*).—In the Common Jay (*Garrulus glandarius*) there is a great deal to remind one of the Magpie, and the Nutcracker (*Nucifraga caryocatactes*) is also mainly destructive.

The damage the Jay does to woodlands and nurseries by scratching up acorns (whence its specific name), beech-nuts, chestnuts, and similar seeds, and by devouring the cotyledons of young seedlings, and the toll it levies on fruit of various kinds in gardens and orchards, are perhaps of less real importance than the indirect effects arising from its attacks on the eggs and young of insectivorous singing-birds. Nor is it by any means indifferent either to the attractions of the eggs and young of game-birds, or even to those of newly-born leverets. There can be little doubt that its natural tendencies of this description far outweigh any fortuitous benefits conferred by hiding acorns and other fruits that germinate later on, generally in places where they are not required, or by hunting up insects occasionally during winter and early spring, and by killing a few mice or voles now and again.—The Nut-cracker Crow adopts a very similar mode of life to our Common Jay, but shows a greater liking for coniferous seeds (which it also breaks out from the cone) than is exhibited by the latter. It is characterised by the same evil tendency towards the destruction of the eggs and young brood of birds, such as Thrushes, that are of real sylvicultural utility in keeping down the numbers of noxious insects. It is to be met with only in the wilder parts of the country, and more especially in rocky mountainous tracts, where it sometimes sows seeds by chance.

Jays can only be kept off nurseries by laying down thorny branches over the seed-beds, or using some sort of framework. Shooting them is, however, better.

4. **Finches** (*Fringillidæ*).—The species of Finches that can unquestionably be classed as more beneficial in destroying insects than harmful in regard to their other habits of feeding have already been enumerated. Certain other species, however, must be regarded as committing direct damage to an extent that outweights the benefits conferred by them in helping to check the prolific tendencies of our insect enemies. To this noxious category belong the Chaffinch or Pie-finch (*Fringilla cœlebs*), the Brambling or Mountain Finch (*F. montifringilla*), and the Hawfinch (*Coccothraustes vulgaris*); while the

Common Crossbill (*Loxia curvirostra*), the only species of the genus *Loxia* that frequently visits Britain, must also be included along with them.

The damage done by the Chaffinch and the Mountain Finch is the more conspicuous owing to their habit of collecting in large flights in autumn, when they visit nurseries and areas on which sowings have been carried out, and in spring, when they feed on the cotyledons of the young seedlings. Whilst the latter pays, on the whole, most attention to the seed and seedlings of the broad-leaved species of trees, and particularly of Beech, the former exhibits a preference for conifers, among which Larch, Spruce, and Pine appear to be its favourite food.—The Hawfinch is a more varied feeder, the damage it does being more noticeable in gardens and orchards than in nurseries or woodland areas. It is difficult to keep the flocks of these small birds away from sowings to which they have once become attracted : even if frequently scared, they soon return to their feeding-ground, and by this persistency often do a considerable amount of damage to the autumn sowings. Sowings in spring are less exposed to their visitations, as at that time of the year larger and more varied supplies of food are available than is the case in late autumn and throughout the winter months.

Where Finches are very troublesome, the seed-beds may require the protection of a framework. Otherwise coating the seeds with red-lead (as above described for pigeons) is cheap and effective. Tying threads or twine across the beds, with white feathers, &c., knotted into them, is also serviceable, but scarecrows are merely of temporary use.

The voracious Crossbill feeds almost solely on tree-seeds and berries, although it sometimes devours *Aphides*. It is particularly partial to the seeds of conifers, although also feeding largely on the fruit of Maples, Ash, and orchard trees. After biting off the cones of Spruce or Pine, it uses its mandibles very dexterously in forcing up the bracts by first inserting the points evenly and then jerking them apart so as to displace the bracts and lay bare the seed. When this manœuvre is not quite successful, it splits open the scales of the cone from above downwards until the seed lying at the base becomes obtainable. The damage thus done is the more noticeable from the fact of this bird frequently settling down on the feeding-grounds in large flocks, and when the attentions of such flights have once been drawn to temporary nurseries, the havoc they commit may become considerable.

Arranging the above-described four classes in tabular form for convenience in overlooking them, the following are the birds of importance to the forester in Britain :—

I. Decidedly useful.		II. Rather useful.		III. Rather injurious.	IV. Decidedly injurious.
Cuckoo.	Robin.	Bullfinch.	Common Crow.*	Shrikes.	**Grouse.†**
Roller.	Whitethroat.	*Goldfinch.*	Hooded Crow.*	Magpie.	Pigeons.
Hoopoe.	Stonechat.	Linnet.	*Cornish Chough.*	Raven.	Doves.
Starling.	*Oriole.*	Greenfinch.	Buzzard.*	Eagle Owl (*B. max.*).	Jay.
Tits.	Wagtails.	Siskin.	Kestrel.*	Sparrow-hawk.	Nut-cracker Crow.
Creepers.	Titlark.	*Larks.*	*Lapwing.*	Goshawk.	Chaffinch.
Swallows, Martins, and Swifts.	*Owls* * (except *B. max.*).	*Woodpeckers.*	*Plover.*	Merlin.	Mountain Finch.
Warblers.	Flycatchers.	Thrushes.	**Snipe.†**		Hawfinch.
Nightingales.	Nut-hatch.	Blackbirds.	Honey Buzzard.		Crossbills.
Wrens.	Black-headed Gull.	Jackdaw.*	**Woodcock.†**		
Accentor (Hedge-Sparrow).		Rook.*			
Redstarts.					

Italics.—Birds benefited by the close time prescribed in the Wild Birds' Protection Acts, 1880-1904.
* Those marked with an asterisk are also of decided utility in keeping down mice and voles.
† Protected under the Game Laws. Grouse have also a close time, but not Snipe or Woodcock.

It is of interest to note what has been done by legislation in the way of preserving the useful species of birds. Of the kinds that are *on the whole injurious*,—though any damage caused is really often slight as compared with the ravages of noxious insects,—only Grouse receive any protection through a close time provided by law. But the eight months' rest provided for them is annually followed by a practical decimation during the other four months of the year. Of the *rather useful* species, Snipe and Woodcock also have the benefit of the protection of the game laws, without, however, any close time being prescribed, hence all they derive from that is the doubtful advantage of being shot only by certain privileged parties. But along with the other useful species printed in italics, they are specially mentioned in the Wild Birds' Protection Acts, 1880 to 1904, and thereby given protection annually from 2nd March to 31st July (both days inclusive), under a penalty of £1 for each bird on each offence. For killing any other wild birds (except eighty-six specially mentioned at £1 for each offence) in the close time, the penalty is a reprimand and costs for first offence, and 5s. and costs for each bird for every subsequent offence.

Whilst we must be thankful to have any of our wild birds protected in this manner by law, the benefits have not yet been so widely conferred as they well might be ; for among the useful species there are many good friends both of the farmer and the forester against which no adequate reasons can be adduced that should debar them from obtaining protection of some sort at an early date.

Note.—In nurseries, **Slugs** (*Limacidæ*) and **Snails** (*Helicidæ*) are sometimes troublesome, and can best be kept down by useful birds.

Prevention and Extermination.—By far the greatest *natural checks* are birds, especially the *Thrush*, which not only eats many slugs, but is very partial to snails, breaking their shells against a stone and picking out the mollusc. *Blackbirds* and *Starlings* devour large numbers of slugs. Toads eat slugs and small snails, and moles and shrew-mice also feed on slugs. Poultry and ducks eagerly search for them. Centipedes attack slugs, and ants frequently kill snails ; but only birds do any appreciable good in keeping down these molluscan pests.

The best *artificial preventives* are :—

1. Drainage, because dampness favours their increase.

2. Avoid long manure, or in fact any organic manure, where slugs are abundant in the soil ; artificial manure is preferable *for a time*.

3. Use dry-dressings of some irritant to kill the pests,—(*a*) soot and lime ; (*b*) salt and lime ; (*c*) lime and caustic soda ; or to act mechanically, (*d*) powdered coke. The lime must be very finely divided and quite fresh. *Two or three dressings must be given*, the second some 15 to 30 minutes after the first. Lime and caustic soda act best (4 parts of caustic soda to 96 of lime, well mixed). Dry-dressings, except powdered coke, should be applied very early in the morning. Heavy applications of soot are best to keep off snails, which should be dealt with mainly by hand-picking, and by trapping with cabbage-leaves.

4. Heaps of bran-mash or moist oatmeal may be placed here and there as baits to attract the slugs, which may then be easily collected.

5. Rows of plants are best protected either by spreading barley-sweepings or cinders and lime along the rows, or by heavy dressings of slaked lime.

6. Hedge bottoms and rough herbage at the base of walls should be cleaned out in winter, and the masses of hibernating snails crushed.

7. Nursery-land that is thoroughly fouled with slugs should be treated with gas-lime, and in the winter deeply trenched.

8. Wherever invasion is from a neighbouring wood, a deep trench should be dug and filled with lime or tar to trap the pests. Ducks and poultry in late autumn, and ducks in spring, greedily devour both kinds of pests (Board of Agriculture Leaflet No. 132—*Slugs and Snails*).

CHAPTER IV.

PROTECTION AGAINST INJURIOUS INSECTS.

Injurious Forest Insects often cause enormous damage to woodlands, though, owing to various reasons, this is not the case throughout Britain. When attacked, both young and maturing crops are damaged and often killed. Increment ceases for the time being, blanks are formed, and sometimes extensive crops are entirely destroyed. Insects that bore into the stem decrease the value of the timber greatly. The market becomes glutted with timber after any extensive destruction of woods by insects, and only reduced prices are obtainable, while perhaps no purchaser can then be found for small timber. Preventive measures and remedies may often cost a good deal; and it is sometimes necessary to let falls lie fallow for three to four years, to get rid of beetles. The extermination of swarms of insects is difficult, because they multiply enormously under favourable circumstances. Indeed, their extermination is then often next to hopeless without natural assistance in the way of epidemic fungous diseases among the larvæ.

Life-History of Insects.—Insects (*Insecta*) belong to the class of animals having jointed feet (*Arthropoda*). Their bodies consist of three main sections—(1) *head*, containing organs of sense; (2) *thorax*, to which the organs of locomotion are attached; and (3) *abdomen*, containing organs of reproduction. They have six legs (three pairs), and generally also two pairs or one pair of wings; and they pass through various stages of development (*Metamorphoses*). Most insects pass through four such stages, each distinctly distinguishable from the preceding and the succeeding stages, namely—(1) *Ovum* or egg, (2) *Larva* or grub, (3) *Pupa* or chrysalis, and (4) *Imago* or mature insect. When all these separate stages are well defined, an insect is said to have a *complete metamorphosis;* but in the insects forming the orders *Hemiptera* and *Orthoptera* there is merely an *incomplete metamorphosis* with no distinct pupal stage, because the larva gradually becomes transformed into the imago, the pseudo-pupa being then known as a *nymph.* The transformation of a *nymph* pupa into the perfect insect takes place by the already formed wings being liberated at the last moult or change of skin. The former class (comprising about 95 per cent of all insects) is called *metabolic* (*insecta metabola*) and the latter (containing only about 5 per cent) *ametabolic* (*insecta ametabola*). The *Ova* or eggs vary greatly in size, shape, and colour. Ovideposition sometimes takes place singly, and at others in clusters on differents parts of trees; sometimes the eggs lie naked and unprotected, and at others they are protected within the bark or else by some sort of special covering. The *Larva* usually hatches out in the course of a few weeks; but in many cases it hibernates within the shell, and only emerges in the following spring. Special names are given to different kinds of larvæ. Those of most beetles are called *grubs—e.g.*, as in the case of cockchafers (*Melolontha*); the sixteen-footed larvæ of butterflies and moths (those of spanners have only ten, and a few mining-moths have none) are called *caterpillars;* the eighteen- to twenty-two-footed larvæ of sawflies with their tail-like extremities are named *tailed caterpillars;* while the larvæ of flies (*Diptera*), which have neither feet nor any complex structure of the head, are called *maggots.* The larvæ of many beetles have three pairs of legs on the first three (thoracic) segments after the head; the caterpillars of moths and butterflies have these also, and in addition from two to five pairs of *prolegs* or clasping feet attached to the abdominal segments, the last pair of which (*claspers* or *anal prolegs*) are on the terminal segment. As it gradually grows in size, the larva moults its skin several times before pupation. The pupa sometimes lies unprotected on the ground under moss and dead foliage, or in fissures or under bark-scales, and at other times it is enclosed within a woven *cocoon* (often of large size in some of the *Bombycidæ*), while with flies (*Diptera*) the last larval skin forms a protective covering. The longest stage of development is that in which the insect hibernates; and this is very often the larval stage, although many of the *Coleoptera* hibernate as beetles. The egg and pupal stages usually last only from two to four weeks, except with insects which hibernate thus.

As soon as the mature insects appear, they usually pair at once and reproduce themselves. The male generally dies soon after pairing,—except in the case of beetles, which often hibernate, and of bees, which live for four or five years.

The *Generation* of any insect, or the complete cycle from egg to egg, varies greatly. It is *multiple* in plant-lice and ichneumons, which produce several generations within the year; *double* in some bark-beetles and sawflies, which produce two generations in each year; *single, simple, or annual* in the case of most butterflies and moths, which yearly produce one generation; *biennial or two-yearly* in wood-wasps, the Pine resin-gall tortrix, and many longicorn beetles; and *plurennial* in the cockchafer, which takes at least three and usually four years to complete its generation. Occasionally two generations take place in three years (as in *Bostrichus bidens*), but this is exceptional.

Metabolic insects feed merely as larvæ and mature insects, and in some exceptional cases (*e.g.*, the Pine-weevil) only do damage as imagines; but with ametabolic insects the nymph also feeds. In both groups the larvæ are often very destructive, and many of them daily devour many times their own weight of foliage.

Insects injurious to Woodlands.—Insects might be classed with reference to the trees on which they mainly feed (Pine insects, &c.), but this would be misleading, because many are not merely *monophagous* but also *polyphagous*, and even *pantophagous*, devouring everything when occurring in vast swarms. Or they might be classed with reference to the kind of damage they do, which may be either *physiological* (interfering with the imbibition, transpiration, or assimilation of food and nourishment, as in bark-beetles and moths) or *technical* (interfering with the value of timber for technical purposes, as in wood-wasps, longicorns, &c.); but this would also be inconvenient, as a great deal depends on species and age of tree, time of attacks, surrounding local circumstances, &c. Or again, they might be classified with reference to the extent of the damage usually done; but this would be very unsafe, because some of the most destructive kinds do little damage if kept in check, yet become exceedingly destructive if circumstances favour their development in enormous numbers, when they may devastate extensive woods.[1]

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[1] A rough classification into (1) **slightly,** (2) **noticeably,** and (3) **very injurious** is too vague and indefinite. Experience has shown that the large and the small Pine-weevils, the cockchafer, the Larch mining-moth, and the Pine sawfly are, or may at any time become, **very injurious**, although under ordinary circumstances they can be kept in check and prevented from doing much damage. The extent of injury that may be done depends entirely on circumstances. Whenever injurious insects become apparent, the forester's motto should be *Principiis obsta*—"take time by the forelock"—and try to exter-

Any attempt to group them with reference to the age of the crops generally attacked (seedling-growth, thickets, pole-woods, and highwoods) is also unsatisfactory, as many insects are dangerous at all stages of tree-growth. But it may be remarked that most weevils, some leaf-rollers, and the cockchafer grubs usually attack seedling growth and young thickets, and that pole-woods and older crops are most exposed to attacks from moths, and then of bark- and cambial-beetles, when physiological disturbances arise and the trees grow sickly. The caterpillars of the Pine owlet-moth and the Pine span-worm always attack pole-woods before migrating to older crops on their numbers increasing largely. In Germany a biological method of classification is often preferred, the noxious insects being classified with reference to the part of the tree usually injured. Such classification distinguishes—

1. **Root-destroyers**, such as the mole-cricket and the cockchafer grub.

2. **Wood-borers**, comprising the larvæ of wood-wasps, cervicorn beetles, certain bark-beetles, and the caterpillars of goat-moths.

3. **Bark-beetles**, including most of the *Scolytidæ* and several weevils, which often, both as beetle and larva, either destroy the cambium and the sapwood (*e.g.*, most *Bostrichini* and several *Curculionidæ*), or else hollow out the pith in young shoots (*e.g.*, some *Hylesinini* and *Tortricidæ*).

4. **Bud- and Leaf-destroyers**, including several weevils, the caterpillars of most moths and sawflies, also leaf-beetles and cockchafers.

5. **Producers of Deformities and Malformations** on foliage, shoots, and fruits by gall-wasps, gall-midges, plant-lice, which are sometimes of much consequence (*e.g.*, as in the case of the Larch-*aphis*).

For the forester, perhaps the simplest and most practical classification of insects is the old-fashioned one according to the natural orders formulated by Burmeister, and based on the morphology of the mature insect:—

I. *Insects with complete metamorphosis* (showing distinctly the four different stages of *Ovum*, *Larva*, *Pupa*, and *Imago*).
   1. *Imago* with biting mouth-parts.
      (1) *Imago* with two wing pairs, of which the fore-pair are merely horny shields or wing-cases (*elytra*), and only the membranous hind-pair are used in flying . . . . **Coleoptera.**
      (2) *Imago* with two pairs of membranous wings with many veins or nerves . . . . **Neuroptera.**
   2. *Imago* with biting mouth-parts, or partly biting and partly sucking mouth-parts, and two pairs of membranous wings with comparatively few veins or nerves . . . . **Hymenoptera.**
   3. *Imago* with sucking mouth-parts.
      (1) *Imago* with two pairs of membranous wings wholly or partially covered with scales . . . . **Lepidoptera.**
      (2) *Imago* with the pair of fore-wings membranous and well-developed, but the hind pair only rudimentary and aborted into small stalked knobs (poisers) . . . . **Diptera.**

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minate the pest before it develops into a scourge, and especially in coniferous forests. *Monophagous* species on multiplying rapidly become *polyphagous* and finally *pantophagous*, devouring the foliage of all kinds of trees.

It would be hard to overrate the importance of discovering any abnormal increase in the usual number of injurious insects, and of taking early steps to exterminate them. Pests that might be exterminated during the first spring at a slight cost may entail a much greater outlay in the following and subsequent years, and great loss may at the same time be involved by having to fell and reproduce immature crops badly damaged. In our comparatively small woodlands area, there is no possibility of vast calamities such as have sometimes necessitated the clearance and replantation of millions of trees in Central Europe. But such devastations teach lessons worth learning, namely—(1) that mixed woods are least attacked by insects, and (2) that the best way of preventing attacks is to keep the woods clean, well-thinned, and well-looked-after at all stages of their growth.

II. *Insects with incomplete metamorphosis* (in which there are no distinct larval and pupal stages).

1. With biting mouth-parts . . . . **Orthoptera.**
2. *Imago* with sucking mouth-parts . . . . . . **Hemiptera.**

But as regards their relative importance, it is perhaps best to consider them in the following order: (1) *Coleoptera*, (2) *Lepidoptera*, (3) *Hymenoptera*, and (4) *Diptera*, then (5) *Hemiptera* and (6) *Orthoptera*. The order *Neuroptera* contains no insects injurious to woodlands.

The following table shows the chief insects that have as yet proved more or less injurious to woodlands and nurseries in Britain, those which are sometimes very destructive being marked with an asterisk, thus *:—

Order of Insects.	Family.	Genus and Species.	Destructive as	Chiefly attacks		Details on page
				Tree.	Portions.	
I. **Beetles** (*Coleoptera*)	A. **Masked Weevils** or **Small Bark-Beetles** (*Scolytidæ*)	*Scolytini*—				
		1. **Scolytus destructor*	Larva	Elm	Stem	74
		2. *Scolytus multistriatus*	Larva	Elm	Stem	76
		Hylesinini—				
		1. **Hylesinus fraxini*	Larva	Ash	Stem	76
		2. **Hylurgus piniperda*	Beetle; larva	Scots Pine	Shoots; stem	79
		3. **Hylastes palliatus*	Beetle; larva	Scots Pine	Stem	82
		4. **Hylurgus minor*	Beetle; larva	Scots Pine	Shoots; stem	83
		5. *Hylastes ater*	Beetle	Pines	Stem and roots	83
		Bostrichini—				
		1. *Bostrichus chalcographus*	Larva	Spruce	Stem and main branches	84
		2. *Bostrichus stenographus*	Larva	Scots Pine	Felled timber	85
		3. **Bostrichus bidens*	Larva	Scots Pine	Crown and branches	85
		4. *Bostrichus laricis*	Larva	Pines	Poles; tree-crowns; stacked fuel	86
		5. **Bostrichus acuminatus*	Larva	Scots Pine	Tree-crowns	87
		6. *Bostrichus lineatus*	Larva	Scots Pine, Spruce, Larch	Felled timber	87
		7. *Bostrichus dispar*	Larva	Oak, Beech	Stems	88
	B. **Proboscid Weevils** or **Long-Snouted Beetles** (*Curculionidæ*)	1. **Hylobius abietis*	Beetle	Scots Pine, Spruce, Larch	Bark of young plants	89
		2. **Pissodes notatus*	Beetle; larva	Pines	Sapwood; bark	92
		3. **Orchestes fagi*	Larva	Beech	Foliage	94
		4. *Orchestes querci*	Larva	Oak	Foliage	95
		5. *Cryptorhynchus lapathi*	Larva; beetle	Willow, Alder	Stem; shoots	95
		6. *Strophosomus coryli*	Larva; beetle	Hazel, Oak, Beech, Birch; Pine	Shoots; seedlings	95

Order of Insects.	Family.	Genus and Species.	Destructive as	Chiefly attacks: Tree.	Chiefly attacks: Portions.	Details on page
I. **Beetles** (*Coleoptera*) —continued	C. **Lamellicorn Beetles** (*Scarabæidæ*)	1. **Melolontha vulgaris*	Larva; beetle	Conifers; broad-leaved trees	Roots of young plants; foliage	96
		2. *Melolontha hippocastani*	Larva; beetle	Horse-Chestnut	Roots of young plants; foliage	99
		3. **Rhizotrogus solstitialis*	Larva; beetle	Conifers; broad-leaved trees	Roots of young plants; foliage	98
		4. **Phyllopertha horticola*	Larva; beetle	Conifers; broad-leaved trees	Roots of young plants; foliage	98
	D. **Longicorn Beetles** (*Cerambycidæ*)	1. *Cerambyx carcharias*	Larva	Poplars, Willows	Stem	99
		2. *Saperda populnea*	Larva	Poplars	Branches	100
	E. **Saw-horn Beetles** (*Buprestidæ*)	1. *Agrilus viridis*	Larva	Beech, Oak	Stem	101
	F. **Leaf-Beetles** (*Chrysomelidæ*)	1. *Lina populi*	Beetle; larva	Poplars, Willows	Foliage	101
		2. *Lina tremulæ*	Beetle; larva	Poplars, Willows	Foliage	102
		3. *Phratora vitellinæ*	Larva	Osiers	Foliage	102
	G. **Click-Beetles** (*Elateridæ*)	1. **Agriotes lineatus*	Larva; beetle	Omnivorous	Rootlets; seeds	103
II. **Moths** (*Lepidoptera*)	A. **Spinners** (*Bombycidæ*)	1. *Dasychira pudibunda*	Caterpillar	Beech	Foliage	105
		2. *Porthesia chrysorrhœa*	Caterpillar	Oak	Foliage	106
		3. *Gastropacha neustria*	Caterpillar	Oak	Foliage	106
		4. *Liparis monacha*	Caterpillar	Spruce, Pine	Foliage	107
		5. *Orgyia antiqua*	Caterpillar	Fruit-trees; Willow, Rowan, Spruce, Pine	Foliage	108
		6. *Liparis salicis*	Caterpillar	Poplars, Willows	Foliage	108
		7. *Porthesia auriflua*	Caterpillar	Fruit-trees; various woodland trees and shrubs	Foliage	109
	B. **Owlet-Moths** (*Noctuidæ*)	1. **Noctua piniperda*	Caterpillar	Pines	Foliage	109
	C. **Loopers** (*Geometridæ*)	1. *Cheimatobia brumata*	Caterpillar	Fruit-trees; Oak, Elm	Foliage	110
		2. *Fidonia piniaria*	Caterpillar	Scots Pine	Foliage	111
	D. **Leaf-rollers** (*Tortricidæ*)	1. **Tortrix viridana*	Caterpillar	Oak	Foliage	114
		2. **Tortrix buoliana*	Caterpillar	Scots Pine	Foliage	115
		3. *Tortrix turionana*	Caterpillar	Scots Pine	Foliage	116
		4. *Tortrix resinella*	Caterpillar	Scots Pine	Foliage	116
	E. **Leaf-miners** (*Tineidæ*)	1. **Coleophora laricella*	Caterpillar	Larch	Foliage	117

Order of Insects.	Family.	Genus and Species.	Destructive as	Chiefly attacks		Details on page
				Tree.	Portions.	
II. Moths (*Lepidoptera*) —continued	F. **Wood-borers** (*Cossidæ*)	1. **Cossus ligniperda*	Caterpillar	Softwoods; also most woodland and orchard trees	Stem	118
		2. **Zeuzera æsculi*	Caterpillar	Maple, Ash, Lime, and fruit-trees	Stem	120
	G. **Clearwing-Moths** (*Sesiidæ*)	1. *Sesia apiformis*	Caterpillar	Poplars	Stem	121
III. **Membrane-Winged Insects** (*Hymenoptera*)	A. **Sawflies** (*Tenthredinidæ*)	1. **Lophyrus pini*	Caterpillar	Scots and Austrian Pine	Foliage	122
		2. *Lophyrus rufus*	Caterpillar	Scots and Austrian Pine	Foliage	124
	B. **Wood-wasps** (*Siricidæ*)	1. *Sirex gigas*	Caterpillar	Spruce, Silver Fir, Larch	Stem	125
		2. *Sirex juvencus*	Caterpillar	Scots Pine; Larch	Stem	125
		3. *Sirex dromedarius*	Caterpillar	Willows	Stem	125
	C. **Gall-wasps** (*Cynipidæ*)	1. *Cynips querci* (and other species)	Caterpillar	Oak	Foliage	126
IV. **Flies and Gnats** (*Diptera*)	A. **Gall-gnats** (*Cecidomiidæ*)	1. *Cecidomyia salicis*	Caterpillar	Osiers	Shoots	127
		2. *Cecidomyia saliciperda*	Caterpillar	Osiers	Shoots	128
		3. *Cecidomyia heterobia*	Caterpillar	Osiers	Shoots	128
		4. *Hormomyia fagi*	Caterpillar	Beech	Foliage	128
V. **Half-Winged Insects** (*Hemiptera*)	A. **Plant-lice** (*Aphidæ*)	1. *Chermes abietis*	During all stages	Spruce	Twigs	130
		2. **Chermes laricis*	During all stages	Larch	Foliage	131
		3. *Chermes coccineus*	During all stages	Spruce	Twigs	132
		4. *Tetraneura ulmi*	During all stages	Elm	Foliage	132
		5. *Schizoneura lanuginosa*	During all stages	Elm	Shoots, leaves	132
		6. *Chermes fraxini*	During all stages	Ash	Bark	132
	B. **Scale Insects** (*Coccidæ*)	1. *Cryptococcus fagi* (formerly erroneously called *Chermes fagi*)	During all stages	Beech	Bark	132
		2. *Apterococcus fraxini*	During all stages	Ash	Bark	132
		3. *Coccus salicis*	During all stages	Ash, Willow	Bark	132
VI. **Straight-Winged Insects** (*Orthoptera*)	A. **Crickets** (*Gryllidæ*)	1. *Gryllotalpa vulgaris*	During all stages	Nursery seed-beds	Roots	133

So far as insects injurious to woodlands and nurseries are concerned, by far the most important of these orders are the beetles (*Coleoptera*) and the moths (*Lepidoptera*). In beetles the structure and the different segments of the mature insect are already externally distinguishable in the pupa, but in moths they are still masked or indistinct.

Extent of Damage.—Conifers are usually much more often attacked by insects than broad-leaved trees; and the attacks are generally far more destructive, owing to the want of recuperative power in consequence of the very much smaller reserves of starchy and nitrogenous substances as compared with deciduous trees. Pine and Spruce suffer far more than any other trees. Oak, Beech, Poplar, and Willow are subject to the attacks of more insects than Ash, Elm, Maple, Sycamore, Birch, or Alder. When Oaks have been almost entirely defoliated in spring by caterpillars of the leaf-roller moth, they can utilise their nutrient reserves and flush into leaf again in July; but when caterpillars have devoured about four-fifths of the foliage of Scots Pine and Spruce, the recovery of the Pine is very doubtful, and the Spruce is almost certain to die. In Britain, the Larch often suffers severely from mining-moths and leaf-lice.

Damage to seedlings and young crops is always more serious to the individual plants than when older poles and trees are attacked. And attacks made in spring are more harmful than those in summer, near the termination of active vegetation, when buds have been formed and nutrient reserves stored up for next year's growth. And if foliage alone be attacked, the loss may perhaps amount only to temporary cessation of increment; but when the roots and the cambium are badly injured, the sapling, pole, or tree usually wilts and soon dies.

The Prolificness of Injurious Insects varies greatly. Those which are most prolific are fortunately not the most injurious kinds. Hard winters are not fatal to most insects, and may even favour the increase of beetles (protected by their horny outer casing) by causing the death of many insectivorous birds. Naked larvæ, without hairy or protective covering, are sensitive to damp cold weather, and are killed off in large numbers when moulting their skins. Warm and dry weather, stumps remaining in the ground after heavy falls of timber, sickly crops of all ages, and badly-nourished, dominated, unhealthy trees with a weakly flow of sap, all form favourable breeding-places for injurious insects, which often increase with alarming rapidity in such material. Bark- and cambial-beetles lay their eggs in stems that have been thrown or broken by wind, or in winter-felled trees left lying till late spring or summer, or in those already rendered more or less sickly by attacks of other insects on the foliage. The large Pine-weevil seeks the stumps of recently felled trees as breeding-places, and feeds on neighbouring young plantations. Moths, in laying their eggs, usually prefer to attack backward crops growing on inferior soil, and therefore all the less able to recover from the injuries of the caterpillars. Such favourable breeding- and feeding-places form centres from which millions of noxious insects may easily spread to other woodlands. Hence the necessity for careful tending in all woods: neglect of any one part of a wooded estate is a danger to all of the timber crops.

Natural Checks to Increase.—Wet, cold, raw weather while caterpillars are moulting their skins, and when beetles and moths are pairing, help to keep down the number of injurious insects. But before any of these can appear in unusual numbers, the balance of nature must somehow or another have been disturbed; and when left to nature the balance is usually restored in the course of about 3 to 4 years, after which bacterial and fungous diseases generally break out epidemically and then almost exterminate the insect. But to await this natural readjustment would usually mean entire loss of the timber crops.[1] In mixed woods there are more insectivorous birds than in pure woods (of coniferous species especially), hence the tendency to excessive increase of noxious insects is checked by these their natural enemies. So far as other considerations permit (*e.g.*, game preservation), all the natural enemies of injurious insects should be preserved. The chief of these are:—

A. **Mammals.**—Bats, which devour cockchafers and moths; moles, that destroy grubs and mole-crickets; shrew, hedgehog, weasel, pole-cat, stoat, badger, and fox, which devour large numbers of beetles and pupæ.

B. **Birds.**—The most generally useful are (see chap. iii.) the cuckoo (the only bird that devours hairy caterpillars), the starling, flycatchers, titmice, tree-creepers, swallows, owls, and most song-birds; then thrushes, blackbirds, rooks, gulls, plovers, the kestrel or wind-hover, buzzards, woodpeckers, sparrows and finches, crows, ravens, jackdaws and larks, which are only of minor utility.

C. **Insects.**—Predaceous and parasitic insects on the whole do far more than either mammals or birds to keep injurious kinds in check. The *predaceous species* prey, often both as larva and imago, on the ova, larvæ, pupæ, and imagines of noxious insects; while the *parasitic species* generally lay their eggs on the ova and larvæ (less frequently on the pupæ or imagines) of the injurious kinds, on which the maggots feed when they hatch out. These useful insects of different kinds generally exist in woodlands in much larger numbers than might be expected; and when the noxious kinds increase abnormally so also do these, their natural enemies, increase in equal or greater ratio, because they have then more food and more frequent opportunities of reproduction. The useful insects belong chiefly to the orders *Coleoptera* and *Hymenoptera;* then to the *Diptera*, *Neuroptera*, *Hemiptera*, and *Orthoptera;* while the *Lepidoptera* contains no useful genus, just as the *Neuroptera* contains no injurious genus, so far as concerns the forester.

1. **The Predaceous Species** include, among the **Coleoptera**, the tiger- or sand-beetles (*Cicindelidæ*); the predaceous ground-beetles (*Carabidæ*); the dung-beetles (*Staphylinidæ*); the carrion-beetles (*Silphidæ*); the nitid or shining-beetles (*Nitidulidæ*); the thread-beetles (*Colydiidæ*); the soft-beetles (*Malacodermata*, including the gold-beetles, *Cleridæ*); and the lady-birds (*Coccinellidæ*).

Note.—*Clerus formicarius* and *Rhizophagus depressus* are two of the most useful beetles in British conifer woods, because they prey on the Pine-beetle (*Hylesinus piniperda*).

Clerus formicarius is easily recognisable by its large black head, and black antennæ with red-brown tips, and its red-and-black thorax. Its abdomen is red at base and black behind, with two well-marked transverse white bands across the wing-cases. The dark-headed larva is rose-red, and consists of twelve segments, the first three of which have legs. The first segment has a horny plate above, and the second and third have each two small horny spots; the last joint is covered with a horny shield, and ends in two small knobs.

Both beetle and larva feed on larvæ, pupæ, and imagines of destructive tree-beetles; and the larvæ bore into the bark to hunt for prey. The beetle always seizes its prey behind the head. It is also the most useful of insects in keeping down bark-beetles (*Scolytidæ*).

Rhizophagus depressus is only about $\frac{1}{8}$ of an inch long, bright rusty-red, with finely-punctured lines on the wing-cases. The larva is about $\frac{1}{4}$ of an inch

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[1] Continental experience has shown that during bad attacks of moth-caterpillars there is first a year of minor damage, then three years of excessive destruction, and a succeeding year of minor damage, but that about the fourth year parasitic insects (*Ichneumonidæ*), fungous diseases, and insectivorous birds increase enormously, and soon decimate and finally exterminate the moths.

These useful *Coleoptera* may perhaps be recognised by the following brief descriptions :—

Family.	Beetles.	Larvæ.	Life-history.	Chief Genera and Species.
1. **Tiger-beetles** (*Cicindelidæ*).	Small, slender; abdomen 6 segments, first 3 fused; jaws powerful, with 3 teeth; legs long, slender, with 5 tarsal joints; antennæ filiform, 11-jointed.	With 6 feet and a broad head; long, flat, and humped at middle.	The beetles are active (both run and fly), and prefer warm sandy places. The larvæ dig holes in the ground and lie in wait at the entrance to seize passing insects and worms. Both beetles and larvæ are predatory.	*Cicindela campestris* is common in woods on sandy soil.
2. **Ground-beetles** (*Carabidæ*).	Varying in size, often large; abdomen 6 to 8 segments, first 3 fused; jaws 1-toothed or smooth; legs long and thin, with 5 tarsal joints; antennæ filiform, 11 jointed.	With 6 feet, long, cylindrical.	Most of the larger beetles only run, and cannot fly. They hibernate under moss, foliage, bark, stones, &c., pair in spring, and ovideposit in ground. Larvæ live in and on ground, and pupate below the surface. Both beetles and larvæ are predatory.	*Carabus* (of which 3 species are common, *C. granulatus, C. catenulatus, and C. cancellatus*) and the tree-climbing *Calosoma sycophanta* and *C. inquisitor* devour moth-caterpillars.
3. **Dung-beetles** (*Staphylinidæ*).	Usually small and elongated, with very short wing-cases; abdomen with 6 or 7 segments; legs with 3 to 5 tarsal joints; antennæ filiform, 10- or 11-jointed.	With 6 feet; long.	Beetles very active, usually found in dung, carrion, humus, &c. They hibernate, and pair in spring. The larvæ feed throughout summer, and mostly pupate in autumn. Both beetles and larvæ are predatory.	*Staphylinus olens* and *S. cæsareus, Creophilus maxillosus.*
4. **Carrion-beetles** (*Silphidæ*).	Usually almost black, and ribbed or wrinkled; oval or oblong, and flattened; abdomen with 6 segments; legs with 5-jointed tarsi; antennæ mostly 11-jointed and clubbed.	With 6 feet; long.	Both beetles and larvæ are predatory, and also feed on carrion and humus.	*Silpha*, of which the species *S. quadripunctata* (with yellow wing-cases and 2 black spots on each) feeds on caterpillars on Oaks.
5. **Shining-beetles** (*Nitidulidæ*).	Small, and oval or oblong; abdomen with 5 or 6 segments; legs usually with 5 short tarsi; antennæ 11-jointed, straight, and clubbed.	With 6 feet, long, and sometimes flattened; head horny and projecting.	Both beetles and larvæ are predatory, living under the bark of trees and preying on bark-beetles.	*Rhizophagus* and *Pityophagus*. The former is useful in attacking the Pine-beetle (see Note on opposite page).
6. **Thread-beetles** *Colydiidæ*).	Small, thin, and elongated; abdomen with 5 or 6 segments, the first 3 or 4 fused; legs with 4 tarsal joints; antennæ 8 to 11 joints, clubbed.	With 6 feet, long, sometimes having horny plates below.	The beetles and larvæ live in the bark of trees or in rotting wood, and feed on the larvæ of bark-beetles.	*Colydium*, of which the species *C. elongatum* frequents old Oaks.
7. **Soft-beetles** (*Malacodermata*), including the **Gold-beetles** (*Cleridæ*).	Generally long, with soft wing-cases; abdomen 6 to 7 segments; tarsi 4 or 5 joints; antennæ 10 to 12 joints, slender; females sometimes like larvæ.	With 6 feet, long, flat, and usually hairy.	The beetles pair in spring and lay eggs in the bark of trees, where the larvæ live preying on bark-beetles. The new brood of beetles appears in the autumn, and hibernates below the bark. Both beetles and larvæ are predatory.	*Telephorus* (black, brown, or yellow beetles, about ½ an in. long) and *Clerus* (small, cylindrical, hairy beetles), of each of which there are several species. The chief is *C. formicarius*, which is of great use in keeping down the Pine-beetle, the Elm- and Ash-bark beetles, &c. (see Note on opposite page).
8. **Lady-birds** *Coccinellidæ*).	Small, smooth, semi-globular, with red or yellow wing-cases dotted with black; abdomen with 5 segments; tarsi 3 joints; antennæ 10 or 11 joints, very short and clubbed.	With 6 feet, long, and pointed behind; covered with warty knobs or prickles, or pitted.	The beetles hibernate under bark, leaves, &c., and pair in spring, laying their yellow eggs in clusters on plants. The larvæ feed till July or August, then pupate, hanging from leaves for about 14 days. Both beetles and larvæ prey largely on plant-lice and mites.	*Coccinella septempunctata* and *C. bipunctata*, the 7- and 2-spotted lady-birds, are the commonest species (larvæ bluish-grey, with 4 to 6 yellow spots). The genus *Halyzia* has some species only found in woods, and chiefly in coniferous woods.

long; the head and prothorax are reddish, and all the other segments whitish above and reddish below. The last segment of the body is red-brown, with two knobs above and a small motor-appendage below.

Both beetle and larva live below the bark in Pine and Spruce, crawling along the tunnels bored by the injurious insects, and feeding on their larvæ and pupæ. It also preys on the larvæ of longicorn beetles.

Among the **Hymenoptera**, the digging or fossorial wasps (*Sphegidæ*) are both predatory and parasitic. They kill or deaden caterpillars, beetles, plant-lice, &c., with their stings, drag them to their holes, and lay eggs inside them. Wasps in general (*Vespidæ*), and especially the hornet (*Vespa crabro*, itself injurious to Ash), prey on moths and flies; while ants (*Formicidæ*), which live in colonies of thousands within their breeding-mounds, devour an immense number of all sorts of injurious larvæ.

Among the **Diptera**, the predatory flies (*Asilidæ*) breed principally in sandy localities, and boldly attack and suck the vital fluid of many other kinds of insects; while the leech-shaped larvæ of the humming- or hover-flies (*Syrphidæ*), commoner in orchards than in the woods, kill plant-lice by sucking their juice.

Among the **Neuroptera** the scorpion-fly (*Panorpa*), the camel-necked flies (*Rhaphidia*), the gold-eyed fly (*Hemerobia perla*), and the ant-lion (*Myrmeleon*), are all useful in preying on noxious insects (though the last also devours useful ants); and several among the dragon-flies (*Libellulidæ*) as larvæ, nymphæ, and imagines (and especially as perfect insects) kill many noxious insects, even including moths; while among the **Hemiptera**, scaly and other bugs (*Pentatomidæ* and *Reduviidæ*) prey on plant-lice. But the predatory genera and species contained in these last two orders are nothing like so numerous or useful as those in the first-named three orders.

2. **The Parasitic Species** are certainly the chief enemies of noxious insects. The most important are the ichneumon-wasps (*Ichneumonidæ*) of the **Hymenoptera**, and the parasitic-flies (*Tachininæ*) belonging to the *Muscidæ* family of the **Diptera**.

The **Ichneumonidæ** vary in size, but are usually long and thin. The abdomen is often stalked, and the female has a long ovidepositor, consisting of a thin borer enclosed within two lateral sheaths. The wing-veins are few in number, and only form distinctly-closed cells when there is a submarginal vein. The antennæ are many-jointed, and usually thin, seldom clubbed. Tarsi have usually five joints. *Larvæ* footless, smooth, generally white, soft, and tapering towards both ends. *Pupa* soft and white, with free limbs. *Imagines* usually fly from May till August, and generally lay their eggs in the larger species of larvæ of noxious insects. Ovideposition sometimes also takes place in pupæ, and occasionally in imagines; while minute species even ovideposit within eggs of injurious insects. *Generation* partly single, but often double, and sometimes manifold.

Of about 5000 known species of ichneumon-wasps, nearly 1000 are parasitic on noxious insects. By means of her long ovidepositor the female lays her eggs either singly for big species, or in large numbers for small species. The larvæ on hatching out suck the vital fluids of the hosts on which they are parasitic, and then eat their way out to the surface, where their cocoons often thickly stud the dying caterpillars. As the generation of the *Ichneumonidæ* is sometimes manifold, they multiply enormously when the number of hosts is large. The infested larvæ then become even more voracious than before to provide nourishment for their parasites, but die in the pupal state if they manage to live so long.

The **Tachininæ**, easily distinguishable from other flies by the rough brush-like hairs on their abdomen, are chiefly parasitic as larvæ on the larvæ and pupæ of moths and saw-flies. The principal species is *Tachina* (*Echinomyia*) *fera*, which destroys large numbers of insects. It generally pupates outside the host, in or on the ground, the pupa being round or oval, and brown or black.

Enormous swarms of noxious insects might possibly in course of time be suppressed by *Ichneumonidæ* and *Tachininæ*, but the normal balance of nature existing before any plague of insects breaks out is usually restored naturally by epidemic diseases produced among the larvæ by *Botrytis*, *Micrococcus*, *Isaria*, &c.

Prevention of Insect attacks.—As injurious insects increase most in backward or sickly crops, careful clearing and weeding of young plantations, and thinning and tending of all older woods, are necessary to remove suppressed, diseased, or damaged plants or trees before they become breeding-places for noxious insects. Such measures are all the more necessary in plantations made on land not properly drained, or where the soil and situation are not well suited to the kinds of trees that have been planted. Danger from insects is least in mixed woods of broad-leaved species and conifers (wherever possible, under given conditions of soil and situation); and it is greatest in pure coniferous crops, or those consisting of conifers only. All woods and plantations should be inspected frequently, and thinnings should be made regularly. Dead branches and *débris* of thinnings should be removed, and not left on the ground. Fallen branches and small thinnings are often left to rot on the ground, although such dead and decaying material forms breeding-places for many injurious insects.

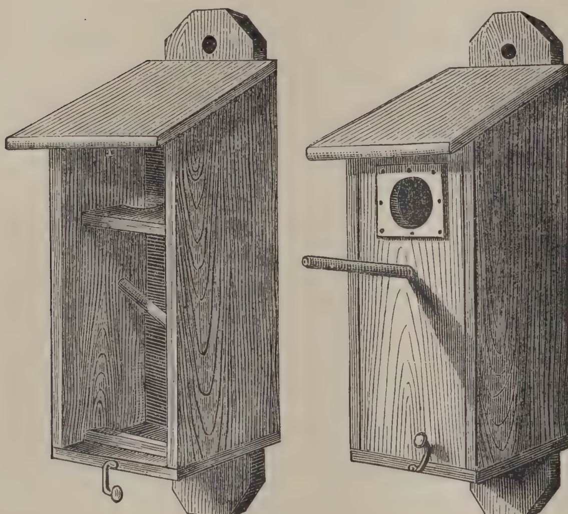
Damage done by frost, snow, ice, wind, or fire should be rectified as far as, and as soon as, may be possible; and damaged timber should be barked or removed from the woods as soon as convenient, to prevent bark- and cambial-beetles breeding in them. It is best to fell conifer crops in summer, and at once bark them (see Fig. 136). Trees should be felled as low as possible, and the bark peeled from the stumps. But when winter fellings have to be made, then some of the logs should be left here and there with the bark on as decoy stems. These should be peeled in the following May, and the bark burned to destroy the broods of bark-beetles they contain.

It is not at all unusual to find that the trees felled during winter are left in the wood or its neighbourhood till far into summer. Each Scots Pine that is so left attracts hundreds of Pine-beetles, besides other noxious insects, and in the month of June and July sends forth thousands upon their work of destruction. Even in woods that are regarded as being well managed this state of things may be seen, and the whole might be almost as easily prevented as permitted. When a timber sale is held in spring, the buyer is often allowed his own time to lift the wood, provided he has paid for it, whereas he ought to be bound to have it removed not later than the 15th of June, or otherwise to cause it to be peeled before that date. The same applies to timber designed for estate work. It is, of course, not enough simply to cart the wood to the sawmill and there allow it to lie. Such a course would do nothing to reduce the number of Pine-beetles. It must either be peeled or cut up, and in the latter case the slabs should be burned or peeled. If it can be managed, it is well to delay stripping the bark till near the middle of June, for there is but little danger of the young beetles escaping before that time, and by so doing time will be allowed for a larger number of beetles to utilise the trees for breeding purposes, and thus they and their larvæ can be destroyed in much greater numbers (Somerville, in *Trans. High. and Agri. Socy., Scot.*, 1891, p. 41).

Wherever a market for firewood makes it possible to grub up coniferous stumps, this should be done immediately after the fall of the timber. No suitable breeding-places are then offered to the dangerous weevils and cambial-beetles. Even palings made of unbarked Larch, Spruce, or Pine poles will show how many beetles find breeding-places in the bark and cambium.

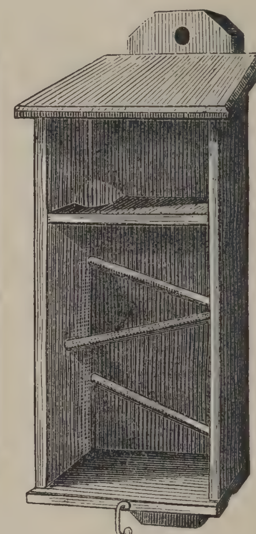
At the same time, measures should be taken to preserve and increase the natural enemies of injurious insects by encouraging the presence of insectivorous birds, and especially in dark, sombre, coniferous woods, where they occur in far fewer numbers than in broad-leaved and mixed woods. And among insectivorous birds none deserves encouragement so much as the starling, for whose protection nesting-boxes (Figs. 132-135) should be hung or nailed up in the woods, to protect their eggs and young against cuckoos, cats, and other enemies. In place of more elaborate boxes, small nesting-cases can easily be made from pole-thinnings of Pine or Spruce cut into 8- or 9-inch lengths, hollowed out, drilled and pegged at

Fig. 132.



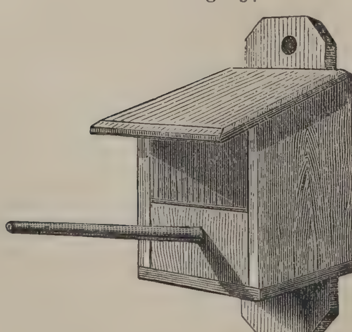
Nesting-Box for Starlings, Wagtails, Woodpeckers, and other birds of that size.

Fig. 133.



Interior view of a Nesting-Box for Tits, and similar small birds.

Fig. 134.



Nesting-Box for Flycatchers.

Fig. 135.

Nesting-Case for Starlings, made of straw coated with tar.

the outer side, and capped and closed above with a bit of wood, when they are ready for nailing on the trees.

Exterminative Measures can only be effective when based on knowledge of the appearance, habits, and life-history of injurious insects, and on constant attention being paid to all recent plantations or felling areas, windfalls, and sickly and backward crops, which may easily develop into breeding-places. Frequent inspection of conifer woods and plantations is particularly advisable.

Noxious insects may be discovered by numerous indications. Bore-holes in trees, bore-dust on cobwebs and on the ground below, or drops of resin on the bark or at the foot of poles or trees, all show that insects are at work in the trees and poles; and gnawed leaves or excrement seen on paths and in cart-ruts, and a gradual thinning of the tree-crowns, show that moth-caterpillars are feeding there. But even before the tree-crowns become noticeably thinner, a palpable increase in the number of insectivorous birds may suggest that moth-caterpillars are present in unusual numbers.

When it is either known or suspected that injurious insects are present and likely to damage the woods, the exterminative methods to be adopted vary according to the habits of the insects in question. To determine the easiest point of attack against it, a knowledge of its life-history is necessary; but as the usual methods adopted against beetles are entirely different from those used against moths, these two orders of insects form two distinct groups as regards methods of extermination.

A. **Extermination of Beetles.**—Many of the bark-beetles and weevils breeding chiefly in conifers can be kept in check by felling and barking the timber and burning the bark containing the eggs, larvæ, pupæ, and often the beetles themselves. The foresters and woodmen should be trained to look out for and detect infested stems, and be taught the advantage of felling a tree here and there as decoy-stems to trap egg-laying beetles and prevent the ovideposition in healthy stems.[1]

Decoy-stems should be felled and placed before the insects pair, because many of them first of all search for sickly and recently felled trees before attacking healthy stems, the strong resinous outflow from which might kill their brood. Stems laid down as decoys in winter or early spring should be barked and removed in May and June, and fresh decoy-stems placed in summer to catch any second brood in August. Poles or trees that are dominated or suppressed, but still healthy, should be used in preference to half-dry stems already moribund, because the latter are not so likely to attract the ovidepositing females. It is best to raise the decoy-stems off the ground on rests, so as to let the beetles breed on the lower side, which remains sappy when the upper half is already becoming dry. The branches should be lopped from the stems to check evaporation through the foliage; but they can also be set as traps for many species of beetles. Timber from any winter fall is always more or less infested with beetles, and should be removed *and barked* not later than the middle of May. Removal alone is not enough, because in the sawyard or elsewhere the broods hatch out and the number of beetles increases greatly.

Decoy-stems should be examined occasionally to see if they are acting well as traps for eggs. Small drops of resin or heaps of bore-dust near the punctures and bore-holes will give the information required; but pieces of bark should also be cut off and inspected to see how far the young brood has developed. When the largest larvæ are about half-grown is the best time for stripping and burning the bark, because ovideposition is then completed, and there is no danger of the beetles laying more eggs elsewhere.

Larvæ can only be collected in the case of cockchafer grubs in nurseries, and the collection of the mature beetles is most practicable with large kinds like cockchafers and longicorns, which can be shaken or tapped down from the crowns of poles or young trees. The large Pine-weevil can be trapped in narrow ditches with vertical walls, and killed by treading on them or pouring boiling water over them. Smaller beetles than these may be trapped in bundles of brushwood or bark, which should then be burned.

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[1] See reference made to exterminating bark-beetles, in footnote to p. 74.

Continental Methods.—In the great forests of Central Europe destruction by insects sometimes assumes proportions impossible in Britain, and even very much more destructive than our Larch disease. The best **preventive measures** have been found to consist in careful thinning of the woods. Whenever dominated or suppressed stems fall into a sickly state, they become predisposed to attacks of injurious insects and fungous diseases; hence they soon develop into breeding-centres. The preventive measures that can be taken by the forester are :—

1. Only to grow crops of trees suitable for the given soil and situation.
2. Formation of mixed woods in preference to pure forests.
3. Careful thinning and tending of the woods, and immediate removal of sickly stems.
4. Frequent examination of the woods and of the condition of the timber crops.
5. Grubbing up stumps of conifers, if possible, before replanting the area.
6. Making falls of coniferous timber only in spring, summer, and autumn, and barking the logs (Fig. 136).[1] Where winter felling is necessary, a few trees should be ringed and left standing here and there as decoy-stems to attract bark-beetles. These should then be felled and barked, and the bark burned to prevent the ova and larvæ developing into mature insects and multiplying.
7. Speedy removal of all thinnings and falls of timber, and clearance of the branches and brushwood.

B. **Extermination of Moths.**—When attacks of caterpillars occur on any large scale, no such remedies as *decoy-trees* can be applied ; nor can spraying with lime-water, solutions of sulphur, tobacco-juice, quassia, paraffin, carbolic acid, Paris green, London purple, &c., take place in extensive woodlands, although suitable and practical in nurseries and orchards. Although something can always be done to destroy the ova, pupæ, and imagines of moths, yet it is mainly during the caterpillar stage that efforts to exterminate them are successful.

Sometimes hairy caterpillars may be hand-picked by workmen wearing old gloves to protect their hands. Hand-picking can also be adopted for caterpillars which hibernate on the ground under moss, &c., or which can be brought down by shaking the poles or tapping on tree-branches with padded mallets or flat axe-heads, or which are found in trenches dug for this purpose. By shaking and tapping the Pine Span-worm caterpillars may be brought down to the ground and collected ; and this method is most effective early in the morning and during cool weather, when the caterpillars have a much looser foothold on the foliage than during warm sunshine. The clusters of caterpillars of the Lackey-moth can also easily be crushed or burned.

When severe attacks are confined to small areas, the migration of caterpillars to adjoining woods may be prevented by digging narrow trenches (about 1 foot deep, and with perpendicular walls) round the infested portions, and ensuring that the leaf-canopy overhead is also interrupted. In these trenches holes, also with clean-cut upright sides, should be made here and there along the sole to catch the caterpillars and lessen their chance of escape. To assist the work of extermination it is also well to cut similar ditches within the area isolated.

One of the lessons taught by the ravages of the Spruce-moth (*Liparis monacha*, rare in Britain, see p. 107) in Bavaria and Western Austria about twelve to fourteen years ago (which cost £100,000 in exterminative measures alone, and involved the clearance of many millions of trees killed by the moths, and by beetles following after them) is the efficacy of *grease-banding*, by forming rings or girdles of patent glue or viscous tar around all stems in infested areas. These bands hinder caterpillars from ascending the trees to feed on the foliage ; or, if the caterpillars are once up, the bands prevent them descending to moult or pupate. Caterpillars which hibernate under moss, &c., on the ground are thus

[1] Spruce-bark is there saleable with profit as tanning material.

Fig. 136.

Clear-felling of a Spruce-wood, mixed with Scots Pine and Beech (*Tharandt, Saxony*, 1900).

The conifers are at once barked for protection against beetles, the bark being collected and stacked, and the brushwood piled in heaps ready for sale. Narrow rings of bark are left at the ends and in the middle of each log, to minimise the number and size of the cracks formed by shrinkage during the natural process of seasoning.

Fig. 137.

A sample-plot ringed with bands of patent tar to ascertain if the Nun-moth (Liparis monacha) *is present in the woods* (*near Dresden, Saxony*, 1900).

prevented from ascending the stems in spring. And the same happens to those which spin themselves down to the ground on gossamer threads, as many do at least once when moulting, and before they lose the power of spinning such filaments, or get too heavy to descend by them; and both of these transformations usually occur gradually and simultaneously about the time of the third moult or change of skin (Fig. 137).

Patent tar for "grease-banding" is only effective while it remains soft and sticky. Its efficacy is not, however, dependent on its stickiness, but on the fact that one (at least) of the ingredients has a smell so exceedingly repulsive to caterpillars that they will not cross the ring till it becomes hard and dry. And even if an occasional caterpillar may face and cross it, the feet and mandibles get so clogged with the gluey composition that it is unable to feed, and soon dies of hunger. It is therefore essential that the grease-bands should remain sticky throughout the whole of the caterpillar stage of the life of the moth—*i.e.*, for at least six to eight weeks (although good patent tar remains sticky for about twenty weeks or more) without the surface toughening and drying. Throughout Germany it costs about 7s. 6d. per cwt., which is enough for grease-banding about 2½ acres on the average,—young pole-crops, of course, requiring more per acre than old woods.[1]

Before grease-banding with patent tar the bark of the stem needs to be cleaned of loose bark, so that the grease may be economised and also made to bite well on to the stem. The stems are cleaned with iron scrapers at about breast-height, a girdle of about 4 inches being cleared, and care taken not to damage the soft inner bark by rough treatment. This should be done in winter and early spring throughout areas known to be infested by moth-caterpillars hibernating under the moss or eggs laid on the stems. About the end of March or early in April the rings of patent tar should be applied before mild weather makes the eggs hatch out or the caterpillars resume breeding. The rings can best be formed with small wooden spuds about 1 to 1¼ inches broad, and smoothed off with other spuds of equal breadth hollowed to a depth of about ⅕th of an inch. The crop should first be thinned to remove all superfluous poles or stems likely to favour the breeding of the moths, and to reduce the cost of grease-banding.

Collecting the pupæ by hand is only practicable when pupation takes place on shrubs or in bark fissures near the ground, and cannot be carried out on any large scale. If the pupæ lie on or in the ground, it is better to herd swine in the woods. They devour smooth-skinned pupæ lying under moss (*e.g.*, Pine Beauty and Pine Span-worm), but they will not touch hairy caterpillars.

Eggs can only be collected and destroyed when deposited low down near the foot of the stem, and even then many eggs and clusters of eggs get overlooked. A daub of patent tar is, however, efficacious in killing egg-clusters of species like the Gipsy and the Pale Tussock.

Continental Measures.—How such an exterminative measure is applied on the Continent may be seen from the following description of the means adopted with regard to the Spruce-moth (*Liparis monacha*) in Bavaria in 1890 to 1892 (Figs. 138-142).

Exterminative Remedies.—When once they occur *en masse*, no radical measures can be taken against the moths, owing not only to their restlessness during the day, but also to the fact that they cover the trees up to the top. Wherever early measures, however, can be adopted, the destruction of every female means the premature cutting off of about

[1] This patent tar (*Raupenleim*) is manufactured by L. Polborn, 1 Kohlenufer, Berlin S.; Schindler and Mützel, Stettin; J. M. Witzemann, Stuttgart; and various other firms. Its composition is indicated on pp. 71 and 539.

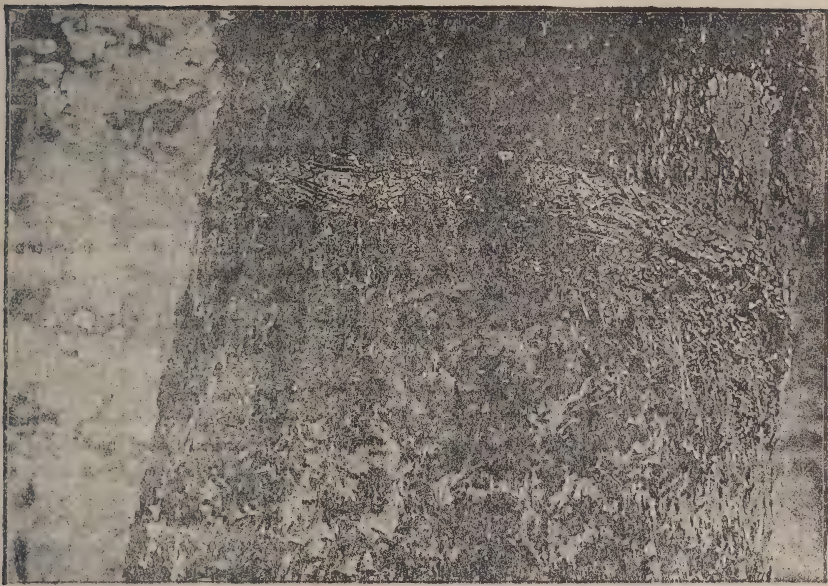
90 in the next, and over 8000 in the succeeding year. It was hoped that by means of electric lights, arranged in the infested localities in front of exhausters, the moths might perhaps be decimated. But though long-continued, the experiments were disappointing; the moths fluttered about in dense swarms within the rays of the light, yet displayed no desire to approach close enough to be brought under the influence of the draught playing into the exhauster.

Fig. 138.

View in the Ebersberger Forest in 1891, *after the clearance of the Spruce-trees that had been killed outright. Only a few Scots Pine remained here and there, as above shown, and these were afterwards mostly blown down by a storm in December* 1891.—(*The late Prof. R. Hartig of Munich is standing beside stem No.* 13).—*This illustration exhibits very well the form assumed by Scots Pine when growing in close canopy along with Spruce.*

The main remedy lies in placing around the stem (either about 15 to 18 ft. above the ground or else at breast-height) a girdle, composed of a viscous gluey or tarry substance, retaining its stickiness and odour until after the caterpillars had done feeding. The great practical utility of this method rests on the characteristic of the young caterpillars spinning themselves down to the ground on gossamer threads during the period before the second change of skin, after which their fully-developed destructive powers come into play. The re-ascent of the stems being prevented by the rings of patent tar, whose odour they loathe, the caterpillars die of hunger. This method was first employed in 1889 in a small 15- to

Fig. 139.



Showing how young Caterpillars, after spinning down to the ground, are hindered by the "grease-band" of patent tar from reascending the stem to feed on the foliage.

Fig. 140.

Caterpillars, after having spun themselves down from the crown, are unable to reascend the stem owing to the grease-band of patent tar.

20-year-old Spruce plantation, which was trimmed of its lower branches and ringed with the patent tar; and as this was found to be successful, similar treatment was also accorded to other localities. In 1890 it found adoption on a much larger scale, and again more extensively in 1891; while in 1892 its application has been extended throughout the whole of the tracts that have been infested on a gigantic scale—the stem of every tree, pole, or thicket-growth of the thickness of a forefinger and upwards being ringed, whilst younger plantations have been isolated. The outlay thus incurred in the State forests of Bavaria alone amounted to £100,000. As practically every caterpillar descends at least once to the ground, and as the majority reach the soil in place of being caught on lower growth, especially in old crops, the results have been that millions of caterpillars perished in 1891 and 1892 under the tar-rings, whilst those that tried to come down the stem before entering the pupal stage also found their way barred, and fell into a sickly state, besides easily falling a prey to the thousands of birds that were naturally attracted to such feeding-grounds, to parasitic insects, and to fungous diseases.

The higher up the stem the girdle is placed the more effectual it is, but also the more expensive. In practice it cannot well be put higher than 15 to 18 ft., somewhat thin patent tar being then used, and the ring being formed by means of a long-handled brush fed from a reservoir above it. The extra expense of high rings is only worth incurring when it is certain that a high percentage of the ova are situated on the lower portion of the stem.

Fig. 141.

Diseased Caterpillars (1891) *swarming on the top shoot of a Spruce-tree.*

Whether rings of patent tar or glue at breast-height will, or will not, be sufficient to save the crop, depends principally on the species of tree, for, with its sparse foliage and less density of crown, Scots Pine is much easier to deal with than Spruce. Timely adoption of this measure can certainly minimise the evil; but when once the caterpillars swarm in enormous numbers, it can only be effective if aided by natural enemies of the insect, and by fungous disease breaking out among the caterpillars owing to the sickly state engendered by hindrance of their usual daily progress up and down the stem towards the end of June or the beginning of July. Thousands of wooden nesting-boxes have now been hung throughout the coniferous forests in Bavaria to protect and increase starlings (Figs. 132-135).

At Ebersberg (1892) the average cost of forming the rings of patent tar has amounted to about 8s. per acre; the cost of the patent tar was 7s. per cwt. at the factory, and 13s. in the forest; while the labour of ringing the stems cost 7s. per cwt. used. About 40 lb. were used per acre on the whole average, so that the mean outlay per acre was 5s. 3d. for patent tar and 2s. 9d. for labour, or 8s. in all.

Before the operation of applying the patent tar is proceeded with, a thinning out should take place in winter, when all suppressed stems and undergrowth should be cleared away. After that the boles must be cleaned wherever the ring is to be put, so that the semi-viscous patent tar may get a firm hold on the bark. For rough-barked trees like Oak and Pine, this cleaning should be about a span broad, but for smoother-barked species like Spruce, Silver Fir, and Beech, it is sufficient merely to free the part from moss and any scaly bark attaching.

The composition of the patent tar or glue is treated as a sort of secret, but it must be an open one, as some fifteen or sixteen firms supply it at about the same price, 7s. to 7s. 6d. per cwt. at the factory. It consists mainly of wood-tar, resin, wood-vinegar, various oily ingredients, and probably black soap; and it must possess the property of not congealing with late frost, of remaining semi-viscous for over three months, and of not running with heat. It should float on water; if it does not, this proves that mineral ashes have been mixed with it, thereby diminishing its efficacy (see also p. 539).

Fig. 142.

Spud and smoothing-stick (about $\frac{1}{5}$th real size).

The ring should be put on thick, but need not be broad, as the caterpillars dislike either the smell or the touch of it so much as to make no attempt to cross over; hence a breadth of $\frac{1}{2}$ to 1 in. and a thickness of $\frac{1}{6}$ to $\frac{1}{5}$ in. is amply sufficient. Owing to its semi-viscosity, the patent tar cannot be put on with brushes, but is affixed by means of special appliances, for it must bite close on to the bark so as not to peel or flake off in places.

Various sorts of apparatus have been invented for putting it on, all of them being more or less like syringes in principle, but the simplest and best method, especially when the ring is formed at breast-height, is to apply the tar with a small narrow wooden spade about $\frac{1}{2}$ to $\frac{3}{4}$ in. broad, and to smooth it off with another slightly broader wooden instrument to the required breadth and thickness (see Fig. 142). The formation of the rings must be undertaken early enough in April to be entirely completed by the time the larvæ issue from the ova.

Observations on living trees and examination of dead stems have shown that no harm is done to the trees by the use of patent tar, and that it does not penetrate into the cambium to interfere with the normal performance of the functions of the latter, although it partially penetrates and softens the bark immediately below the ring. (Nisbet in *Trans. High. and Agri. Socy.*, 1893, pp. 199-205.)

I. Beetles or Chafers (*Coleoptera*).

These are the "sheath-winged" insects, so called from the outer pair of wings (*elytra*) being generally horny or leathery, and serving as a cover to the inner pair or true wings, when these are not in use for flight.

An old-fashioned but simple and practical subdivision of the Coleoptera is the classification of Ollivier and Latereille according to the number of joints found in the tarsi, thus:—

1. *Trimera*, with all the tarsi 3-jointed.
2. *Tetramera*, " " 4- "
3. *Pentamera*, " " 5- "
4. *Heteromera*, with first 4 tarsi 5-jointed and posterior pair 4-jointed.

1. The **Trimera** include few beetles of any importance in British woodlands. To it belong the Lady-birds (*Coccinellidæ*), which feed on plant-lice (*Aphides*), and also the Spanish fly or Blister-beetle (*Lytta vesicatoria*), rare in Britain, but often destructive in Central and Southern Europe.

2. The **Tetramera** is the most important class, including the Weevils or Snouted-beetles (*Rhynchophora*: subdivisible into *Scolytidæ* and *Curculionidæ*, the latter being larger and having a more strikingly elongated proboscis), the Long-horned beetles (*Cerambycidæ*), and the Leaf-beetles (*Chrysomelidæ*).

3. The **Pentamera** include the predaceous Ground-beetles (*Cicindelidæ*, *Carabidæ*, &c.), the Cockchafers (*Melolonthidæ*), the Saw-horn beetles (*Buprestidæ*), and the Click-beetles (*Elateridæ*).

4. The **Heteromera** are unimportant to the forester. They include the Oil-beetles (*Melöeidæ*) the Churchyard-beetles (*Blaps*), and the Meal-worms (*Tenebrio*).

A. **Masked Weevils or Small Bark-Beetles** (*Scolytidæ*).—These include some very injurious insects in our woodlands. They do far more injury to broad-leaved trees than to conifers. Attacks on the former occur far more often in avenues, and on ornamental trees in parks and gardens, than in woodlands. The broad-leaved trees most liable to attack are the Elm, Ash, and Birch, then Oak and Beech; but on broad-leaved trees most bark-beetles are polyphagous, and often attack them more or less indiscriminately. Both in broad-leaved trees and conifers, however, the attacks are usually confined to middle-aged and old trees in a sickly condition.

Seedlings and saplings, as well as poles and young trees badly damaged, soon die off from the injuries received; but in the woods the larvæ may often bore for years before trees show signs of decay. Broad-leaved trees have (owing to their larger nutrient reserves) a far greater recuperative power than conifers in recovering from injuries; and many of the bark-beetles infesting the former class of trees live more in the sapwood than in the cambium, and therefore interfere less with the process of nutrition.

Beetles, small and cylindrical, with round head sunk deep in the convex thorax, and short antennæ; abdomen with five segments (the first and second generally indistinct); legs short, with spinous teeth on outer edge of tibia, and four-jointed tarsi (the third sometimes lobed). *Larvæ* cylindrical, ventrally incurved, and covered with tubercles and strong hairs. *Pupæ* short, thick, and sprinkled with spines and hairs. *Generation* mostly annual, but sometimes extending over one and a half and two years.

The *Scolytidæ* are small insects, more or less cylindrical in shape, and of quiet indefinite colour. Except during the short time the beetles swarm and reproduce themselves, they pass their life inside woody fibrous plants, within which the eggs are laid. They mostly hibernate as beetles, but some reappear early in spring during warm days in March, while others only come out again in April or May.

For breeding-places they first of all select the most suitable species of trees, preferring neither dead nor very dry wood, nor sound healthy trees from which a strong flow of resin would kill the beetles and larvæ of most of the species. Windfalls, damaged and sickly trees, those broken or injured by wind, snow, or ice, falls of timber and their stumps left, and backward crops, are the most favourable breeding-places. The beetles seek out the fissures of thick-barked trees of this sort, and bore quickly into the sapwood. For such species as only pair inside the stem, a fairly large pairing-chamber (*camera copulatrix*) is hollowed out under the bark. From this central point begin the mother-galleries, of equal breadth, characteristic of the *Scolytidæ* (the breadth of course depending on the size of the beetle). Along these the female lays her eggs in small holes notched alternately right and left. Ovideposition in clusters is less frequent.

The *Primary, Main-, or Mother-galleries* are formed partly in the cambium, sometimes being more in the bark and sometimes more in the wood (*bark-galleries*), and partly in the sapwood (*wood-galleries*). The beetles which breed in the bark or in the wood may be distinguished by the direction in which they bore. Thus, *vertical galleries* may be formed, running longitudinally along the stem, or *horizontal galleries*, running round the circumference of the stem, or *star-shaped galleries*, when several radiate from the pairing-chamber as a central point.

Vertical and horizontal galleries are forked, and have either one or two branches, according as they are bored into on one or both sides of the entrance-hole.

The eggs, often numbering up to 100 or 120, are laid within three to four weeks, and in about fourteen days the feetless grubs, curled in at the ends towards the belly, dirty-white in colour and with a brown head, begin to bore the larval or secondary galleries at about right angles from the main gallery. The borings, small at first, gradually enlarge as the grubs grow in size, and finally they end in a *pupal chamber* formed for the chrysalis. As they broaden, these larval galleries diverge from each other, and from their direction at right angles to the main gallery, so that sometimes the longest are finally almost parallel to the latter. Each grub usually bores its own gallery and keeps clear of the neighbouring galleries.

In the few species which lay their eggs in clusters, the larvæ form galleries in common (*family galleries*). The timber-boring beetles do not form true larval galleries; the larvæ live in the main-galleries, and only hollow out short pupal chambers on each side of the main-gallery (*ladder-like galleries*). These main and larval galleries generally assume such characteristic shapes that the species of bark-beetle committing the damage can usually be determined by this alone. This is the more convenient, as it would otherwise not be possible to determine the species by means of the larvæ only.

The period of development from egg to beetle lasts on the average only from eight to ten weeks. It varies, however, not only for different species, but also depends greatly on climate, weather, and temperature of the breeding-place. It is longer in mountainous tracts than on warm plains. In the pupæ all the different segments of the beetle are already distinguishable, the main differences consisting in their lighter colour and softer structure. After about eight days of pupal rest the fully-developed beetle emerges. It usually, especially during cold raw weather, spends a few days feeding on the soft cambium round the pupal chamber, and this obliterates to some extent the characteristic shape of the larval galleries. But in fine weather the beetle bores a small round *exit-hole* in the bark, and at once begins to fly, pair, and reproduce itself. This new brood develops completely in the same season, but does not generally emerge until the following spring, the beetles hibernating under the bark-fissures and cracks, or in roots, tree-stumps, &c. Most bark-beetles, if not all, have such a double generation, but local and climatic conditions always more or less affect the period of development, so that any one given species may sometimes have a double generation under favourable conditions, and only a single or annual generation under less favourable circumstances.

When stems lying on the ground are attacked by bark-beetles, bore-dust can be seen at the entrance-hole; while both the entrance-holes and the air-holes opened here and there along the main-gallery are easily seen unless the bark is very rough and scaly. The presence of beetles in standing timber is shown by the outflow of white drops of resin, while the bore-dust falling down from above gets caught on rough bark-scales and collects near the foot of the tree. When numerous exit-holes are to be seen scattered irregularly over the stem, this shows that the beetles have already emerged, and that it is then too late to try and destroy the larvæ and pupæ.

Prevention.—As bark-beetles usually attack sickly and backward crops, damage is least likely to occur if the woods are well thinned and cleared of unhealthy material, of windfalls, and of broken or damaged trees. Recent falls of timber should be removed as soon as possible; the stumps of such trees should be grubbed up, and their roots and branches made use of; and if that cannot be done, then the felled stems should be barked. These are the only good and practical measures for preventing the attacks of bark-beetles on a large scale. When suitable breeding-places are not available, the beetles also attack sound trees, and are mostly killed by the ensuing outflow of resin; but when thousands of such small-bore wounds have been punctured, the tree sickens and then becomes a favourable breeding-place for the remaining beetles. This is always the case when bark-beetles swarm in very large numbers. All sylvicultural operations tending to obviate injuries of any sort (from wind, ice, snow, game, &c.) are also useful in preventing serious attacks of bark-beetles. The chief protection against these, as against other injurious insects, consists in forming mixed woods in place of pure forests; because in mixed woods the conditions are not only less favourable for the breeding of noxious insects, but insectivorous birds are also usually more numerous than in pure woods.

Annihilation.—Laying down decoy-stems as beetle-traps here and there (see p. 63) and peeling and burning the bark from these after all the eggs of a new brood have been laid, and before any of the beetles have had time to emerge,[1] is the best measure to adopt. It is best to burn the bark; but if this is inconvenient, it should be exposed, soft side upwards, to the sun if the brood has been trapped in the larval stage. But if the bark be piled in large heaps when bark-beetle attacks are on any big scale, burning the bark is necessary to destroy the brood. It is also necessary to follow up these first results with another supply of decoy-stems prepared against the second brood in summer. Fresh decoy-stems should as a measure of safety be laid down every four to five weeks during summer and well on into autumn, wherever bark-beetles are likely to breed in large numbers.

What has above been said applies especially to the bark-boring beetles. The much less numerous wood-boring beetles in conifers and broad-leaved trees (*e.g.*, Oak) are technically injurious insects. The trees they attack, and especially the broad-leaved trees, often long survive the damage done, although it is best to fell and use them as soon as convenient, because they gradually lose in value. In these latter cases decoy-stems are of no use as traps. Winter fellings and thinnings and early removal of felled trees, or barking of those that have to remain longer on the fall, are here the only practicable measures.

The bark-beetles are divisible into three groups of importance to the forester:—

(1) **Sapwood-Beetles** (*Scolytini*), with abdomen obliquely shortened. They mostly attack broad-leaved trees, especially Elm.

(2) **Cambial-Beetles** (*Hylesinini*), with wing-cases extending beyond the abdomen, and not flattened or toothed at lower end. They mostly attack conifers by boring in the bark or slightly into the sapwood, but do not bore deep into the wood of the tree.

(3) **True Bark-Beetles** (*Bostrichini*, syn. *Tomicini*), with wing-cases often contracted or flattened and toothed towards the end. They mostly attack conifers rather than broad-leaved trees, and bore partly under the bark and partly in the wood. They do not breed in tree-stumps and roots like many *Hylesinini*.

(1) **Sapwood-Beetles** (*Scolytini*).—This group consists of only one genus (*Scolytus*), formed by the large and the small Elm-bark beetles, which mainly infest and greatly damage the Elm (and chiefly the English Elm) by the mass of larval-galleries hollowed out in the cambium and slightly entering the sapwood. The vertical main-galleries go deeper into the sapwood. Avenue and park trees are very liable to attacks from this insect, and the Elm-trees in the London parks have suffered much during recent years.

1. The large **Elm-bark Beetle** (*Scolytus destructor*) is one of the most destructive of the bark-boring beetles in Britain (Fig. 143).[2] It deposits its eggs between the soft wood and the inner bark of the Elm, and occasionally also of the Ash.

Appearance.—It varies considerably in length, but it is generally about $\frac{1}{6}$ to $\frac{1}{4}$

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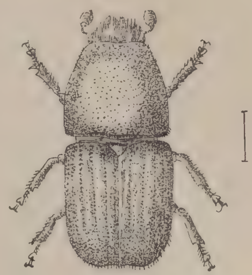
[1] "In a piece of bark measuring 28 in. long by 12 in. broad, which I cut from one such trap-tree, I found thirty mother-tunnels; and allowing 100 eggs for each, no fewer than 3000 beetles might have escaped from this piece alone."—(R. S. MacDougall on Pine Beetle (*Hylesinus piniperda*), in *Trans. High. and Agri. Socy. Scot.*, vol. xiv., 1902, p. 231.)

[2] A monograph on *The Elm-bark Beetle* is contained in the *Trans. High. and Agri. Socy. Scot.*, vol. viii., 1896, pp. 258-269.

of an inch long, and black with chestnut-brown wing-covers, and reddish-brown antennæ and legs.

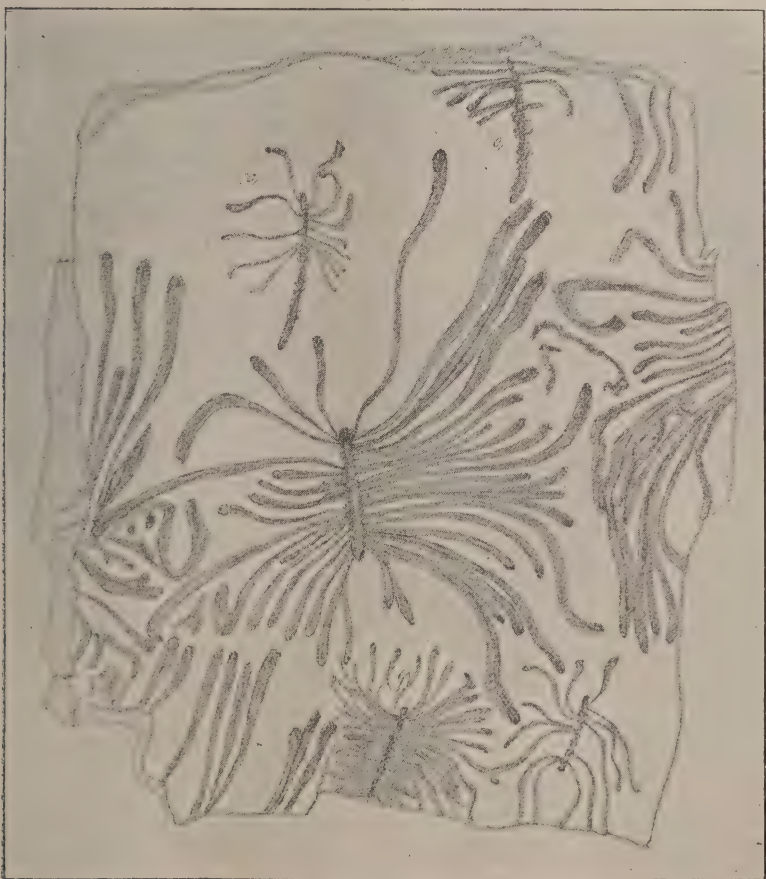
Fig. 143.



The Elm-bark Beetle (Scolytus destructor), *magnified five times.*

Life-history.—The female bores through the bark in June, forming a more or less vertical tunnel 3 or 4 inches in length, along which the eggs are deposited at intervals. The larvæ, hatched out in autumn, at once begin to feed on the inner bark of the tree, forming secondary-galleries to the main tunnel. They continue this until the following spring or early summer, when they pupate and emerge through the bark as perfect insects either in August or the following spring. After pairing, the female bores into the bark as before, laying her eggs, &c., as the galleries, increasing with the size of the grubs, are formed partly in the bark and partly in the sapwood. The stem is more or less completely girdled, hence the tree soon becomes diseased and is often killed outright. Trees from which the beetles have emerged look as if

Fig. 144.



Elm-bark showing borings of Scolytus destructor ($\frac{1}{4}$ nat. size). *a.* Galleries in which only part of the eggs have hatched out; *b.* Galleries of *S. multistriatus.*

the bark had been riddled with fair-sized shot; and very fine sawdust will be found either at the bottom of the tree or upon the bark. They never attack dead trees, but usually select young or old healthy and vigorous stems, although often found upon unhealthy trees. On the Continent there is a double generation (August and May), but, fortunately, in Britain only a few beetles emerge in August.

Prevention and Extermination.—If only old moribund trees are attacked, it is best to fell and bark them late in July or early in August, and to burn the bark to prevent the beetles spreading to other Elms. A plan adopted with success in France is to shave off with a spoke-shave the rough outer bark of infested trees in which the bore-holes of the female beetle are noticed, as many of the grubs are killed by their burrows being exposed, and by the flow of sap which takes place. The application of insecticide washes is then often successful.

There are several other species of this genus. These include (Fig. 144) the **Small Elm-bark Beetle** (*S. multistriatus*), which is only about half the size of *S. destructor*, but otherwise resembles it in appearance and life-history, and usually accompanies it in its attacks; *S. ligniperda*, which bores into some of the conifers; *S. intricatus*, which attacks the Oak; *S. vittatus*, on the Lime; and *S. fraxini*, on the Ash. All of these bore like the *S. destructor* into the bark of the trees which they attack, and destroy their healthy cambial action.

For monograph on *The Biology and Forest Importance of* Scolytus (Eccoptogaster) multistriatus, see *Progs. of Roy. Socy. Edin.*, vol. xxiii., 1900.

(2) **Cambial Beetles** (*Hylesinini*).

1. **The Ash-bark Beetles**[1] include three species found in Britain (*Hylesinus fraxini, H. crenatus, and H. oleiperda*). They bore between the bark and the wood, and the first two often do a very considerable amount of damage to ash-trees of all ages, more especially in the warmer tracts of Central and Southern England. Though sickly trees are most liable to attack, these pests often infest round healthy stems and cause their decay.

Appearance.—These three species may be distinguished as follows:—

Species.	Size.	Appearance.	Wing-cases.	Feet and legs.	Main-galleries.	Larval-galleries.
H. fraxini .	Inch. About ⅛	From light-brown to dark-brown; under-surface thickly covered with grey hairs.	Marked with five longitudinal punctures and small tubercles in front, and covered with grey scales.	Reddish-brown, bristly.	2-armed, running transversely, and about equal in length.	Shorter, and more at right angle to main-gallery (Fig. 145).
H. crenatus .	⅕ to ¼	Black (occasionally brown); with few hairs.	Marked with broad crenated lines and toothed interspaces.	Do.	2-armed, running transversely, but one often much longer than the other.	Longer, more irregular, and often finally running parallel to main-gallery (Fig. 146).
H. oleiperda .	About $\frac{1}{10}$	Black, and covered with yellow hairs and bristles.	Marked with punctured lines and broad tuberculed interspaces.	Yellowish (also antennæ).	2-armed, broad, and deeply cut in the wood of branches.	Usually soon cross, and become irregular and confused (Fig. 147).

[1] A monograph on *The Bark-Beetles of the Ash* will be found in the *Trans. High. and Agri. Socy. Scot.*, vol. xi., 1899, pp. 245-262.

Fig. 145.

Portion of young Ash-trunk with borings of H. fraxini, $\frac{3}{4}$ *nat. size.*

Fig. 146.

Borings of H. crenatus *on Ash-stem,* $\frac{1}{2}$ *nat. size.*

Fig. 147.

Borings of H. oleiperda, *nat. size.*

(*a*) **The Common Ash-bark Beetle** (*Hylesinus fraxini*) is the commonest and most destructive species all over Britain. When once it bores into healthy Ash-poles and trees (as is often the case) they soon sicken, then become much infested, and are quickly killed (Fig. 145).

Life-history.—The beetles emerge from their winter quarters in late April or early May, and bore into the stem and branches of standing Ash-trees or in felled stems in order to lay their eggs. Ash-logs lying in woods or parks till May or June are usually the breeding-places for thousands of these beetles. Felled timber forms perhaps their chief breeding-places.

In a few days the larvæ hatch out (in May), from twenty to sixty eggs being laid along each arm of the (2-armed) mother-gallery, which varies from 2 to 4 inches in length. They are reddish or purplish at first, with brown head and jaws, and are legless, transversely furrowed, and tapering to a point at the tail. The larval-galleries, formed at right angles to the main-gallery, vary from ½ an inch up to 4 inches in length (usually 2 to 4 inches), according to the more or less crowded and infested condition of the bark. The larvæ feed for about ten weeks, then pupate either in the bark (when it is thick) or in the sapwood (when the bark is thin). The young beetles emerge in August (when their exit-holes give the trees the appearance of having been riddled with shot), and at once proceed to hibernate in the bark of neighbouring live Ash-trees or freshly-felled logs, where they bore right into the cambium. Here they form galleries and feed during the autumn, then remain dormant in winter, and feed again in March and April, before emerging for pairing.

Prevention and Extermination consist mainly in planting Ash only on soil and situations really suited to it ; in removing felled timber before August ; in cutting out sickly Ash-poles and trees at least by February and March ; and in barking infested stems in June and July, and burning the bark. In parks, Ash-logs may be left as decoys, the bark being peeled and burned as above.

(*b*) **The Black Ash-bark Beetle** (*Hylesinus crenatus*) is generally to be found at work along with *H. fraxini*. It usually only attacks weakly old trees, or those already injured by *H. fraxini ;* but when once it infests such, it breeds there till the tree is killed (Fig. 146).

Life-history.—The beetles appear and pair from May to August, but chiefly in July and August. They lay their eggs in the cambium of old, weakly, overmature, or sickly trees with thick bark ; but failing such, healthy trees and dead stems are attacked. Eggs are rarely deposited in felled timber. The beetles form 2-armed mother-galleries cutting into the sapwood, and sometimes extending up to 4 or 5 inches in total length, and about ⅛ of an inch wide. The white elongated eggs are laid in niches on the upper and lower sides of the gallery, and numbering from 10 to 30 in each arm.

The larvæ are long, legless, tapering, pearl-white, wrinkled maggots, with brown head and jaws. On hatching out they eat deeply into the sapwood in fairly straight and parallel lines, but soon diverge and become tortuous, crowded, and confused. Later on they eat more in the bark, and most of them form their pupal-chambers there rather than in the sapwood. They are more or less active throughout the winter in mild seasons, and only pupate in the following spring, to emerge as beetles some time between May and August. Thus the normal generation takes about 12 months, while stragglers need 15 to 18 months. The beetles emerging in August and September sometimes bore and ovideposit in the same autumn, but more often they hibernate like *H. fraxini*, and do not pair and lay their eggs till the following spring. In the latter case mother-galleries are at once formed, but without the niches for placing the eggs. Thus both larvæ and hibernating beetles can often be found in infested stems.

Prevention and Extermination consist in at once felling and removing Ash-trees found to be infested.

(*c*) **The Ash-branch Beetle** (*Hylesinus oleiperda*) also often attacks along with *H. fraxini* in England, but is not found far north in Scotland. It is a pest in the Olive-groves of Southern Europe (whence its name), but in England it only attacks the twigs of Ash-trees. Sometimes it breeds in dead and decaying branches, but generally in sickly shoots and fresh sappy wind-fall branches (Fig. 147).

Life-history.—The beetles mostly fly in July and August (stragglers later), pair, and lay eggs on small branches up to about 1 inch diameter in healthy and growing trees (being sometimes also found on coppice-shoots), or up to about a foot diameter in sickly and moribund trees. It does not attack any part of large-sized trees covered with thick bark. The broad 2-armed galleries are bored by the beetles deep in the sapwood, and are widened into short spurs near the long entrance-gallery. The arms of the mother-gallery are seldom more than ½ an inch long, and in each arm from 10 to 20 eggs are laid rather closely together. Eggs of late stragglers may be found as late as October in the mother-galleries.

The larvæ, marked with pink lines near their lower end, eat deep in the sap-wood. Their galleries are usually 6 to 8 or 10 inches long, and are at first fairly parallel, but afterwards often cross each other and become confused and irregular. This irregularity, and the long entrance-gallery, form easy marks of distinction between the borings of this beetle and of the much more regular *H. fraxini*. The larvæ are more or less active throughout mild winters, then pupate in spring in the sapwood, to emerge as beetles in the following July and August. Its generation is therefore simple annual, the life-cycle extending over 12 months.

Prevention and Extermination are much the same as for *H. fraxini*, except that small branches form the best beetle-traps, because thick-barked stems are not suitable breeding-places. The decoy-branches should be collected from August to October, and removed for use as fuel, &c.

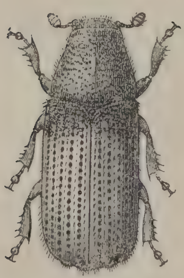
2. **The large Pine-Beetle** (*Hylesinus* (*Hylurgus*) *piniperda*).—Next to the Pine-weevil this is the most destructive insect in our Pine-woods. It attacks plantations at nearly all stages of growth, till the trees are well advanced in age. Besides attacking young growing branches, it is also found in decaying branches left in the woods. Much of the damage attributed to this beetle in Scotland is, however, no doubt due to *Hylesinus palliatus*, which often attacks Pine-woods along with *H. piniperda* (Fig. 148).

This insect does far less damage as a grub than as the fully matured beetle. Owing to the strong flow of resin from healthy stems, it chiefly attacks felled timber or sickly and unhealthy plantations; and healthy trees are only attacked when the pest has increased to excessive numbers. The attacks of the beetle are usually worst along the edge of green lanes and in pole-woods, where it may easily become an annual nuisance, interfering with the normal growth of the crown, and often doing serious damage. Woods in the vicinity of timber depots, saw-mills, &c., are specially liable to its attacks.

Appearance.—The Pine-beetle (Figs. 148-150) is $\frac{1}{5}$ to $\frac{1}{6}$ of an inch in length, and almost cylindrical. On first emerging it is reddish-brown, then turns mostly glossy black or dark-brown, with a black thorax, and reddish-brown (knobbed) feelers and legs. The wing-cases have longitudinal rows of very fine punctures, the spaces between which are wrinkled with punctures and small knobs, and have a row of little knobs with brush-like tufts of thick hair. But as the second space on each side of the middle line on each wing-case has no tubercle near the end, it therefore appears somewhat indented or slightly pressed in (which distinguishes it from *H. minor*, an almost purely Continental species).

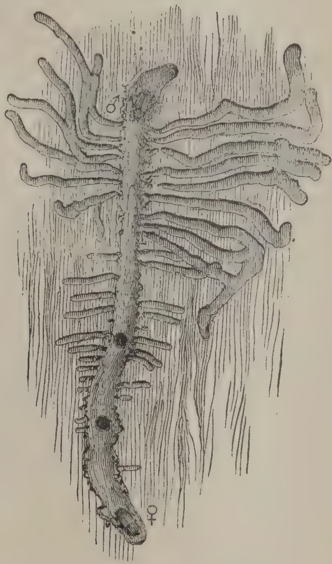
Life-history.—The Pine-beetles emerge from their pupal-chamber or their winter quarters late in March (in dry warm years) or in April, then pair and lay eggs under the bark of newly-felled stems or in stacked fuel. If such breeding-

Fig. 148.



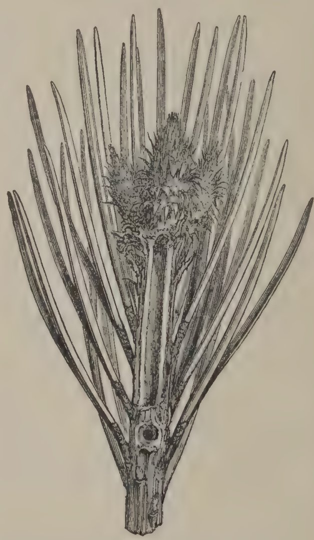
Hylesinus piniperda, *magnified about seven times.*

Fig. 149.



Inner side of bark, showing mother- and larval-galleries in process of formation and 2 air-holes—natural size. The male keeps near the original bore-hole, while the female bores the gallery.

Fig. 150.



Shoot of Scots Pine, showing the entrance-hole, and a slice removed to show the boring of a Pine-beetle —two-thirds natural size.

places are wanting, it attacks sickly trees, depositing the ova in thick-barked portions of the tree, or in recently cut Pine stumps. So long as such breeding-places are obtainable it selects for ovideposition the Scots or some other species of Pine (Weymouth Pine is often attacked), although it also occasionally makes use of Spruce and Larch.

After pairing, the female generally enters some bark-fissure, bores under it, and lays its eggs along a vertical main-gallery commencing with a curve and then stretching about 3 to 5½ inches parallel to the axis of the stem. The boring of the mother-gallery and the ovideposition continue for 3 to 5 weeks, up to 100-120 eggs being laid close to each other in niches cut right and left along the edges of the main-gallery. The bore-holes, where an entrance is effected, are sometimes marked by the yellowish outflow of resin on the bark.

On hatching out after an egg-stage of 14-20 days the larvæ do not bore into the sapwood, but eat sinuous galleries in the cambium on each side of the main-gallery, and after about 8 weeks they pass through the chrysalid stage (about 14 days) in pupal-chambers formed in the bark. The beetle, at first brighter in colour than afterwards, usually issues in June, about 11 to 12 weeks after ovideposition (or later if the spring has been cold and backward). As many beetles may breed in one stem after their issue, it may sometimes look as if riddled with snipe-shot. The beetle bores its way out through the bark, and may either at once pair and produce a second generation within the year, or else it may bore into young Pine-shoots for food and shelter (Fig. 150), and may then breed either during any of the warmer months, or not until the following spring. Warm weather favours a double generation.[1]

The beetles belonging to the second generation, as well as stragglers of the first generation, late in developing, bore into the tops of the youngest Pine-shoots just below the buds (the entrance-hole being generally noticeable by a shell of resin round it), feed on the pith, and either turn and leave again by the entrance-hole, or else make a special exit-hole. Shoots thus hollowed break during storms and fall to the ground, while the trees attacked look somewhat as if they had been pruned. When the attacks have been frequently repeated, the crowns assume a pointed pyramidal shape, from continuous loss of side-shoots, and the trees often become stag-headed. The beetle hibernates either in bark-fissures or under moss, or even more commonly by boring into the thick bark of the collar of the stem near the ground.

Prevention and Extermination.—Like the other bark-boring beetles, its chief natural enemies among insects are *Clerus formicarius* and *Rhizophagus depressus.* The best measures consist in keeping the woods clean, removing all windfalls and sickly trees, or stems having bore-dust lying round them, or on which the white shells of resin and the entrance-holes in the thick bark indicate that they are already infested. Decoy-stems may also be placed here and there during spring and summer, from which the bark should be peeled and burned at the proper time. Winter-felled timber may thus be used; but if not removed from the woods by the end of May, it certainly ought then to be barked.

Collecting and burning the hollowed shoots and twigs lying scattered on the ground is of little use, as the beetles have usually emerged from them before they break off.

Most trees are felled in autumn and winter, and to leave Pines lying in their bark in or near woods till the middle of the following summer is a sure way to propagate this and many other destructive forest insects. There need be no fear of the Pine-beetle breeding in stems from which the bark has been removed, but the barking of winter-felled Pines is a somewhat expensive proceeding. The removal of the trees, or their conversion before the month of June, should always be attended to, but the ideal method of procedure is as follows. Let the trees felled in autumn or winter remain in or near the wood till the month of May, by which time they will have attracted most of the Pine-beetles in the

[1] Tracing out the life-cycle in one brood, the following might stand as a calendar in favourable weather conditions (Prof. R. S. MacDougall, in *Trans. High. and Agri. Socy. Scot.*, vol. xiv., 1902, p. 232) :—

Nov. 1901 to March 1902.	April and May.	June.	July.	Aug.	Sept.	Oct.
Beetles in winter quarters	Beetles Eggs Larvæ	Pupæ Beetles of first brood	Beetles Eggs Larvæ	Larvæ	Larvæ Pupæ Beetles of second brood	Beetles of second brood

neighbourhood. Before the end of May all such trees should be barked, and as, by that time, the stems will be thickly beset with larvæ, the bark can be removed quite easily. In delaying the process of barking till May the logs are not only rendered unfit to serve as future breeding-places, but, what is most important, they are utilised as lures or traps, to which a large proportion of the beetles in the neighbourhood are attracted, and in which they are subsequently destroyed. On no account, however, must barking be delayed beyond the end of May. The bark removed should be deposited so that its inner surface, where the larvæ and chrysalids are found, is freely exposed to the sun and birds, and if this is attended to there is small chance of any of the young insects escaping. It is only when the bark is very thick that there is a likelihood of the immature insects completing their development in the bark after it is stripped off, and, in such a case, burning may be undertaken.

Small brushwood does not offer satisfactory breeding facilities for this insect, but it may serve the purpose for others, so that it is well to destroy it. Large branches, however, should be treated as recommended for stems. The Pine-beetle will also breed in the part of the stools above ground; and in the month of May the bark of stools should be pressed off by means of a spade, or other suitable tool, and, being generally thick, should be burned.

All Pines that die in the course of the summer should be felled and barked within two months.—(Board of Agriculture Leaflet, No. 91, *The Pine-Beetle* (*Hylesinus piniperda*). See also J. Clark, *A Battle with Beetles*, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvi., part ii., 1900, pp. 274-276).

3. **The Crutch Pine-Beetle** (*Hylesinus* (*Hylastes*) *palliatus*) often occasions great damage along with *H. piniperda* in the north of Scotland. It is perhaps often overlooked, as it does not require freshly felled material for its breeding-place, but can make use of stems that have been felled for some considerable time. The beetle chiefly attacks Scots Pine, but also Spruce, Larch, and Silver Fir in Scotland in middle-aged woods; but both beetles and grubs damage the bark and cambium.

Appearance.—The beetle is only about ⅛ of an inch long, and somewhat broad for its length. The head and the edges of the wing-cases are black or brown-black, and the thorax and wing-cases are red-brown or brown-red. The thorax is broader than long, and is much narrowed in front. On examination with a magnifying-glass, it will be seen to be thickly covered with coarse punctures, and to have a smooth raised line running down the middle. The wing-covers exhibit rows of finely punctured longitudinal lines, and the spaces between these contain little tubercles and rows of fine hairs.

Life-history.—There are two generations in the year, the time from ovideposition to the issue of the new beetles taking about three months, but varying of course a little according to weather conditions. The cycle is sometimes continued much longer in the case of individuals still in the grub stage in late autumn, when they hibernate before pupating. Pairing and egg-laying take place in March and April. After boring into the bark of recently felled or older stems, a main-gallery is formed longitudinally. It begins with a boot-shaped or crutch-like bend (whence the beetle's name), extends for about 1½ to over 2 inches, and is somewhat bent; and while this is being formed, both the male and female beetles are to be found in it. The eggs are laid in little niches hollowed out along the sides of this gallery. On hatching out, the curled, yellowish, legless grubs, which have brown heads and biting jaws, begin to eat larval-galleries at right angles to the main-gallery, then deviate more or less irregularly or longitudinally, so that these galleries often cross and interlace. The pupal-chamber is formed either in the bark or in the sapwood. After the beetles emerge, the trees look as if riddled with small snipe-shot. The beetles issuing in July pair and reproduce themselves at once, the eggs being laid in the stems already previously used as breeding-places. This second brood of beetles issues in October, and the beetles hibernate in bark-fissures, moss, &c., till pairing-time in the following March and April.

Prevention and Extermination consist in the use of decoy-stems from March till October, which should be examined and destroyed, along with the brood contained, at intervals of not more than six weeks from the time of preparing them. —(MacDougall, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvi., part i., 1899, p. 153.)

4. **The smaller Pine-Beetle** (*Hylesinus* (*Hylurgus*) *minor*).—This beetle is occasionally found in the north of Scotland along with *H. piniperda* and *H. palliatus*, chiefly in Scots Pine, and occasionally also in Spruce, pole-woods and middle-aged crops. This beetle prefers to breed in sickly standing Pine-trees rather than in felled timber, because the thin-barked parts dry soon.

Appearance.—It is $\frac{1}{7}$ to $\frac{1}{6}$ of an inch long, and is distinguishable by having uninterrupted the knob-like tubercles with brush-like tufts at the extremities of the wing-cases. It is more of a brown or red-brown colour than deep brown or black.

Life-history.—Unlike *H. piniperda*, which forms vertical main-galleries, this beetle forms two horizontal galleries branching on each side of the bore-hole. These main-galleries are formed usually in the thin-barked upper parts of trees, and less frequently in thick-barked parts. Both the main- and the larval-galleries are therefore always partly, and the pupal-chambers entirely, formed in the sapwood.

Its life-history is otherwise much like that of the Pine-beetle. Its generation is sometimes single and sometimes double within the year. As a beetle it damages young shoots in the same way as the former, and is perhaps in so far the more dangerous of the two that it more frequently deposits its eggs in standing trees than in felled timber.

Prevention and Extermination consist in laying down decoy-stems and poles with thin smooth bark; but it is more difficult to operate against it thus than against *H. piniperda* and *H. palliatus*, because the thin-barked parts of trees and poles soon dry and then fail to attract *H. minor*. The decoy-stems must be barked early, before pupal-chambers are formed in the sapwood.

5. **The black Pine-cambial Beetle** (*Hylesinus* (*Hylastes*) *ater*) only does damage in the beetle-stage, when it attacks young 2- to 6-year-old plantations of Scots and other Pines. It is fairly common in Britain, but is not reckoned one of the very injurious insects.

Appearance.—This beetle is about $\frac{1}{6}$ to $\frac{1}{5}$ of an inch long, and black with red-brown feelers and feet. Thorax with parallel sides, elongated, densely and deeply punctured, and with a smooth ridge along the middle. Wing-cases with lines of deep punctures, wrinkled and with tubercles between the spaces.

Life-history. — The beetles, after hibernating in stumps or injured plants, fly from March to May, pair and lay their eggs in fresh stumps and roots of recently felled Pine-trees (chiefly Scots). The larvæ soon hatch out (in about 3 to 4 weeks) and begin to feed in the cambium, but without forming distinct well-defined galleries, and the whole cambial layer becomes a mass of confused borings filled with brownish bore-dust. In June the new brood of beetles issues and attacks young Pine plantations, gnawing the thin bark near the base of the stem and the upper part of the roots. At the same time they also bore into the bark, and often tunnel all round the cambium. In consequence of this, plants attacked either sicken and cast their leaves or die, according as they may be only partially or completely girdled. The June brood of beetles may pair and produce a new generation in October, or they may hibernate in stumps and damaged plants, and reproduce themselves in the following spring.

Prevention and Extermination.—So far as practicable, grubbing of stumps and roots during May and June, after the eggs have been deposited, burying decoy-sticks in the ground as breeding-places, pulling up and burning sickly young plants, and delaying the replantation of recently cleared falls until the stumps and roots have become too dry to serve as breeding-places, are the best, and indeed the only, measures that can be adopted.

(3) **True Bark-Beetles** (*Bostrichini*, syn. *Tomicini*).

1. **The small 3-toothed Spruce-bark Beetle** (*Bostrichus* (*Tomicus*) *chalcographus*).—This beetle is only occasionally found in Britain, and usually on Spruce-trees, though also on Pines, Larch, and Silver Fir. It chiefly attacks the upper parts of the stem and the main branches, where the bark is thin; but it is also found in pole-woods that are not thriving. As such poles and trees attacked soon grow sickly, they form favourable breeding-places for more dangerous insects.[1]

Appearance.—This is one of the smallest of bark-beetles. It is only about $\frac{1}{12}$ of an inch long, almost hairless, shining, and glossy. It is bright reddish-brown, with a dark thorax, and its dark-brown elytra are smooth towards the ends, dotted near their base with fine rows of punctures, and have on each side 3 dark tooth-like processes (hence the name 3-toothed). These are larger in the male than in the female.

Life-history.—The beetle usually flies from about the middle of April till the middle or end of May. It flies mostly during warm sunshine, and for egg-laying seeks windfall trees and recently-felled timber. But if not finding favourable breeding-places of this sort, it goes to the thick-barked parts of standing trees and lays its eggs in the upper parts of the stem. Its favourite breeding-places are then the sunny edges of woods and the warm side of trees standing next to falls and blank spaces—and in trying to exterminate this pest, it is there that decoy-stems should be laid as traps.

From the central pairing-chamber short mother-galleries radiate in 4 or 5 (and up to 7) star-like branches, and these form a characteristic of this species. The pairing-chamber and the stellate mother-galleries, as well as the larval-galleries, are bored partly in the bark and partly in the sapwood. The female lays from 30 to 50 eggs (and sometimes up to about 100, it is said) in small dents made close to each other and alternately on the right and left of the stellate main-

[1] Fortunately this is not a common insect in British woods, and its generation here is usually only simple and annual. On the Continent there are often two broods in the year, or else three generations require two years for development (the second generation in this case hibernating as larvæ). This and another similar beetle (*B. typographus*), also occasionally found in Britain, sometimes do enormous damage in Spruce-woods in Central Europe. Trees attacked by large numbers of these beetles soon stagnate and die through the larval-galleries interfering with the flow of the sap; but the beetles always emerge from the stems before they are quite dead, so that the felling of such trees does not help to exterminate the pest. On the Continent this beetle is almost always to be found here and there in Spruce-woods; but when circumstances specially favour its increase (after extensive windfall, or damage by snow, &c.), it may multiply to such an extent as to commit enormous destruction. It only exceptionally attacks other trees than Spruce.

galleries, the eggs being fixed in the dents with gluey substance. The larvæ hatch out about 14 days later, and bore sidewards from the main-gallery. The larval-galleries are at first at right angles to the latter, but gradually broaden and bite deeper into the cambium, until they are finally about 2 to 4 inches long. Then each gallery terminates in the pupal-chamber of the chrysalis. After pupating for about 8 days (or longer in bad weather), a bright yellow beetle emerges from the stem by a circular hole, but very soon darkens in colour. The development from egg to beetle takes about 8 weeks on the average (eggs, April, May; larvæ, May, June; pupæ, June, July; beetles, July, August), or up to 12 weeks under unfavourable conditions.

The first brood of beetles flies from the middle of June till end of July. It immediately produces a new brood, which emerges as beetles in autumn. This second brood either pairs and reproduces a third generation within the year, or else the beetles hibernate and do not pair till the following spring. This beetle can therefore increase enormously under favourable circumstances.

Prevention and Extermination include the speedy removal of felled timber, the barking of stems that cannot be soon removed from the woods, and careful inspection of windfalls to see that they are not becoming breeding-places. Infested poles and trees should be felled and barked, and decoy-stems should be laid down in suitable places, and the bark afterwards peeled and burned.

2. **The large 6-toothed Pine-bark Beetle** (*Bostrichus stenographus; Tomicus sexdentatus*).—This is the largest of the bark-beetles; but it is not a very destructive species, and it is not common in Britain. It generally lays its eggs only in freshly felled timber, windfalls, and fuel-stacks; and it mostly attacks old thick-barked Scots Pine. Other Pines are less frequently used for ovideposition, and it is sometimes found on Spruce. When felled or stalked timber is wanting, however, it also attacks standing timber in old woods, and even pole-woods of twenty to thirty years of age.

Appearance.—The beetle is cylindrical, from $\frac{1}{4}$ to $\frac{1}{3}$ of an inch long, glossy-black or deep-brown with yellow hairs, and somewhat constricted at lower end. The antennæ and legs are yellowish-brown. The wing-cases have rows of deep grooves and punctures, and are pinched in where they curve downwards; at their lower ends they have 6 tooth-like processes on each side (12 in all), of which the fourth is the longest.

Life-history.—In habits and life-history it much resembles the preceding species. It flies in April and May, and lays its eggs in vertical mother-galleries, which are up to 8 inches long or more, on each side of the entrance-hole and pairing-chamber. They are mainly in the cambium, and hardly, if at all, penetrate the sapwood. The larvæ hatch out in June and July, feed for about 4 weeks, then pupate for about other 4 weeks, and emerge as beetles in August and September. Sometimes a new brood is at once reproduced, which also reaches the beetle-stage by autumn and hibernates under bark before pairing in April and May; but if pairing has not taken place in August and September, the beetles hibernate till the following spring. The generation is in Scotland usually simple and annual, though there is often a double generation in the year in warm Continental localities.

Prevention and Extermination.—Barking timber attacked usually keeps this not very destructive beetle well in check.

3. **The 2-toothed Pine-bark Beetle** (*Bostrichus bidens; Tomicus bidentatus*).—This is a frequent pest in Conifer woods throughout Britain, and

it is the commonest species of *Bostrichus* in our woodlands. It chiefly attacks Scots Pine, but is also found on other Pines, and occasionally also on Spruce and Larch. Its attacks are mainly confined to 10- or 12-year-old plantations, or to the thin-barked portions (the crowns and branches) of poles and trees. It may sometimes become a very injurious insect, doing extensive damage in plantations, and even interrupting the canopy of old Pine-woods.

Appearance.—The beetle is only about $\frac{1}{10}$ of an inch long, and is black, glossy, and covered with fine hairs. The wing-cases are usually dark-brown, and have rows of fine punctures. In the male both wing-cases are broadly and flatly indented ; on the upper edge of each of these indentations there is a large, hooked, tooth-like process (hence the name *bidens*) ; but these indentations and tooth-like processes are absent in the female.

Life-history.—The beetles appear in May and June, and lay their eggs on the thin bark of young plantations, pole-woods, and living or dead branches of Pine-trees. The larvæ hatch out in June and July, feed for about 4 weeks, then pupate in July and August, and emerge as beetles in August and September. The main-galleries radiate in a star-shape, but differ from those of *B. chalcographus* by greater irregularity, by both the main- and the larval-galleries entering more or less into the sapwood, and by the pupal-chamber being mainly in the sapwood.

The first generation usually emerges in July, and proceeds to pair and produce a second generation, appearing in September. In warm dry seasons this can also produce a third generation, which hibernates as larvæ ; but this second generation of beetles usually hibernates till the following May or June.

Prevention and Extermination mainly consist in keeping the woods clean, in thinning and removing sickly poles, and in laying down traps of small thin-barked branches and twigs (such as may be cut from decoy-stems set for larger bark-beetles), and then burning them after egg-laying is finished in June. Seedlings or saplings attacked should be pulled up and burned, and poles infested should be felled and barked, and the bark burned.

4. **The Larch Bark-Beetle** (*Bostrichus* (*Tomicus*) *laricis*).—Next to *Bostrichus bidens*, this is the *Bostrichus* most often found in British Conifer-woods. This beetle is not chiefly found on Larch (as its scientific name would imply), but on Scots and other Pines ; it also, however, attacks Spruce, and sometimes Larch and Silver Fir. It is found chiefly in poles, the upper parts of trees, and stacked fuel.

Appearance.—The beetle is $\frac{1}{7}$ to $\frac{1}{6}$ inch long, broad and cylindrical, usually dark-brown (but sometimes light-brown), with scattered grey hairs, and rusty-brown antennæ and legs. The wing-cases have close rows of punctures, terminate abruptly (almost at right angles), are circularly indented, and are toothed with from 3 to 6 processes on each side.

Life-history.—The beetle flies in April and May. The larvæ hatch out in May and June, pupate in June and July, and emerge as beetles in July and August. The July beetles pair and produce a second brood, the beetles of which emerge in October. This latter brood, as well as stragglers of the first brood, hibernate under the bark as beetles.

The mother-galleries are vertical but irregular, often twisting about and branching off into short supplementary galleries. The pairing-chamber is generally boot-shaped ; and the female lays 30 to 40 eggs in one or two clusters at the end of a main-gallery often only about 1 to 2 inches long. The larvæ feed in common in *family-galleries* running irregular and confused in different directions ; hence the larval-galleries are not distinct as with most other bark-beetles.

Prevention and Extermination.—If timber infested be barked or removed from the woods before the beetles emerge in July, this should suffice to prevent any large increase of the insect. Decoy-stems can also be laid down as traps, as for other bark-beetles.

5. **The Acuminate Bark-Beetle** (*Bostrichus* (*Tomicus*) *acuminatus*).—This is sometimes rather a destructive beetle in Scots Pine woods in Scotland and the north of England, where it infests the crowns of middle-aged and maturing crops.

Appearance.—The beetle is about $\frac{1}{8}$ to $\frac{1}{6}$ of an inch long, and brown with yellowish-grey down. The wing-cases have regular rows of punctures, and are sharp-pointed where they come together near their upper end (hence the scientific name); and each wing-case has there 3 tooth-like processes, the third being the largest.

Life-history.—The beetles fly in April and May, when the female lays her eggs high up in the crown of old Scots Pine. The brood-galleries are stellate, with 3 to 5 arms radiating from a rather large pairing-chamber, and biting deep into the sapwood. The larval-galleries are mostly in the cambium, and are confused and irregular, often crossing each other. Like most of the other *Bostrichini*, the beetles emerge in July and August, and pair and produce another brood, which emerges as beetles in autumn, that hibernate under the bark (along with late stragglers of the summer brood), and pair in the following spring.

Prevention and Extermination consist in felling and removing mature timber before the spring is far advanced, and in thinning out sickly trees in woods approaching maturity. As the eggs are laid high up in the crowns of old trees, it is difficult to operate against this beetle by means of decoy-trees as traps.

6. **The Wood-boring or Three-striped Bark-Beetle** (*Bostrichus* (*Xyloterus*) *lineatus*).—In the north-east of Scotland this beetle attacks most conifers, but chiefly Scots Pine, Spruce, and Larch, and it has not as yet proved very destructive. It mainly attacks recently-felled timber, and is only exceptionally to be found in standing crops of poor growth. It differs from all the previously described bark-beetles in its habits and life-history, and injures timber by boring into the wood, often riddling it with holes. But as the galleries, fortunately, are for the most part confined to the sapwood, the damage is not so great as it otherwise would be.

Appearance.—This small timber-boring *Bostrichus* is cylindrical and blackish, about $\frac{1}{8}$ to $\frac{1}{6}$ of an inch long, with dull yellow-brown wing-cases, antennæ, and legs, and with three dark longitudinal stripes along the inner and outer edges and the middle of each wing-case (whence *lineatus*). It has no tooth-like processes at the ends of the elytra like the bark-beetles previously described.

Life-history.—The beetle flies in March and April, and lays its eggs in timber lying in the woods. The female bores straight into the stem for about 1 to 2 inches, and then forms a 1- or 2-armed horizontal mother-gallery following the circumference of the stem along an annual ring; and on the upper and lower sides of this brood-gallery she alternately lays her 30 to 50 eggs in small niches. On hatching out in May the larvæ feed chiefly on sap oozing out from the walls of the main-gallery, and only when about full-grown bore short larval-galleries about $\frac{1}{4}$ of an inch long and at right angles to the former. The main and subsidiary galleries therefore look like a single-pole ladder and its rungs (*ladder-gallery*), because the short larval borings are uniform in breadth. Pupation takes place within these larval borings in June and July, in a cocoon formed of the bore-dust. The beetles emerge in July without special exit-holes, as they crawl back into the main-gallery and issue from the original entrance-hole formed in the sapwood. The walls of the galleries and the surrounding wood soon become blackened by fungi. A second brood is formed by the July beetles, which also emerge as beetles in October, and hibernate (along with stragglers of the first brood) in the stems till the following spring. Its generation is, however, usually double during the year.

Prevention and Extermination.—Decoy-stems may be laid down as traps for ovideposition in summer, and then removed or charred before the beetles emerge in July. But by far the best thing is to remove winter-felled timber before the beetles emerge in spring. If that cannot be done, then the early removal of stems containing the eggs and the barking of logs are advisable, as the young brood is likely to die when the timber is dry.

Bostrichus (*Xyloterus*) *domesticus*, another wood-boring beetle closely related to the above species, is found in Britain in tree-stumps and windfall timber. It is about the same size as *B. lineatus*, but its wing-cases are bright yellow, and it is only found in broad-leaved trees (Oak, Beech, and softwoods), not in conifers.

7. **The Oak-boring Bark-Beetle** (*Bostrichus* (*Xyleborus*) *dispar*) is mostly to be found on Oak and Beech and on orchard-trees (chiefly Apple and Pear in Gloucestershire and neighbouring counties), but it also attacks most other hardwoods, together with Birch and Alder among softwoods. It is often very destructive to stout Oak saplings and transplants, which the larvæ can kill off rapidly. The beetle sometimes bores into and breeds in the stems of old Oak, Beech, &c., that have become somewhat sickly, and spoils the timber. It also bores into timber lying on the ground. Trees or saplings infested can be known by the bore-dust to be found on the ground below the bore-hole.

Appearance.—The beetles are black, with reddish antennæ and legs. The female is about $\frac{1}{8}$ of an inch long and cylindrical, while the male is only about $\frac{1}{12}$ of an inch long, ovoid, and convex. The wing-cases are well-rounded towards their apex, and have rows of deep punctures.

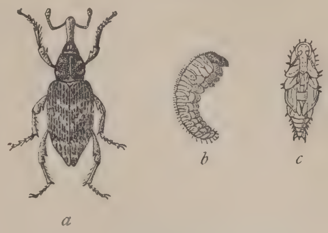
Life-history.—The beetles fly in May, when the females bore into healthy Oak and other saplings. The mother-galleries consist of (1) a short entrance-gallery, (2) secondary-galleries, and (3) brood-galleries. There are no larval-galleries, as the larvæ do not live by boring. The female usually enters just under a twig and bores upwards for a short way before tunnelling one or more secondary-galleries horizontally along one of the annual rings in the sapwood; and from these the brood-galleries are bored longitudinally up and down the stem for about 1 inch or more. The latter resembles the larval-galleries bored in Spruce by *Bostrichus lineatus*, but are much longer. The eggs are laid in small clusters in these brood-galleries, and the larvæ which hatch out here feed on the exuding sap and on the fungus mycelium with which the mother-galleries soon become filled. The larvæ hatch out in June, feed on the sap, &c., for about 4 weeks, then pupate in July in the secondary-galleries for about 4 weeks. The beetles emerge in August, but hibernate in the galleries, and do not pair till their flight-time in the following May. The generation is therefore simple and annual.

Prevention and Extermination.—Saplings attacked should be cut back, and the infested parts burned. In orchards, the entrance-holes may be daubed over and filled with patent tar, or the beetles may be picked out with wire; but these measures are not practicable in the woods.

Bostrichus (*Xyleborus*) *Saxesenii*, a species closely related to the above, is also found attacking Oak in Scotland.

B. **Proboscid Weevils or Long-snouted Beetles** (*Curculionidæ*).—The main characteristic of weevils is the elongation of the head to form a snout (*rostrum*) by which the larger of them are easily recognisable. The great majority of *Curculionidæ* feed on broad-leaved plants, and not a few of them on woodland trees; but the most destructive species are those which attack young conifer plantations.

Fig. 151.



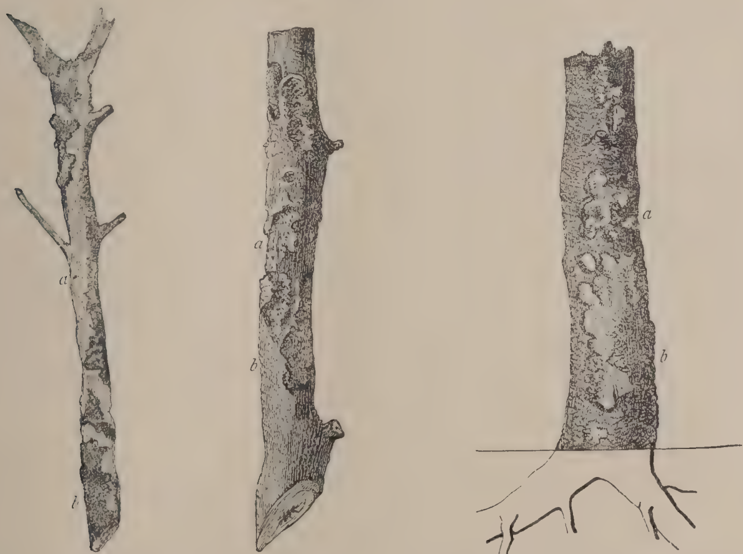
The large brown Pine-Weevil
(Hylobius abietis).

a. Beetle (natural size).
b. Larva (natural size).
c. Pupa (natural size).

In some cases the larvæ do damage by living in the interior of the plants and destroying their tissue, while in others very great injury is inflicted by the beetles devouring bark and cambium.

1. **The large brown Pine-Weevil** (*Hylobius abietis*) is now the most destructive insect in our British woodlands, although the damage is only done during the adult stage (Fig. 151). It attacks young conifers in plantations and nurseries, and does most damage in 2- to 5- or 6-year-old plantations of Scots Pine, Spruce, and Larch, though broad-leaved plants mixed with these are also

Fig. 152.



Young Spruce plants gnawed by the large brown Pine-Weevil (Hylobius abietis), *natural size.*
a. Parts gnawed. *b.* Parts still covered with bark.

attacked, pieces of bark being gnawed away into the cambium (Fig. 152). It also attacks Weymouth Pine, Douglas Fir, Silver Fir, and Japanese Larch. Whole plantations may thus be totally destroyed. When the bark gets thicker and harder there is less risk of damage, so that plantations of about ten years of age are comparatively safe from attacks. The injury is easily noticeable from the flow of resin. It does most damage in warm dry seasons. It sometimes attacks older trees, but the wounds soon get coated with resin and heal up. It is only found where conifer crops have been recently cleared.

Appearance.—This weevil is about $\frac{1}{3}$ to $\frac{1}{2}$ an inch long, and is stoutly built and convex in shape. It is deep-red to dark-brown or black in colour, and has a long thick proboscis. It is marked with clusters of yellow scales or hairs between the eyes, on the sides of the thorax and abdomen, and on the wing-cases. These small yellow patches look like cross-bands on the wing-cases, and are very prominent when the beetle emerges from the chrysalis, but they gradually get more or less rubbed off.[1]

Life-history.—The adult beetles live for two years or more, so that beetles which have recently emerged (with distinct markings on their wing-cases) and older beetles (with faint markings) that have been out for some considerable time, as well as larvæ in every stage of development, may all be found simultaneously.[2]

The beetles appear from April till early in June, when they crawl and fly towards freshly cleared coniferous falls, and deposit their eggs in the fresh sappy stumps and roots. As a rule, however, they do not fly much except in pairing-time. Pairing and reproduction are continued during summer as long as fresh stumps are available for breeding-places. The eggs are laid singly on roots from $\frac{1}{2}$ an inch upwards in diameter ; but they are sometimes also laid in sawdust heaps near sawmills in the woods. On hatching out in about 4 weeks they at first bore only in the dead cambium, but later on also enter the sapwood and form long winding galleries, trending downwards and sometimes over 3 ft. long, at the end of which the pupal-chamber is formed. The yellowish-white larvæ have a large brown head, and are curved or bent by ventral contraction ; they sometimes grow to about $\frac{3}{4}$ of an inch long. In autumn, when full grown, they hollow out their pupal-chamber in the sapwood, and seal it up with bore-dust and wood-chips. Here they remain as larvæ till the following June, when they pupate and emerge as beetles about three weeks later. The whole development from egg to beetle thus occupies about 15 months. They find their most favourable breeding-places in autumn and winter, on falls of the mature conifer crops.

The beetles which emerge in July and only partially reproduce themselves are not so destructive as in the following spring. They begin to hibernate from about the end of August till autumn. They hibernate in thick grass or weeds, preferring the edges of woods adjacent to their breeding-places on the last fall of timber, or in the stumps of dead trees, or below timber lying on the ground, or in dead heaps of

[1] It is distinguishable from the small brown Pine-weevil (*Pissodes notatus*) as follows:—

	Length.	Destructive as	Thighs.	Feelers inserted.
Large brown Weevil (*Hylobius abietis*)	$\frac{1}{3}$ to $\frac{1}{2}$ inch	Beetle only	All 6 with a spine or tooth on lower side	Near the apex of the proboscis
Small brown Weevil (*Pissodes notatus*)	$\frac{1}{4}$ to $\frac{1}{3}$ inch	Beetle and larva, but chiefly larva	All 6 without any spine or tooth	Near the middle of the proboscis

[2] By von Oppen's observations, made on beetles confined under circumstances conforming as nearly as possible to natural conditions, it was found that this beetle can live up to two years, and that the same individuals can pair and lay eggs repeatedly. This function can be partly performed in one year, and resumed after hibernation. This explains the simultaneous appearance of recently emerged and older beetles, as well as of ova, young and full-grown larvæ, and chrysalides.

branches in the plantations. Early in autumn, when the females are laying their eggs, they often gather in large numbers in these places, whence they emerge in the following spring to pair again.

Though the boring of the grubs is not very injurious, the damage done by the beetles is often very serious. They gnaw off patches of soft bark from the stem and shoots of young Pine, Larch, and Spruce, and also of other conifers to a less extent, and sometimes even attack broad-leaved trees (especially Oak) mixed with those. Besides the bark, the beetle also eats into the cambial layer above the sapwood, stripping patches about the size and shape of a lentil; and these, becoming covered with resin, give a scabby appearance to the plants. Young plants attacked die off in large numbers, and plantations are often either ruined entirely or else need partial replanting.

Prevention and Extermination.—Clear-felling of mature crops over extensive areas stocked with Scots Pine and Spruce, which is often usual, and making large clearances side by side with the young plantations without grubbing up stumps and roots, where they cannot even be sold as fuel, must always favour the increase of this very destructive pest. Windfall timber and branches broken by heavy snowfall also favour their appearance, because great masses of stumps and roots offer the most favourable breeding-places.

The best means of preventing attacks is, of course (though it is not always practicable), to stub up all stumps and roots and sell them as fuel; and wherever this can be done, there is little danger of the Pine-weevil doing much damage. Felling the timber by cutting through the main roots with an axe and pulling over the tree, though it does not leave so large a stump as in felling with axe and saw, is not sufficient to obviate danger, as even then many thick roots are left in the ground.

Where only a few of these weevils are noticeable, the stumps and roots may be stubbed at any convenient time. But when they are present in large numbers, the stumps should be used as traps for the eggs, and only stubbed up during the late summer, after the eggs have been laid, or at latest in the early spring.

For the protection of areas where young plantations are soon to be made, it is best to let the land lie fallow for one or for two years after a clear fall of timber.[1] If the fall be at once replanted, then breeding-places and feeding-grounds are provided for the beetle on one and the same area; and of course the danger will be all the greater if it has not been possible to root out the stumps (see vol. i. p. 462).

In trying to exterminate this pest, the beetle must, if possible, be caught in its breeding-places in the falls of the previous year. Narrow trenches about 10 to 12 inches deep may be dug round the last fall in early spring to prevent the beetles crawling from their winter quarters and laying their eggs in the fresh stumps. The trenches should be cut with smooth perpendicular walls, and holes about 1 foot deep should be dug here and there along the base, to serve as pitfalls and traps.[2] As the beetles fly, especially during pairing-time, these trenches prove most useful in the summer of the second year, because they prevent newly-emerged beetles

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[1] Protection can also be obtained by allocating the annual falls of timber so that there is a suitable interval between two contiguous falls in the mature crop; and the longer the time between the planting of each two contiguous falls, the greater is the protection against this weevil (see also Part V., p. 257).

[2] Experience at Scone (Perthshire) in 1899-1900 showed that the Pine-weevil can easily fly. Ditches were opened and filled with water, but this did not stop the beetles. On coming to the edge of the trench they spread their wings and flew across, going fully 10 to 12 yards. It was also found that putting stones or sods on the bark-traps only rot the latter in the damp climate of Perthshire. The best traps were there found to be pieces of fresh bark put inner side downwards on the ground, and renewed as soon as they get dry. If it is not convenient to replace them at once, then green sappy Pine twigs may be placed under the bark-traps till fresh bark can be laid down. The bark-traps must, of course, be examined frequently to catch the beetles.

crawling away from the area. But the trenches must be examined every day, and the beetles collected and destroyed.

On freshly-cleared areas and places already infested, bark-traps should be laid to decoy the beetles. Bark-traps, consisting of pieces of fresh Spruce or Pine bark, should be laid down with the soft inner side next the ground, and weighted down with stones, or freshly cut Pine or Spruce poles may be cut into faggots about 3 or 3½ feet long, and a strip of bark about 1½ to 2 inches broad peeled off lengthways, before they are laid down, with the barked part resting on the ground. The beetles, attracted by the fresh resinous odour, attack the cambial layer of these decoys, and can easily be collected daily. The beetles will also feed on bundles of fresh Pine branches spread over the fall cleared, and can be collected by being shaken out on sheets spread on the ground to receive them as they fall. When collected, the beetles can be destroyed by pouring boiling water over them.

The beetles will also lay their eggs in specially prepared breeding-faggots, made of small Pine or Spruce thinnings cut to about 3 or 3½ feet long, and buried near the ground surface, several being set close to each other and the places marked with a peg for easy recognition. After the eggs are laid, the brood is destroyed by peeling the bark from the sticks. This method is often successful during the second year, when neither the hibernated nor the newly-emerged beetle find other sappy breeding-places among the dried-up stumps on the previous year's fall.

Efforts should always be made to destroy the beetles where they emerge, and such operations should be taken in hand before the young plantations are attacked.

2. **The small brown or banded Pine-Weevil** (*Pissodes notatus*) [1] is also in Scotland very destructive to Scots Pine (Fig. 153), as well as to Austrian, Corsican, and Weymouth Pines, and occasionally also Spruce and Larch. It attacks both as larva and beetle; but in the former stage it is very destructive. The larvæ bore in the bark, and between the bark and the sapwood, gnawing away parts of the latter where the bark is thin. The weevil does not gnaw the bark, but pricks with its proboscis through the bark, right into the sapwood near the base of young plantations from 3 to 6 years old, and then sucks the sap. A badly attacked stem looks as if it had been there pricked all over with a needle. From these punctures beads of resin ooze out. It is very often found along with the large brown Pine-weevil.[2]

[1] A monograph on *The Genus* Pissodes *and its Importance in Forestry*, by R. S. MacDougall, will be found in *Trans. Roy. Scot. Arbor. Socy.*, vol. xv., part i., 1896, pp. 25-43, and another on *The Biology of the Genus* Pissodes, in *Progs. of Roy. Socy. Edin.*, vol. xxiii., 1900. See also Board of Agriculture Leaflet No. 138 (*Pine-Weevils*).

[2] Two other species, *P. pini* and *P. piniphilus*, also in Scotland attack Pine pole-woods. The Pine-pole Weevil (*P. piniphilus*) very much resembles *P. notatus*, but is rather smaller. It is rusty-brown in colour, with a characteristic rusty-yellow patch on each wing-case. It lives in the thin-barked upper parts of Pine pole-woods, but is also found on older stems, where the female deposits her ova singly in holes bored for the purpose. On hatching out the larvæ tunnel sinuous irregular galleries in the cambium, which gradually increase in breadth, and end in small pupal-chambers made in the sapwood. The beetles appear in June, and the generation may either be annual or may extend over two years when the pairing continues after hibernation. *P. pini* is about ⅜ inch long, and of a red-brown to black-brown colour, with sparse yellow scales on both upper and lower surfaces. It is common in central and N.E. Scotland, and usually attacks old stems of Scots and Weymouth Pines. The damage done by *P. pini* is no doubt often attributed to the large and the small brown Pine-weevils. Badly injured poles and stems sicken and die off; and if attacks continue the canopy gradually becomes interrupted. The best protective measures consist in felling poles and stems attacked, when resin is seen oozing out of the punctures made for ovideposition. It is not necessary to peel the bark after felling stems, as the larvæ die when the bark dries.

Appearance.—The beetle is from $\frac{1}{4}$ to $\frac{1}{3}$ of an inch long. It is dark red-brown in colour, and irregularly covered with small scale-like greyish-white hairs. On the thorax there are six to eight plainly marked small white or yellowish dots. The wing-cases have two broad rusty-red transverse bands bearing white and yellow scales, the upper band being interrupted at the junction of the wings. The proboscis is long and thin (see also footnote to p. 90).

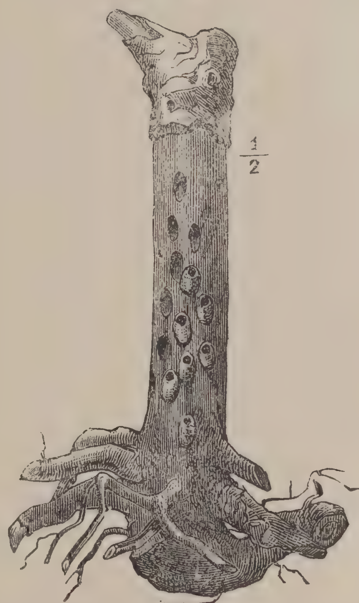
Life-history.—The beetle swarms in April and May, and then lays it eggs (often in small clusters) for the most part under the whorls of 3- or 4- to 8-year-old Pines (Scots and others), and also in Pine-cones and in the bark of sickly dominated poles, from April to September. When the yellowish-white brown-headed larvæ hatch out, they tunnel downwards, eating sinuous star-shaped galleries in the cambium, which terminate in a pupal-chamber formed in the sapwood. On entering this to pass the chrysalid stage, the vacant space is filled up with bore-dust and wood-chips (Fig. 154). Frequently one may find several of the pupæ embedded just below a whorl of branches. The beetle bores a circular hole and emerges in August or later, pairs and reproduces itself, then hibernates in November under moss, or in the bark-fissures of trees, and comes out again and pairs once more in the following April and May. But the generation is usually annual, though there may be three generations in two years.

Fig. 153.

The small brown Weevil (Pissodes notatus).

a. Beetle (magnified four times).
b. Beetle (natural size).
c. Larva (magnified twice).
d. Pupa (magnified twice).

Fig. 154.



Young Pine-stem barked to show the pupal-beds with exit-holes of Pissodes notatus (*half natural size*).

Prevention and Exterminative Measures.—When young shoots of plants infested by the larvæ droop and look sickly about July, they should be pulled up and burned. This is the only thorough way of exterminating this pest; and if persevered in for several years in succession, it ends in almost completely annihilating it. Poles attacked should also be felled and barked; but it is much easier to recognise attacks on young plants than to detect infested poles.

Prof. MacDougall (*Trans. Roy. Scot. Arbor. Socy.*, vol. xv., part iii., 1898, p. 310) makes the following suggestions :—

A great means the forester has in proceeding against this pest, once it has got to work, is the preparation of catch-trees or decoy-stems. These will be sickly plants or trees left here and there in nursery or plantation, or plants can be artificially weakened and left standing, or an older tree can be cut down and allowed to lie as a breeding-place. In consequence of the long-continued life and egg-laying, such trap-plants must be arranged, and visited and renewed, at intervals throughout the whole year, from March till October inclusive.

These catch-trees or traps must be barked or removed before the enclosed brood has reached maturity, and their contents, in the shape of larvæ or pupæ, destroyed. My experience is that, where ripe larvæ have been exposed to the light and weather by a removal of the bed-coverings, they rarely complete their development, yet it is safer not to give them the opportunity. Where the barked stems are not removed, special care must be taken that beds deep in the wood are not overlooked, but their contents destroyed. (This must specially be attended to in the case of *P. pini*, whose beds can be found deep in the alburnum.)

As thin twigs may be used for breeding in, these, if not removed and burnt, must be slit up for the destruction of enclosed grubs or pupæ. Their yielding to pressure, here and there, will be a guide to their having been tunnelled.

I am certain, from my experiments, that where *notatus* is plentiful (and in such cases perfectly healthy plants can be attacked and will succumb), collecting the imagos would prove very serviceable. This measure could be certainly adopted in nurseries with good results. The beetles would require careful looking for, however, owing to their protective coloration; but favourite places for them are below the whorls, at the bases of the bifoliar spurs, and lying between the buds. I have pointed out that imagos may be found during many months, and new imago issue also, yet the intervention of winter will give rise to a certain seeming periodicity of imago appearance. Collecting, then, will probably be most successful in the spring-time, when the over-wintered beetles and earliest - issuing renew or proceed to their egg - laying, and also from August onwards, when escape will be at its height.

Where the beetles have not yet got a footing, a timely and vigorous rooting out of all suppressed or sickly Pines will go far to prevent injurious attack.

As guides denoting attack we may mention :—

(*a*) The bead-like drops of resin that issue from the wounded bark.
(*b*) The drooping of the plants, with a reddening of the needles.
(*c*) The little proboscis punctures.
(*d*) In young or smooth-barked parts, on the finger being passed over the bark, little risings may be felt, or little ridges may be seen. These mark the places of larval tunnels or pupa beds.

3. **The Beech leaf-mining Weevil** (*Orchestes fagi*) is a common insect in Britain. It often swarms in millions in Beech-woods, and has lately been very destructive in defoliating Beech-trees to a considerable extent. Though its attacks are not fatal, yet they interrupt the growth of trees infested by beetles in large numbers, as often happens on seed-bearing standards and trees near the edges of compartments. The damage is confined to the foliage and flower-buds of Beech (among woodland trees), though Cherries and fruit-shrubs in orchards are also attacked, the leaves of old trees being selected for ovi-deposition in preference to those of young ones.

Appearance.—This small black weevil is only about $\frac{1}{12}$ to $\frac{1}{10}$ of an inch long, and covered with fine grey hairs ; the wing-cases have rows of coarse punctures ; the antennæ and legs are light-brown ; and the rostrum, when not in use, is bent back under the thorax. The thighs of the hind-legs are thick, and formed for springing.

Life-history.—The female bites small holes on the under surface of very young leaves, and deposits one egg in each hole near the midrib, when the Beech-leaves flush in spring. The larvæ hatch out 2 to 3 weeks later, and mine within the substance of the leaf, forming whitish galleries (which soon oxidise to brown), increasing in breadth as the grub grows in size. The damaged leaves turn brown, as if nipped by late frost. The pupal stage is passed in the leaf. The beetles emerge in June, and feed on the foliage and the nut-cupules till autumn, when they descend and hibernate under dead leaves on the ground.

Prevention is hardly possible in woodlands ; but the attacks are least extensive in mixed woods, where insectivorous birds are always most plentiful. Ornamental trees may be sprayed with arsenic solution formed by stirring ½ lb. Paris-green paste in 100 gallons water, and adding 1 lb. lime. If this does not prove successful, the infested leaves should be picked in May and burned, while the beetles should be shaken down and killed in June.

4. **The Oak leaf-mining Weevil** (*Orchestes querci*) is somewhat similarly destructive to Oak foliage.

Ichneumon-parasites are common in both *O. fagi* and *O. querci.*

5. **The Willow and Alder Weevil** (*Cryptorhynchus lapathi*) often gnaws the bark of young shoots of old Willow-trees, and attacks young Alder-trees ; but its larvæ do far more damage by burrowing into the wood and forming galleries from which the bore-dust is cast out at the entrance.

Appearance.—The beetle is broad and strongly built, about ⅓ of an inch long, and is strongly marked by having its wing-covers dark-brown for the first two-thirds of their lengths, and white-scaled for the last third. When not in use, its beak rests in a groove under the thorax.

Life-history.—The beetle feeds in May and lays its eggs. The grubs soon hatch out and feed till August, when they pupate. Some beetles emerge in autumn and hibernate in any convenient hiding-place, but most of them remain inside the shoots (either as pupæ or beetles) till the spring.

Prevention and Extermination.—Branches or trees badly infested should be cut and burned in July. Trees attacked should be shaken over sheets in May, and the beetles killed.

6. **The Hazel Weevil** (*Curculio* (*Strophosomus*) *coryli*).—The larva is chiefly found on Hazel, Oak, Beech, and Birch, but also attacks other broad-leaved trees and conifers, and hollows out the buds before gnawing the young shoots. The wingless weevil also sometimes, in spring, feeds on the edges of needles and on the bark of young Pine and Spruce, especially of 2-year-old seedlings. It often occurs in large numbers, when it may do a good deal of damage.

Appearance.—This weevil is ⅙ to ¼ of an inch long, almost spherical, and brownish-grey, with greyish metallic sheen. The basal junction of the wing-cases is black, without hairs or scales ; the antennæ and legs are rusty-red. The rostrum has a fine groove along the middle. It is wingless and cannot fly, but crawls up stems.

Life-history.—The weevil pairs and lays its eggs about June.

Prevention and Extermination.—In nurseries the beetles may be shaken down into vessels containing a little paraffin, or else shaken down and collected ; but they drop to the ground when even slightly shaken, and crawl quickly away. Grease-banding the stems with patent tar prevents the fallen beetles from reascending.

C. **Lamellicorn or Platicorn Beetles** (*Scarabæidæ*).

This family is distinguished by their antennæ always ending in a club composed of several "leaf-like" joints, disposed like the arms of a fan, the leaves of a book, the teeth of a comb, or in a series of funnels placed above and within each other. The males often differ from the females in the larger size of their mandibles and in having horn-like projections on the head and thorax—most notably so in the Stag-beetle (*Lucanus cervus*) often found in Oak- and Beech-woods, but not doing any appreciable injury.

1. **The Cockchafer, May-beetle, or White-grub** (*Melolontha vulgaris*).—As a beetle, this insect chiefly attacks broad-leaved trees, and feeds on the leaves and flowers of Oak chiefly, but also on Beech, Elm, Maple, Sycamore, Lime, Horse-Chestnut, Willows, and Poplars. During bad "chafer-years" it almost defoliates the trees attacked. Among Conifers it mainly eats the soft tufts of Larch-needles and the male flowers of Pine. It is, however, as a grub that this insect is most destructive, when it does great damage to young Conifer seedlings and Oaks, especially in loose, porous, sandy soil. From the second year, as a voracious growing grub, it gnaws the tender roots of all kinds of young plants, and especially of perennial grasses, weeds, and young coniferous seedlings, so that the latter soon die off, while older plants sicken when attacked. In seed-beds, where the porous well-prepared soil attracts the female beetle when laying her eggs, and on extensive falls of Scots Pine on light sandy soil grubs are often exceedingly destructive, so that the cockchafer belongs to the very injurious class of insects (Figs. 155, 156).

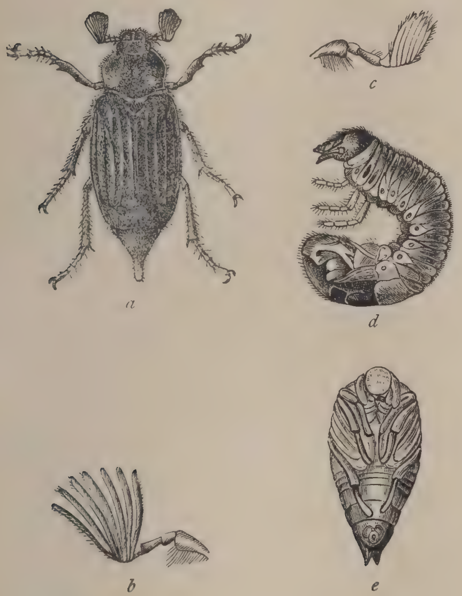
Appearance.—The beetle (see Fig. 155) is from 1 to 1¼ inch long. The thorax is black or reddish-brown; the wing-cases and legs are ruddy-brown, and each of the former has five longitudinal ridges, the four depressions between which are covered with fine hairs. The abdomen is black, with five triangular white spots on each side, and gradually terminating in a broad, elongated, and pointed tail. The antennæ have ten joints, the laminæ being 7-jointed and feathery on the male, but 6-jointed, smaller, and narrower on the female. The male can thus easily be distinguished from the female by its feathery-leaved antennæ. The full-grown larva or *grub* is 1½ to 2 inches long. It is thick, fleshy, and dirty-white, the tail-end being swollen and darker in colour, and generally bluish, owing to the excrement showing through. It has a thick, yellow-brown head, strong biting jaws, and six long feet attached to the thorax. The chrysalis is brownish-yellow, with two horny processes on the last abdominal segment.

Life-history.—The beetle flies in May and June. After pairing the female seeks open spaces with bare loose soil, into which she burrows, and lays about 70 eggs in all, in clusters of from 10 to 30 at a depth of 2 to 4, or sometimes as much as 6 or 8, inches below the surface. The eggs are creamy-white, and about the size of hemp-seed. This done, she reascends to the surface and soon dies.

The larvæ or grubs hatch out about 4 weeks later. During the first year they feed on grass-roots and decomposing foliage, &c. In autumn they burrow deeper as a protection against winter cold, but reascend nearer the surface in spring, and then begin to feed on the roots of plants (chiefly Scots Pine, Larch, and Spruce) until autumn, when they again hibernate as grubs. Reascending in the third spring, they once more feed on the roots of seedlings and young plants; and as the grubs are nearly full-grown, it is then that they do most damage. Again (for the third time) they hibernate as grubs after burrowing deep into the soil, and in the following spring they reascend and feed for a short time. In June, three years after hatching out from the egg, they burrow deep into the soil and pupate in an oval hole with smooth hard walls. After from 4 to 8 weeks of pupal rest the beetle comes out soft and white, but gradually hardens and deepens in colour. Without coming to the surface it hibernates below ground, and does not emerge till the following spring (May), when it issues from a hole such as is made with the point of a walking-stick.

This beetle requires in Britain four years for its normal generation (though in

Fig. 155.



The Common Cockchafer (Melolontha vulgaris).

a. Beetle (male—natural size).
b. Feeler of male (7 lamellæ—magnified four times).
c. Feeler of female (6 lamellæ—magnified four times).
d. Larva or grub (natural size).
e. Chrysalis (seen from below—natural size).

Fig. 156.

Young Beech Seedling, the roots of which have been destroyed by Melolontha vulgaris (*natural size*).

warm southern countries the generation takes three years only). They may therefore be expected to swarm at regular intervals of every four years, although a few stragglers may usually be seen in the intervening years.

Prevention and Extermination.—So far as practicable, the female beetles should not be given any favourable opportunity of laying their eggs on large blank spaces with loose soil in years when many beetles may be expected. For example, notching is then preferable to pit-planting on suitable soil. In localities where chafers are known to abound nurseries should not be formed near pastures or young Oak crops, as the beetles may fly from these to lay their eggs.[1] Nurseries,

[1] See also Mr F. Moon's *Account of a Chafer Infestation*, in the *Trans. Roy. Scot. Arbor. Socy.*, vol. xviii., pp. 201-207, and a Note on the Cockchafer, in Prof. MacDougall's *Report, ibid.*, pp. 208-210; also Board of Agriculture Leaflet No. 25.

whether temporary or permanent, should be surrounded by a trench preventing the entry of grubs. The best protection, however, is to hang up nesting-boxes for starlings all round the nursery, as these most useful insectivorous birds take kindly to this assistance, and well repay the cost and trouble taken to increase their number.

But besides the starling, there are many other animals which prey on cockchafers and white grubs. Pigs, hedgehog, badger, fox, mole, &c., devour grubs in the ground, and bats, owls, crows, rooks, jackdaws, gulls, goat-suckers, stannelhawks, sparrows, &c., also destroy many of them when swarming and laying eggs.

These natural remedies fail, however, to check the periodic chafer-years. One of the best ways of trying to exterminate the pest is to collect the beetles from the lower branches of trees along the green rides and open spaces, and from Oak-coppices. The beetles can easily, and especially in the early morning, be shaken down from young poles (lightly, else they hold on firm), picked up from the ground, and afterwards killed by pouring boiling water over them, or by dipping the sacks containing them into hot water, when the dead beetles are eaten greedily by pigs and poultry. But to be effective such collection must take place as soon as the beetles appear (to be in advance of the egg-laying), and it should be made simultaneously throughout the whole neighbourhood infested. Another way of killing them when in large numbers is to put them into a hermetically sealed wooden box with a small quantity of sulphide of carbon, and keep them there for some hours. (This will also kill book-worms, if infested books be similarly treated for thirty-six hours.) Farmers are quite as much concerned as foresters in annihilating this pest, and should therefore co-operate and collect all chafers found in their pasture-lands and orchards, or on field and hedgerow trees.

To exterminate the grubs is difficult, and can only be managed in nurseries, where their presence is soon shown by the withering of seedlings attacked. The grub can then usually be found on one of the nearest plants. It is only by digging and hunting each grub that the beds can be protected. The grubs can also be trapped with sods of turf, about 8 to 12 inches broad and 6 to 8 inches thick, laid, grassy side downwards, on the ground ; or heaps of turf humus, dung, &c., may also be employed. The grubs collect under these, and can then be gathered and destroyed. Or potatoes may be placed below the surface of the ground, and examined daily.

Where soil-preparation is necessary before sowing or planting, the grubs should be collected while the soil is being broken up, and here they can often be trapped in sods of turf laid grassy side downwards. The herding of pigs is then also of use. But in young plantations swine cannot be employed, as the grubs lie too deep in the ground to be reached without a good deal of snouting.

2 and 3. Equally abundant and just as destructive as the Cockchafer are the two smaller species, the **Summer-Chafer** (*Rhizotrogus solstitialis*) and the **Garden-Chafer or Bracken-clock** (*Phyllopertha horticola*), and all three have increased very much in Britain during the last ten years. Though they feed on almost any roots, those of grass and seedling trees are most liable to attack, young Oak and Pine often suffering severely.—These two smaller beetles are easy to distinguish from the larger Cockchafer, but the grubs are very similar when young, and difficult to identify, though they are smaller when full-grown. The habits of the grubs are very similar to those of the Cockchafer.

Appearance and *Life-history.*—The Summer-Chafer is about $\frac{3}{4}$ of an inch long, reddish-brown, and slightly hairy.—The Garden-Chafer varies from about $\frac{1}{4}$ to $\frac{1}{2}$ an inch long. The front part of the body is greenish with a metallic sheen, and the wing-cases are reddish-brown. The male beetle is very hairy.—These both appear in June and July, or about a month later than the Cockchafer ; and this is a point of importance with regard to collecting and destroying the beetles. The larval or grub stage varies from one to two years for the Summer-Chafer, and is only one year for the Garden-Chafer, while it is three years for the Cockchafer.

Prevention and Extermination are as for the common cockchafer.

4. Two other species of the same genus which only do slight damage are :—

The Horse-Chestnut Cockchafer (*Melolontha hippocastani*), which much resembles the Cockchafer in appearance, habits, and life-history, but occurs less frequently, and can easily be distinguished by its red thorax and its smaller size. It especially attacks the Horse-Chestnut.

The Fuller or Garden Beetle (*Polyphylla fullo*), the largest of the Cockchafer genus, which is found here and there in sandy tracts, and is easily recognisable by its brown wing-cases with white marbling.

D. Longicorn Beetles (*Cerambycidæ*).

The long-horned family of beetles is chiefly characterised by the antennæ being often several times as long as the body (hence the name). Some are large, and generally they have elongated strongly-built bodies and long legs. They are not very destructive in Britain, and chiefly attack Poplars and Willows. The beetles live on leaves and flowers, and are practically harmless; but the larvæ live in the wood, and are therefore destructive.

Appearance.—The *beetles* are long, have a round thorax (often with prickles at the sides), and somewhat flattened wing-cases considerably wider than the thorax at the base and tapering towards the apex. The abdomen has five segments. The long antennæ have usually eleven or more joints (the second always being the shortest), and taper in size towards the end. Legs long and slender, with 4-jointed tarsi, the third of which is bilobed. The *larvæ* are soft, whitish or whitish-yellow, and either cylindrical or slightly flattened, with a large head and strong horny upper-jaws. In place of feet they mostly have six small wart-like tubercles. The *pupæ* are spindle-shaped, and are easily recognisable from the long antennæ stretching backwards from the head. The beetle emerges from an oval exit-hole after boring obliquely upwards to the surface.

Life-history.—The beetles fly in summer and lay their eggs on the bark of trees, sometimes by means of an ovidepositor. When the larvæ hatch out they feed superficially at first, and then go deeper into the wood. Their borings are broad and shallow, but gradually enlarge as the larvæ increase in size; and they are full of the bore-dust.

Generation is usually biennial; but it varies, being simple and annual in some species, and multi-annual in others.

The longicorn larvæ live chiefly in the wood of broad-leaved trees, and mostly attack sickly or unsound stems, so that the damage they do is therefore not great; but they sometimes riddle sound stems with holes, and depreciate their value as timber.

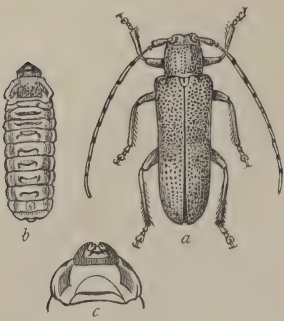
Only two species of *Cerambyx* are of any practical importance to the forester in Britain, namely :—

1. **The large Poplar Longicorn**, *Cerambyx* (*Saperda*) *carcharias*, the larvæ of which chiefly infest Poplars and Willows up to about 20 years old. This is the commonest of the British longicorns (Fig. 157).

Appearance.—The beetle is about 1 to 1¼ inch long (with antennæ of about same length), clay-grey to yellowish brown, and with thorax and wing-cases covered with shining black spots. The round, legless, yellowish-white larvæ are about 1½ inch long when full-grown, and have small heads with brown jaws and also brown plates on scales from the third to the tenth segment, while the neck-shield is very conspicuous (Fig. 157 *c*; compare also *Sesia apiformis*, p. 121).

Life-history.—The beetle flies from June to August, being usually late in Britain. The female lays her eggs mostly on Poplars in bark-fissures near the ground, and about four weeks later the larvæ hatch out and bore into the sapwood. Here they hibernate, boring deeper in the second year, and again hibernating as larvæ. During the following May or June pupation takes place, head downwards, in a pupal chamber formed by erecting a wall of bore-dust. After a pupal rest of four weeks or more, the beetles emerge from June to August for pairing and reproduction. The generation is therefore biennial, the larvæ feeding in the wood for two years.

Fig. 157.



Large Poplar Longicorn.

a. Beetle (natural size).
b. Larva (natural size).
c. Head of larva (magnified).

Prevention and Extermination.—Saplings infested should be cut and burned before June. From June to August beetles may be shaken down from the trees, collected, and destroyed. The grubs may be extracted with bent wire; and the bore-holes may be syringed with paraffin; or cotton-wool, soaked in a strong solution of ammonia, may be rammed in and the bore-hole plugged up with putty; or the stems of young saplings, &c., in infested areas may be smeared with patent tar.

2. **The small Poplar Longicorn,** *Cerambyx (Saperda) populnea*, is a common insect in Central and Southern England, where it often infests the branches of young Aspen and other Poplars, without, however, doing very much harm to them.

Appearance.—The beetle is only about ½ an inch long, and black, with yellow or yellowish-grey hairs. The wing-cases have a central line and a broad stripe, with three or four downy spots on each side. The antennæ are blue and black, with white rings. The larvæ are yellow.

Life-history.—The beetles fly in May and June, and the females lay their eggs in bark-fissures on young 2- to 6-year-old Aspen saplings or suckers, also on other Poplars, and less frequently on Willows. The larvæ hatch out about four weeks later, and at first feed in the sapwood, but during the second year bore upwards into the pith, and cause the formation of spindle-shaped swollen nodes, which are very noticeable on the slender stems of Poplars, but do not form on Willows. After feeding for about two years, pupation takes place, and in May or June the beetle emerges by a circular hole bored in the middle of the swollen node. The generation is therefore also biennial.

Prevention and Extermination. — Stems infested should be coppiced and burned, and the beetles should be shaken down in May and June, and destroyed.

The larvæ of another injurious species, *Rhagium bifasciatum*, is not uncommon in gate-posts and palings.

E. **Saw-horn Beetles** (*Buprestidæ*).—These are mostly long, thin, bright-coloured beetles with metallic lustre, compressed bodies, and short weak legs. It is only during their larval stage that they damage woodland-trees. They are not common in Britain, and none of them does much damage in our woods.

The *beetles* have usually hard wing-cases, tapering towards their upper ends, and short, 11-jointed, serrated antennæ (hence the name). The legless *larvæ* are white, soft, and elongated, and are either cylindrical or flat. They are somewhat like longicorn larvæ, but can be distinguished from these by their first segment being strongly developed, and often also by two horny tail-tips pointing outwards. They bore sinuous irregular galleries in the cambium and the sapwood, which broaden as the larvæ increase in size, and which are filled with bore-dust. Pupation takes place in a cocoon made of bore-dust and wood-chips in the sapwood at the end. On emerging from the pupal chamber, the beetle issues from the stem through a hole like a half-moon, flat on the upper side.

Generation.—Biennial.

The Green Beech Saw-horn Beetle, *Buprestis* (*Agrilus*) *viridis*, is the only species of any importance to the forester.

Appearance and Life-history.—It is about ¼ of an inch long, and usually of blackish ground-colour, with a lustrous metallic blue, green, or olive sheen. It flies on bright sunny days in June and July. The female lays her eggs, either singly or in small clusters of 2 or 3, on the bark near the base of young Beech or Oak; and when the larvæ hatch out about four to six weeks later, they feed on the cambium, and either kill the saplings or make them sickly and cankered-like. Strong Beech transplants are sometimes attacked while they are in rather a sickly condition, before establishing themselves after being planted.

The larvæ hibernate inside the stems for two winters, then pupate in the cambium or the sapwood in the following April or May, and emerge from a half-moon hole (◡) with flat side above during June and July. The generation is therefore biennial.

Prevention and Extermination.—Plants attacked may be pulled up and burned before the beetles emerge in June.

F. **Leaf-Beetles** (*Chrysomelidæ*).—This class of beetles, common all over Britain, and especially in the warmer parts, feeds on the foliage of many broad-leaved trees, but seldom does much damage in woodlands, although one or two species can be rather destructive in Osier-beds. Both beetles and larvæ feed on foliage, gnawing away the soft tissues between the midrib and the veins, so that only the leaf-skeleton is left. Their work is thus very easily distinguished from that of other insects. Their attacks are usually confined to soft woods—Poplars, Willows, and Alders. The Osiers most injured are those belonging to the two species *Salix purpurea* and *S. pentandra*, and their varieties.

The *beetles* are usually small, and are short, squat, convex, strongly-arched, and oval or semi-globular in shape. They are often bright-coloured, and many have a metallic sheen; abdomen with 5 segments; antennæ short, bead-like, and 11-jointed; legs strong and adapted for springing. *Larvæ* short, flat, 6-legged, and usually black or variegated. *Pupæ* thickish, pear-shaped, often depending tail-end-up from leaves. *Generation* simple, annual.

1. **The Red Poplar-leaf Beetle**, *Chrysomela* (*Lina*) *populi*, is injurious both as beetle and larva, feeding on Poplar, Aspen, and Willow foliage, and often proving somewhat destructive in seriously retarding the development of the withes in Osier-beds.

Appearance.—The beetle is barely ½ an inch long, with a blackish-blue body, and brick-red wing-cases, tipped with black at their upper ends; antennæ short, compressed, and thickening considerably towards their ends. The 6-footed larvæ are dirty-white, with numerous black spots, and two white lateral processes on the second and third segments. The yellowish-brown pupa is marked with regular black spots and bands, and is somewhat pear-shaped, tapering off towards the tail-end. The pupæ hang head-downwards, and attached to leaves by their sharp-pointed tail-end.

Life-history.—The beetles fly in May and June, and the female lays from 100 to 150 eggs in clusters of 10 to 12 on the foliage of young saplings, stool-shoots, and suckers. The larvæ hatch out about four weeks later, feed for about other four weeks, then pupate on leaves, and emerge as beetles about the end of August. In October they hibernate under moss or dead leaves, then reappear and pair in the following May. The generation is therefore simple and annual. In Central Europe, however, it often has a double generation.

Prevention and Extermination.—The beetles may be shaken or rapped down from trees while pairing in May or June, or else from August till October, between the time of emerging and of hibernating. Spraying the Osier-shoots and the soil beneath them with insecticides is often effective (see pp. 106, 124, and 132).

2. **The Aspen-leaf Beetle**, *Chrysomela* (*Lina*) *tremulæ*, is very much like *C. populi* in appearance and life-history, except that it is only about ⅓ of an inch long, and has no black tips at the top-ends of the wing-cases. It is also usually somewhat more destructive than the larger insect, because it attacks the shoots while still young and soft. The larvæ and pupæ are hardly distinguishable from those of *C. populi*.

3. **The Willow** or **Osier Beetle** (*Phratora vitellinæ*) occasionally does a good deal of damage by defoliating Osiers.

Appearance.—The beetle is about $\frac{1}{6}$ to $\frac{1}{5}$ of an inch long, bronze, green, or coppery in colour, and oblongly-oval in shape; the wing-cases have rows of fine punctures.

Life-history.—The beetles fly in late April, May, and June, pair, and lay their large oblong eggs in clusters of about 10 or 12 on the lower side of osier-Willows, tree-Willows, and Poplars. On hatching out about four weeks later, the larvæ skeletonise the leaves, destroying both the spring and afterwards the summer flush of foliage before descending to the ground to pupate. The beetles emerge in August, feed for some time, then hibernate either in the ground or in bark-fissures, or in almost any other kind of hiding-place. The generation is usually single, though sometimes the early-comers in August pair and produce a second brood before the time for hibernation arrives.

Prevention and Extermination.—As for *Chrysomela populi.*

4. **The Blue Alder-leaf Beetle**, *Chrysomela* (*Agalastica*) *alni*, is a small violet or steel-blue beetle, about ¼ of an inch long, with black antennæ, thorax, and legs. The 6-footed larva is less than ½ an inch long, and blackish with greenish lustre, rather hairy, and with transverse dorsal marks across the abdominal segments.

The beetles fly in May and June, and the larvæ hatch out in June. Both beetles and larvæ feed on Alder foliage, and are sometimes troublesome in nursery-beds. The beetles should be collected during May and June, and again after August.

5 and 6. **The common Earth-flea** (*Haltica oleracea*) and **The springing Oak-leaf Beetle** (*Haltica erucæ*) are minute insects only about $\frac{1}{8}$ to $\frac{1}{5}$ of an inch long, and bluish-green, with finely punctured wing-cases. They are sometimes destructive in gardens and nurseries, and can best be exterminated by sprinkling the beds with ashes or lime, or watering them with a weak solution of carbolic acid or a decoction of wormwood.

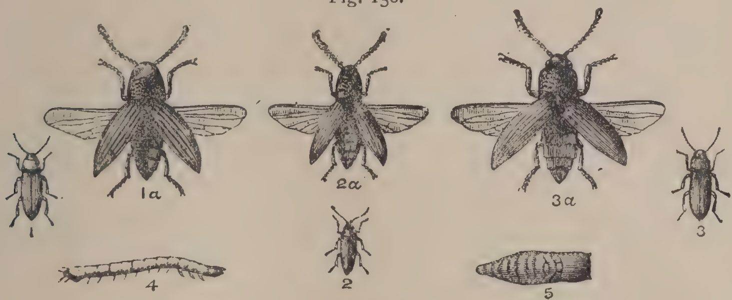
G. **Click-Beetles or Skip-Jacks** (*Elateridæ*).—These beetles derive their common names from the peculiarities that if one end of the beetle be held firmly, it bends its body with a clicking sound, and that if laid on its back, it rights itself by springing up in the air with a click. The beetles eat acorns, beech-nuts, and seeds of other broad-leaved and of coniferous trees, and may be destructive to young shoots; but the larvæ, known as "**wire-worms**," are very destructive to the roots of plants in nurseries. As they are omnivorous, and remain for at least three years as larvæ, it is difficult to exterminate them when once they have obtained possession of nursery-beds. The attacks of wire-worms in nurseries are worst during a cold wet May, and are least to be feared during warm spring weather when the young plants grow vigorously. Wire-worms are far more injurious to the farmer than to the forester. They feed on roots and young stems at all times of the year, except during very hard frost, when they burrow deep into the ground.

The *beetles* are long, narrow, and hard, very much like the *Buprestidæ*, but mostly without their metallic sheen; abdomen with five segments; antennæ 11-jointed, filiform in female, serrate or pectinate in male; legs short and weak, tarsi with five joints. *Larvæ* ("wire-worms") 6-legged, long, narrow, and brownish-yellow, with flat, brown-black, horny heads, and a prominent tubercle on the terminal segment. They live in or on the ground for three years or longer. *Pupæ* in small earthy cocoons deep in the ground. *Generation* from three to five years, probably mainly according to the amount of food available for the larvæ.

1. **The Striped Click-Beetle** (*Agriotes lineatus*) is the commonest and the most destructive species (Fig. 158, 1 and 1*a*).

Appearance.—The beetle is ⅜ of an inch long, with a wing-expanse of slightly over ½ an inch; thorax tawny; wing-cases brown, with yellowish-

Fig. 158.



Wire-worms.

1 and 1*a*. *Agriotes lineatus.*
2 and 2*a*. *Agriotes sputator.* (Natural size and magnified.)
3 and 3*a*. *Agriotes obscurus.*
4. *Wire-worm*, larva of *Agriotes lineatus.* (Natural size.)
5. Pupa.

brown lines; antennæ reddish-yellow; legs brown. The larva, or "wire-worm," is from ⅝ to ⅞ of an inch long, very shiny, and yellow (but becoming almost chestnut when dead), with a few hairs on its body, three pairs of 4-jointed legs on the first three segments, and a swelling on the lower surface of the terminal segment. It has strong jaws adapted for biting through roots.

Life-history.—The beetles are found under stones, in grass-roots, on grasses, flowers, and trees, in hedges, &c. They fly in July and August, and (like the cockchafer) lay eggs in the earth, in nurseries, and wherever the soil has been turned up and loosened. Some of the beetles hibernate in sheltered places, and pair in the following May and June. The wire-worms which hatch out live in the earth, near the roots of the plants on which they feed.

After feeding for three to four years, according to circumstances, the larva goes down deep into the earth and pupates in the month of July in a small oval earthy cocoon, from which the beetle emerges two or three weeks later.

Prevention and Extermination.—Once the ground is infested with wire-worms little can be done to check their attacks for the time being; but dressings of nitrate of soda may help to prevent eggs being laid in nursery-beds. In nurseries the beetles may be trapped by laying small heaps of lucerne, clover, or sainfoin on the ground, and covering them with tiles or pieces of board during May and June, as long as beetles are noticeable. They fly to these heaps, shelter beneath the green material (particularly if the ground is clean), and lay their eggs there. These traps must be examined as often as possible, to collect the beetles (up to 100 have been taken from one trap in a week), while the green stuff should be destroyed every ten days, and the ground beneath well beaten down to squash any eggs left there. Boards or tiles placed beneath the bait prevent eggs from reaching the ground.

The larvæ can also often be trapped by laying down pieces of beetroot under the earth in nurseries, marking the spot with a peg, and examining them every few days, and killing the wire-worms found buried in the baits.

Leaf-mould and manure-heaps should never be allowed to have weeds growing on them, but should be covered with a coating of gas-lime to prevent the beetles laying their eggs there. Plovers especially, also rooks, starlings, and jackdaws, assist greatly in destroying wire-worms.

It is desirable to examine the ground selected for the nursery, and to reject the plot if it appears badly infested, or to cleanse it thoroughly before planting. As the acreage required is small, there should be no difficulty in doing this by methods known and practised in agriculture, such as paring off and burning two inches of the top-soil early in autumn, or dressing with gas-lime, chloride of lime, or ammoniacal waste, and leaving it fallow till the effect of the poison has worn off. Fallow land kept clean and free from weeds during the period of egg-laying in June will have comparatively few wire-worms, but in the absence of better food these probably feed on humus, especially when young.

If seedlings are actually attacked, handpicking is a good remedy when facilitated by the use of potatoes, carrots, or sliced mangold, laid on the ground as a bait and regularly visited. A dressing of rape-cake or mustard-cake, popular in hop-growing, may be tried, but the value of it under these circumstances remains to be proved. Serious injury from wire-worm is unlikely to extend beyond the first year of growth.—(Blandford.)

For further details, see also Board of Agriculture Leaflet No. 10 (*Wire-worms*).

2. *Agriotes sputator* and *A. obscurus*, the former somewhat smaller and the latter rather thicker and of stouter build than *A. lineatus*, are two other click-beetles whose appearance and habits are much the same as above described. The beetles feed on acorns and other tree-seeds, while the wire-worm larvæ infest nurseries and young plantations (Fig. 158, 2, 2*a*; 3, 3*a*).

II. **Moths** and **Butterflies** (*Lepidoptera*).[1]

This order of "scale-winged" insects derives its name from the ordinary membrane of their wings being covered with a number of minute scales, set over-

[1] The order *Lepidoptera* is divided into the two great classes of **Moths** and **Butterflies**, which may thus easily be distinguished :—

Class.	Antennæ.	Wings while at rest.	Habits.
1. Moths (*Heterocera*)	*Variable* in form (filiform, pectinate, brush-like, &c.	Usually expanded and somewhat apart	Usually more or less nocturnal.
2. Butterflies (*Rhopalocera*)	Always ending in a *club-like* knob	Usually elevated and close together	Diurnal.

Very few of the Butterflies are destructive to forest trees, and that only slightly. One such is *the large Tortoiseshell Butterfly* (*Vanessa polychloros*), with a wing-span of 2¼ to 2½ in. It is of a yellowish-red above with dark-brown edges; the fore-wings are lapping like the tiles on a house-top. These scales are generally of brilliant colour.

Large numbers of moths do great damage to woodland trees; but mention can here only be made of the more important kinds which are destructive in the woods and plantations throughout Great Britain and Ireland.

A. Spinners (*Bombycidæ*).

This family includes some of the most injurious moths, whose voracious caterpillars are sometimes enormously destructive to foliage in the coniferous forests of Central Europe.—*Moths* usually nocturnal species, with large wings and long thick bodies, mostly densely haired, and female generally larger than male; antennæ short, pectinate in female, doubly pectinate in male. *Eggs* often laid in clusters, and covered with fluff from the tail of the female. *Caterpillars* 16-legged, usually hairy. *Pupæ* short and thick, enclosed in a silky cocoon, into which the larval hairs are often spun. *Generation* annual.

1. **The Hop-Dog, Pale Tussock Moth** or **Beech Spinner,** *Bombyx* (*Orgyia, Dasychira*) *pudibunda.*—The Hop-dog or Beech-moth is a common insect in England, and may occasionally be found on most kinds of broad-leaved trees, but it mainly attacks the Beech, and is its chief insect enemy. It is often also destructive in the hop-gardens of Southern England. Its attacks are mainly confined to old Beech-woods growing on poor soil, and it usually only migrates to pole-woods and younger crops after the old woods have been defoliated. As the caterpillars feed mostly during late summer, after the young buds for the next year's flush of foliage have already been formed, the damage is less than would otherwise be the case; and though the generation is simple and annual, an attack seldom extends beyond two consecutive years.

Appearance.—The wings of the female span 2 to nearly 2½ inches, while the somewhat smaller male is distinguished by yellowish-brown feathery antennæ. The fore-wings and front part of body are reddish- or greyish-white, with two or three dark, waved, transverse stripes; hind-wings and lower part of the body are lighter, with a faint, broad, greyish, transverse band.

The 16-legged *caterpillar* is, when full grown, about 1½ inch long. It is at first greenish-yellow, becoming brownish or reddish. It is easily known by four thick, yellowish- or brownish-grey tufts of bristles on the fourth, fifth, sixth, and seventh segments, between which are velvety black bands, and by a long rose-red or ruddy-brown tuft of hair on the second last segment.

The dark brown to greyish-yellow hairy *pupa* rests in a cocoon spun with the hairs of the larva.

Life-history.—The moth flies late in May and early in June. The female lays about 100 eggs or more on the smooth bark of poles or trees, and usually within about 3 to 10 feet off the ground. The eggs are at first greyish-green, darkening to a brownish- or bluish-grey. About three weeks later, in June or July, the young caterpillars hatch out, eat their egg-shells, and cluster in colonies for a few days before scattering and ascending to feed on the foliage. They only gnaw the

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spotted with black, three spots being on the yellow ground; the hind-wings have a large black spot on the upper edge, and a blue moon-spot near the fringe. The greyish-blue caterpillar is about 1¾ in. long, with yellow dorsal and side stripes and rusty yellow prickles. The pupa is angular, reddish-grey, and with several mother-of-pearl spots. After hibernation the female in spring lays clusters of blackish-grey eggs on the twigs of fruit-trees, but also on Elm, Willow, and Aspen. The caterpillars hatch out in May and June, live in colonies in nests, and feed on the foliage till the end of June, when they scatter and pupate.

leaves slightly at first, but with growing strength devour more of them, and often gnaw them completely through near the petiole, so that the ground is often strewn with parts of leaves. Towards the end of September or early in October they come down from the trees to form cocoons in moss or under dead leaves, herbage, &c., where they hibernate as pupæ.

Preventive and Exterminative Measures.—Insectivorous birds (crows, cuckoos, thrushes, finches, tomtits, &c.) and predatory and parasitic insects (*Carabidæ* and *Ichneumonidæ* chiefly) prey on the caterpillars; but the sudden cessation of attacks is mainly due to a fungous disease (*Isaria farinosa*) infecting the caterpillars. The latter are also very sensitive to sudden changes to cold and wet weather, although hardy as regards snow and cold in winter. It is not of much practical use to try and collect the pupæ or kill the caterpillars when descending to pupate on the ground. The egg-clusters laid on the smooth Beech-stems within about 10 feet of the ground can, however, easily be collected and crushed; or the eggs and clusters of tiny caterpillars can be destroyed by a daub of patent tar. Grease-banding the stems about 12 feet with narrow rings will prevent most of the caterpillars from getting up to the crown to feed on the foliage, and will also hinder those hatched out from eggs laid above that from being able to descend for pupation on the ground.

Two other Spinners, the Brown-tail Moth and the Lackey Moth, of the tribe called "Tent Caterpillars," from their forming tent-like silky nests while the young larvæ still live in clusters or colonies, also attack Oak, Elm, Hawthorn, and other woodland trees and shrubs, though the chief damage they do is to Apple-, Plum-, and Pear-trees in orchards throughout Central and Southern England.

2. **The Brown-tail Moth**, *Bombyx* (*Liparis*, *Porthesia*) *chrysorrhœa*, is a shining white moth having a wing-span of about 1¼ to 1½ in. In the female the abdomen is mostly brown, with a thick red-brown woolly tuft near the end, while the male is blackish-brown with a red-brown woolly tuft at the end. The 16-footed *caterpillar* is not quite 1½ in. long. It is dark grey-brown above, with two irregular red stripes along the sides, and covered with tufts of yellowish-brown hairs; it is grey beneath, with yellow marbling. The hairy *pupa* is dark-brown, and has a pointed tail.

Life-history.—The moths fly late in June and early in July. The female lays about 200 to 300 brownish-yellow eggs, on the lower surface of the leaves of Oak chiefly, but also other kinds of broad-leaved trees, and covers them with spongy wool from her thick tail. The caterpillars hatch out in August, and form "tents" or colony-nests round the young shoots and leaves. In autumn they strengthen these and form tough nests of about the size of a fist, where they hibernate. In spring they again feed on the foliage, returning to their "tents" at night-time or during bad weather; but about the middle of May they abandon these and wander about freely to feed. Early in June they pupate for about three to four weeks in a greyish-brown transparent nest made between the leaves. They have therefore a simple annual generation.

Preventive and Exterminative Measures.—In orchards the winter nests can easily be destroyed, but this is not practicable in the crowns of high Oaks, &c.

This pest can be annihilated in orchards by spraying with Paris-green wash or London-purple (½ lb. to 100 gallons water, then 1 lb. lime thoroughly mixed and well stirred), and arsenate of lead (see Board of Agriculture Leaflet No. 69, on *Tent Caterpillars—the Lackey Moth and the Brown-tail Moth*).

3. **The Lackey Moth**, *Bombyx* (*Gastropacha*, *Clisiocampa*) *neustria.*—This moth has a wing-span of about 1¼ to 1½ inch. Its body and fore-wings are yellow- or reddish-brown, with a broad, light-edged transverse band; the hind-wings are somewhat lighter, and crossed in the middle by a faint darker band. The *caterpillar* is slightly haired, and about 1¾ inch when full-grown. It is marked with alternate stripes of light blue, reddish-brown, and white (like a lackey's waistcoat, hence its name); its head is pale-blue, with two black spots.

Life-history.—The moths fly, towards evening, in July and August. The female lays 300 to 400 brownish-grey eggs in a close spiral band round twigs and small branches, chiefly of fruit-trees and Oaks, but also on Elm, Hornbeam, Poplars, and Willows. The young caterpillars hatch out towards the end of April or early in May, and at once begin to feed on buds and leaves. They live in communities inside "tents" or nests until full-grown. About the end of June they break up their colonies, and pupate singly between leaves or in bark-fissures, by attaching themselves to these with a few loosely spun threads.

Protective and Exterminative Measures.—As for the Brown-tail Moth.

4. **The Black Arches, "Nun,"** or **Spruce Moth,** *Bombyx* (*Liparis*) *monacha.*—In Central Europe this is one of the most destructive pests in Spruce and Pine woods, but in Britain damage to any considerable extent has never yet been recorded. It is usually only to be found on broad-leaved trees (especially Oak) in the warmer parts of England.

Appearance.—When extended, the wings of the female *moth* have a span of about 1½ to 2½ inches. The smaller male is easily distinguishable by its double-combed antennæ. In both the outer wings and the upper part of the body the ground-colour is white, marked with numerous deeply-arched, zigzag, brownish-black or black stripes (hence the name "Nun," from the plain black-and-white colouring); the lower wings are brown-grey, edged with black spots. The abdomen, though sometimes blackish, is mostly rose-colour, with black transverse bands; but melanic (black) sports are not uncommon.

The *caterpillar*, about 1½ inch long when full-grown, is whitish- to reddish-grey on the upper side and dirty-green on the lower. It has a broad grey dorsal stripe, commencing from a black heart-shaped patch on the second segment of the body, but narrowing and interrupted by a broad light patch on the seventh and eighth segments. Each segment has six small tubercular hairy warts, of which the two first, on the first segment, rise above the others, whilst those on the other segments, to the right and left of the dorsal stripe, are blue. These form a constant characteristic of this caterpillar, however much it may vary in general colour.

The densely-haired *pupa*, at first greenish, then turning a bronzy-brown, lies in a flimsy cocoon, formed of a few dirty yellow threads spun between bark-fissures on the lower part of the stem, among foliage on branches and twigs, or on underwood and brushwood.

Life-history.—The moths fly late in July or early in August. In the daytime especially during dull weather, they swarm low down on the stem, whilst during bright sunshine they are restless, the males in particular keeping flitting about. But, like most other moths, their habit is mainly nocturnal.

The female moth lays her eggs on or beneath bark-scales, or under some such protection as lichens. The eggs are at first of a bronzy rose-red, but afterwards turn greyish-brown with mother-of-pearl lustre. When the insect is not in large numbers, the eggs are usually laid on the lower part of the stem within 15 feet of the ground; but during great devastations (such as that which occurred in the Spruce tracts of Bavaria and Western Austria in 1889-91, the fight against which cost £100,000, and the sacrifice of many millions of trees) they cover the whole of the stems from top to bottom. One female can lay from 150 to 170 ova, mostly in clusters of 20 to 50, though sometimes all are deposited in one patch.

Although the larva becomes fully formed in four weeks, yet it hibernates within the shell, and only hatches out in the following April or May. The young caterpillars remain for several days in clusters, the blackish caterpillars often showing up plainly against the brown Spruce bark. After about four to six days these colonies scatter, and the young caterpillars ascend to feed on the foliage. They first attack the lower branches, then gradually work upwards, clearing the branches and twigs of needles. Spruce foliage they devour entirely, but on the Pine they bite through the needle about half-way up, and eat only the remaining lower part. When they attack broad-leaved trees, they gnaw through the mid-rib, so that the top part of the leaf falls to the ground, which is often covered with the top parts of needles and leaves during bad attacks.

The caterpillars moult their skin four times, and until about half-grown they spin gossamer threads to let themselves down to the ground. They feed till late in June or early in July, when they descend in masses from the stems to pupate under bark-scales, or on the undergrowth, &c.

Preventive and Exterminative Measures.—One can hardly prevent this moth from appearing now and again. But as soon as its presence is discovered annihilative measures are now in Germany promptly taken to exterminate the brood and obviate serious damage. Constant careful inspection of the woods should discover the presence of the characteristic fragments of bitten leaves and needles scattered about the ground, while the gradual thinning of the foliage, and later on the moths themselves, will show when exterminative measures are called for (see Figs. 137 to 141, pp. 67-70).

The eggs may be collected from August till April, if merely laid near the base of the stem, when the egg-clusters can be scraped off with a knife into a bag. But many egg-clusters are sure to get overlooked (especially on the thick-barked Pine), so that this method can at best only prove partially effective. It is perhaps easier to crush the little colonies of caterpillars whilst collected together for four to six days just after hatching out. While thus clustered near the foot of the stem, they are easily killed with a leather flap tied to the end of a stick; but even this is also at best only partially effective.

There are few natural enemies of this moth, and especially of the hairy caterpillar. Many kinds of birds (tomtits, &c.) feed on the eggs in winter, and useful insects (*Ichneumonidæ* and *Tachininæ*) prey on the caterpillars. This moth is comparatively insensible to changeable weather and climatic influences. Its ravages usually cease after the third year, when the caterpillars become degenerate and die off in large numbers.

During the Bavarian and Western Austrian calamity, after various remedies had been tried during 1889-90 (including experiments made with exhaustors working close behind strong electric lights), a young forester named Mayer suggested trying grease-banding with rings of patent tar round all the stems in a young 12- to 15-year-old Spruce plantation cleared of all lower branches for this purpose. This proving successful, it was continued on a larger scale in 1891, and all stems, from the thickness of a finger upwards, were ringed with patent tar wherever it was known that the moth was present. Millions of stems were thus ringed at breast-height, as this is much less expensive than, and quite as effective as, ringing at 15 to 18 feet above ground, because the success of this measure is due to the fact that nearly all the caterpillars spin down on threads from the tree-crowns to the ground before they lose this spinning-power, and when they reascend the trunks, they are prevented by the viscous band of tar, whose smell or taste or touch they abhor; and being thus unable to ascend, they starve and die of hunger below the rings.

Other Spinner-moths, all of them also of minor importance in British woodlands, include the following three species:—

5. **The Common Vapourer Moth**, *Bombyx* (*Orgyia*) *antiqua*, with a wing-span of 1 to 1¼ inch. The male is rusty-brown, with two dark transverse bands and a white moon-spot on each fore-wing; the female is yellowish-grey, with wings aborted into white stumps. The caterpillar is ashy-grey with yellowish hairs, a velvety-black back and carmine warts; it has two long black tufts of hair behind its head, other two projecting at right angles to the sides on the fifth segment, and one standing erect on the eleventh segment. It flies in August and September, and lays from 150 to 300 eggs on the nest from which it has emerged. The larvæ occasionally hatch out in autumn, but mostly not until spring. It chiefly attacks buds, foliage, and young fruit in orchards, but is also found on Willow, Mountain-Ash, Spruce, and Scots Pine. It pupates in June or July, the pupation lasting about six weeks.

6. **The Satin Moth**, *Bombyx* (*Liparis*, *Leucoma*) *salicis*, has a wing-span of 2 to nearly 2½ inches. The wings are white and lustrous, and the legs are ringed with black and white. The caterpillar is 1¾ inch long, and grey, with yellowish-white dorsal spots, small red warts, and light-brown hairs. The female lays 150 to 200 eggs in June and July on the bark or leaves of Poplars and Willows, and covers them with a white membrane. The *caterpillars* sometimes hatch out in autumn, but mostly not until the following spring, when they feed on the foliage until they pupate about the end of May loosely attached to leaves or twigs.

7. **The Gold-tail Moth,** *Bombyx* (*Liparis, Porthesia*) *auriflua*, lives chiefly on fruit-trees, but also on Oak, Beech, Elm, Birch, Lime, Willows, and various shrubs. It has a wing-span of 1½ to 1¾ inch, and much resembles the Brown-tail Moth; but its body is of a lighter golden colour, and the inside edge of the wings has a longer fringe. In June and July it lays 150 to 200 eggs in clusters on foliage, and covers them with golden-yellow fluff from its tail. The *caterpillars* hatch out in August. They are black, with blackish-grey hairs, two vermilion dorsal lines, and patches of white hairs. They feed on leaves, buds, flowers, and young fruit, hibernate on the ground or in bark-fissures near the ground, and recommence feeding in the following spring till they pupate, about the end of May or in June, in rolled-up leaves or on twigs. The *pupa* is blackish-brown, and enclosed in a thin whitish-brown cocoon.—Grease-banding with patent tar in early spring is recommended.

B. Owlet-Moths or Night-Moths (*Noctuidæ*).

Moths with narrow wings, the fore-pair usually characteristically marked with transverse lines and spots; body thick and generally downy; antennæ long, fine, and fringed, but sometimes pectinate in male. They seldom fly during the day, but mostly in the twilight and the dark. *Eggs* round and dull in colour. *Caterpillars* (destructive species in woodlands) with 16 legs, and seldom hairy. *Pupæ* usually dark in colour, thin, and spindle-shaped; pupation either without a cocoon, or else with one formed of a few threads. *Generation* annual.

1. **The Pine Beauty or Owlet-Moth,** *Noctua* (*Trachea, Panolis*) *piniperda.*—The Pine Owlet-moth or Pine Beauty, common throughout Britain, lives mostly on Pines (rarely on Spruce) and especially in pole-woods of 20 to 40 years of age. But when its increase is favoured by warm dry weather it is very prolific, and may become a very serious pest, doing considerable damage over large areas, and sometimes totally destroying Pine pole-plantations.

Appearance.—The male and female *moths* are about the same size and are somewhat similarly marked; but the antennæ of the male are more feathered, and the abdomen of the female is rather thicker. The fore-wings and upper part of body are brown-red spotted with white or marbled with grey, and the large lower spot on each wing forms a crescent pointing downwards when the moth is at rest; the hind-wings and abdomen are of a dark-grey brown, the wings having a lighter edge. The moth is bluish-red beneath, merging into blackish-grey near the base of the fore-wings, and into a black point on the hind-wings. Melanic and other sports are fairly common. The wing-span is about 1¾ inches.

The 16-legged *caterpillar* is fully 1½ inch long when full-grown. It is yellowish-green, with three to five whitish longitudinal stripes, and a yellow or orange stripe on each side just above the spiracles and the legs; and it has very few hairs Its head varies from light-brown to dark. As the two first abdominal legs are malformed, it moves somewhat like a span-worm, and while young the caterpillar can also spin gossamer threads freely.

The *pupa* is from ½ to about ⅔ of an inch long, greenish at first, but afterwards turning dark-brown, and with two hooked processes at its tail-end.

Life-history.—The moth flies from about the end of March or early in April until the beginning of May. After pairing at night, high up in the trees, the female lays from 30 to 70 round green eggs, for the most part singly, on the needles of Scots Pine-poles and older trees (less frequently on Spruce and Weymouth Pine), pole-woods of 20 to 40 years of age being chiefly selected for oviposition. When the caterpillars hatch out in May, they at once begin to gnaw the sides of the needles, but as they grow and become stronger, they eat the whole of the needle right down to the sheath. Towards the end of July or early in August, the caterpillars descend from the trees and pupate under moss and dead foliage, or in loose earth and stump-holes, or on the ground, scattering themselves over the whole area attacked. They hibernate as pupæ and emerge as moths in the following spring, the pupal rest extending over the exceptionally long period of about eight months.

Preventive and Exterminative Measures.—The Pine Beauty has many natural enemies, which devour the almost hairless caterpillar and the pupæ lying unprotected on the ground for about eight months. These include all insectivorous birds, predatory insects (*Carabidæ*), flies (*Tachininæ*), and ichneumon-flies (*Ichneumonidæ*), also swine, hedgehog, and mice. Raw, damp, cold weather often kills the caterpillars quickly. Fungous disease (due to species of *Empusa*) also soon break out epidemically among them and terminate their attacks.

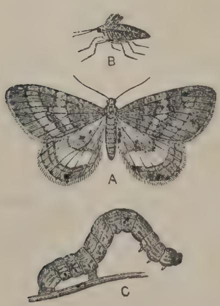
When pole-woods are infested, the caterpillars can easily be shaken off the young poles; or if the stems are too large for that, they can be tapped with a padded mallet or axe-head. They can also often be collected and killed in large numbers when they have finished feeding on the foliage and come down from the trees to pupate, because they often cluster together at the foot of the tree before hibernating as pupæ. Herding swine in the woods is also useful, because they hunt and devour the pupæ. Digging a trench round a plantation attacked is not of much use, as the caterpillars are not migratory.

C. Loopers or Span-Worms (*Geometridæ*).

Moths with slim bodies; usually fly in twilight or dark; wings large and broad; antennæ filiform or silky and brush-like, and sometimes pectinate in male. *Caterpillars* with 10 (sometimes 12) feet, bare or only slightly haired, and progressing with an arched or "loop-like" movement (whence their name). *Pupæ* long, brown, with a short pointed tail; pupation generally on the ground or under moss, leaves, &c., and not enclosed in any cocoon. *Generation* annual.

1. **The Winter Moth or Winter Span-worm**, *Geometra* (*Cheimatobia*) *brumata.*—This moth, common throughout England, is often very injurious to orchard trees (and especially to Apple-, Pear-, and Plum-trees), but also attacks most kinds of broad-leaved trees, being oftenest found on Oak, Elm, Hornbeam, and Lime (Fig. 159).

Fig. 159.



Winter Moth (*natural size*).
A. Male. B. Female. C. Caterpillar.

Appearance.—The male *moth* has a wing-span of about 1 to 1¼ inch, with fore-wings of a reddish- or yellowish-grey or grey-brown, marked with dark wavy transverse lines; the hind-wings are lighter, and marked with a faint dark stripe. The female is about ⅓ of an inch long, greyish-brown, with white scales, long antennæ and legs, and only abortive rudimentary wings, so that it cannot fly.

The 10-footed *caterpillar* feeds on foliage till full-grown. Grey at first, it changes after the first moult of the skin to yellowish-green, with a green head and a pale dorsal stripe; but later on, when full-grown, it is about 1 inch long and green with a dark dorsal stripe, three narrow white lines along each side, and a brown head.

The *pupa* is light-brown, with two hook-like processes at the tail-end. It pupates in a very loose flimsy cocoon.

Life-history.—The moth flies from October till December (hence its name), when the males flit about towards dusk in search of the females, crawling up and down the trunks of the trees. After pairing the female lays from 200 to 300 eggs (greenish at first and reddish later on), either singly or in very small clusters, on buds, leaf-scars, and twig-points in the crowns of broad-leaved trees.

The caterpillars hatch out in April and May, and feed on leaf- and flowering-buds before attacking the foliage, which they twist in much the same way as leaf-roller moths. Early in June they spin themselves down by gossamer threads to the ground, and pupate in sheltered places or in smooth holes formed about 2 to 3 in. below the ground. The moths mostly emerge in autumn (simple annual generation), though stragglers often hibernate as pupæ and only appear in the following spring.

Preventive and Exterminative Measures, which are only really practicable in orchards, consist of spraying with poisonous washes (see Brown-tail Moth) or grease-banding with patent tar, or strips of stiff paper can be smeared with the viscous tar or with cart-grease and tied firmly round the stems (renewed in spring, if necessary) to prevent the abortive-wing females from crawling up the stems to the tree-crowns. The soil in orchards may also be dug to bury the pupæ deep in the ground, and thus prevent their emerging.

2. **The Pine Geometer or Bordered White Moth, or Pine Span-worm,** *Geometra* (*Fidonia*) *piniaria*.[1]—This is a common moth in the coniferous localities of Britain. It usually attacks 25- to 40-year-old pole-woods of Scots Pine, and occasionally also of Weymouth Pine, Spruce, and Silver Fir. It is not here a very destructive insect, and the danger from its attacks is diminished by these only taking place after the Pine-leaves are fully developed and the buds for the next year's foliage have been formed (Fig. 160).

Appearance.—The male and female differ little in size, the wings (which are borne upright while at rest) when extended having a span of from 1 to 1½ inch. But they vary greatly in colour. The female has rusty-brown wings (both pairs), with paler edging. Two faint dark-brown transverse stripes run across the lower pair of wings, and one across the upper pair. The lower edges of both wing-pairs have a row of alternate light and dark spots. The yellowish antennæ are bristle-shaped.

The ground-colour of the wings of the male is white (in Scotland) or yellowish-white (in England), with a large triangular dark-brown patch at the apex of the fore-wings, and with broad dark-brown edging and transverse stripes, while the fringes of both wing-pairs are tipped with alternate brown and yellow spots. The large feathery antennæ are dark and double-combed.

The under side of the wings, similar in both genders, is of reddish-brown, with dark transverse lines (fainter in the female), a broad yellowish-white longitudinal stripe, and many small brown and white spots.

The yellowish-green 10-footed *caterpillar* is at first about ⅛ inch long, and increases to 1 or 1¼ inch when full-grown. A white line runs along the middle of the back, with two parallel dark-green lines farther down on either side, and a pale-yellow line close below the brown spiracles. All these lines extend to the green head, where the dorsal middle line forms a V mark. On the lower or ventral side there are three yellowish longitudinal stripes. Of the 10 feet, 3 pairs are thoracic, and 2 pairs are after-feet (one of these last 2 pairs forming the anal claspers).

The *pupa* (which much resembles, but is smaller than, that of the Pine Beauty) varies from about ¼ to ½ an inch in length, and is at first greenish, but gradually changes to dark-brown.

Life-history.—The moths (which live for about a fortnight) fly late in May and throughout June, when the males flit about in the daytime, although like

[1] A monograph on this moth will be found in the *Trans. High. and Agri. Socy. Scot.*, vol. ix., 1897, pp. 106-123.

other moths their habits are nocturnal. In June the female lays about 60 to 70 bright-green eggs on Pine-needles near the top of poles and at the extreme end of side-shoots. The caterpillars hatch out early in July (in about two to three weeks), and at once begin to gnaw the needles slightly, and afterwards bite them through about the middle, so that the upper half falls to the ground. Then they

Fig. 160.

Part of Pine branch, showing damage done by caterpillars of the Pine Geometer Moth (Fidonia piniaria). *Here and there eggs can be seen on the needles.*

feed on the lower half remaining. They can spin down to the ground on gossamer threads, and often descend thus before entering the pupal stage.

Pupation begins in October and continues till April. It takes place either under moss or dead needles, &c., or in the ground, the pupa lying free, and not enclosed in a cocoon. Caterpillars often lie on the ground waiting for the final moult, when they enter the pupal state. The pupæ lie scattered about the whole area infested, and not merely near the trees on which they have been feeding.

The life-cycle is therefore as follows (MacDougall, *op. cit.*, p. 113) :—

November to April—Pupa under moss or dead needles, or in the ground. *May*—First moths appear (May 21). *June*—Flight of moths at its height. Eggs laid on the needles. *July*—Small caterpillars eating the needles. *August and September*—Growing caterpillars continue feeding. Their excrement noticeable under the poles and trees infested. *October*—Caterpillars, full-grown, descend the trees for pupation.

Protective and Exterminative Measures include shaking and tapping poles during summer in woods where span-worms have been seen, and herding swine in the woods during autumn and winter, to devour the pupæ. The dead foliage may be raked in heaps and burned in autumn, when the caterpillars and chrysalides remaining on the cleared strips are either devoured by birds or perish from the winter cold. But this is only practicable on a comparatively small area.

Like the caterpillar of the Pine Beauty, the Pine Span-worm is very sensitive to changes in weather and temperature (dry warm seasons favouring increase, and cold wet seasons proving destructive), whilst numerous enemies prey on the caterpillars and pupæ, such as jays, thrushes, blackbirds, starlings, and tits. But when the moths increase in very large numbers, fungous epidemics usually soon attack the caterpillars and quickly kill them off.

Continental Note.—During the last 10 or 12 years *Fidonia piniaria* has proved very destructive in Germany, and is now classed along with the Pine moth, the Nun or Black Arches, and the Pine Owlet-moth, as among the worst enemies of the German woodlands. It did immense damage in the forests near Nuremberg in 1892-96, and in Friedesdorf in 1893-95, while more recently a series of dry summers led to very destructive attacks in the Letzlinger Heide, in North Germany, from 1899 to 1903. The hot dry summer of 1901, favourable to the insect, brought the culmination of the attacks; but the cold wet May and June of 1902, and the natural increase in parasitic *Ichneumonidæ* and *Tachinæ* that generally takes place after three years of any such insect calamity, stopped further damage.

Although the Pine-woods attacked were chiefly young crops, 20 to 40 years old, it was found that the portions twice stripped bare of foliage by the caterpillars were quite past saving, and had to be felled as soon as possible to keep down bark- and cambial-beetles (*Hylesinini*). The consequence was that in 1903 and 1904, in place of an annual fall of 2,220,000 cubic feet, 41,370,000 cubic feet had to be felled on about 21,500 acres, of which about 17,000 acres had been entirely denuded of foliage.

In combating this attack, it was found that the best plan was to try and destroy the pupæ during winter. Grease-ringing the stems to prevent the ascent of caterpillars blown down by wind, &c., did not prove effective, as at most only about one-fourth of the caterpillars are thus brought to the ground. Driving in swine was out of the question throughout the whole of the area infested, as 50,000 would have been needed, so that this plan could only be adopted near villages. There, however, free pannage was given, and rewards to the swineherds. Hens were also bought and kept in the woods, and proved useful, although many of them died from diphtheria and soft crop, or were carried off by foxes, hawks, &c. Over large areas, however, the best means was found to be the removal of the soil-covering of dead foliage and moss, which could be sold locally as litter.

The Letzlinger Heide is a poor sandy stretch between Berlin and Hanover, where sylvicultural measures of prevention are hardly applicable. "One reads in text-books (1) underplanting; (2) mixed crops; (3) protection of this insect's enemies. But where can these be carried out? Protecting its enemies—of course!" The sandy soil is there generally too poor for mixed crops; but where Spruce and Pine were growing together, both were attacked, and also Juniper. The local experience there has been that "attacks of the Pine-looper cannot be effectually prevented by sylvicultural measures; but during the early stages the best means of exterminating the insect consist in removing the layer of soil-covering, and in herding swine and feeding hens where the pupæ are" (Nisbet, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xviii., 1905, p. 177).

D. Leaf-roller and Twig-twister Moths (*Tortricidæ*).

Moths with long, narrow, and somewhat rhomboidal wings, the fore-pair generally brightly coloured; antennæ short, and filiform or bristly. *Caterpillars* with 16 legs (10 prolegs); usually with a horny shield on the prothorax, and a horny flap at the tail, and dotted with small warts bearing a few short hairs. They roll up the leaves of broad-leaved trees (whence the name), spin gossamer threads freely, and are active in habit. *Pupæ* with rows of dorsal spines; pupation in a cocoon, mostly in the crowns of trees, but sometimes in the ground. *Generation* usually annual, sometimes biennial (*Tortrix resinella*).

1. **The Oak Tortrix or Leaf-roller** (*Tortrix viridana*) is a pretty little green moth, which every few years defoliates the Oaks in many parts of the country. The Oaks in Windsor Park, for example, were damaged badly in 1902. The caterpillars strip the Oak-foliage entirely, and then attack other broad-leaved trees when their natural food is insufficient in quantity for them. It lives almost exclusively on middle-aged and old Oaks (Fig. 161), occasionally swarming in great numbers over extensive areas, entirely devouring the Oak foliage, checking the growth of the tree, and preventing the ripening of acorns. Owing to the Oak's strong recuperative power, and its large store of nutrient reserves, the damage is not usually lasting. As the eggs are laid on buds and young twigs, the caterpillars always begin to feed near the top of the tree and move downwards, totally defoliating the tree. The foliage can, however, to a certain extent, be replaced when the midsummer flush of leaves takes place.

Fig. 161.

The Oak Leaf-roller Moth (Tortrix viridana)—*natural size.*

a. Moth.
b. Caterpillar spinning itself down by a gossamer thread.
c. Rolled-up Oak-leaf in which the caterpillar pupates.
d. Pupa.

Appearance.—This *moth* has a wing-span of less than 1 inch. The fore-wings are pale bright-green, with a whitish or yellowish-white fringe round the lower edges, and with light-grey hind-wings edged with white or greyish-white.

The 16-legged *caterpillar* (10 prolegs), which is about ½ an inch long when full-grown, is at first grey-green, then becomes dark yellowish-green, with a black head and small black tubercular warts on the back, which bear a few fine hairs.

The *pupa* is blackish-brown, slender, and less than ½ an inch long.

Life-history.—The moth flies late in June and early in July. The female lays her eggs either singly or in small clusters on the buds then being formed in the crowns of Oak-trees. The caterpillars hatch out when the Oak-leaves flush in the following May. They feed on the leaves, and spin threads to drop to lower foliage when changing their feeding-ground. Early in June they begin to pupate either in remnants of leaves rolled together (hence their name), or in bark-fissures, &c. When nearly full-grown the caterpillars can spin themselves down to lower branches by gossamer threads to continue their feeding, and to find suitable places for pupating. About three weeks later the moths emerge, pair, and lay their eggs. The generation is therefore simple and annual.

Preventive and Exterminative Measures can hardly be applied against this pest, because the whole life of the insect is spent on the tree, and the females can fly and distribute their eggs far and wide. When late frosts nip the young Oak foliage during years when the caterpillars abound in large numbers, these are starved to death. Birds form the best natural check, and should be encouraged to breed in nesting-boxes. Many birds feed on the caterpillars, and during the winter many ova are also no doubt destroyed by starlings, thrushes, sparrows, tits, woodpeckers, &c.

2. **The Pine-shoot Tortrix or Pine Twig-twister,** *Tortrix* (*Retinia*) *buoliana.*—Though a small moth, this common species in Britain may sometimes become a very dangerous pest in Pine-woods. When the moth swarms in large numbers, young Pines are attacked year after year, and of course become sickly and stunted. Attacks are mainly confined to Scots Pine (less frequently on Weymouth, Austrian, and Corsican Pines) of 5 to 12 years old growing on poor soil with a warm southerly exposure.

Appearance.—The *moth* has a span of less than 1 inch. The narrow forewings are reddish-yellow, with six or seven broad, wavy, silvery-white, transverse bands, tinged bluish about their middle, and with greyish-white edging; and the hind-wings are glossy dark-grey, while both pairs have light-grey or greyish-white fringes. Below, the wings are glossy dark-grey, with yellowish-red and white spots near the upper edges.—The 16-legged *caterpillar* (10 prolegs) is about ½ an inch long when full-grown, and is light-brown, with a glossy black head and thorax.

The *pupa* is dirty yellowish-brown, and about ⅓ of an inch long, and has a row of fine dorsal prickles.

Life-history.—The moth flies in the evening during the whole of July, and in the daytime it is hidden among the needles and shoots of young Pines, with wings ranged over each other like roof-tiles. The female lays her eggs singly on the terminal buds of young Scots Pine shoots, in plantations of 5 to 12 years old. On hatching out in August the caterpillars at once begin to bore, but are so small that the damage is hardly noticeable during the first autumn. In September they hibernate in the buds, and in the following spring the caterpillar, now larger, stronger, and more active, does greater damage; but the bud develops partially before the shoot dies in consequence of being hollowed out. As a rule the terminal bud is hollowed out first, and then the side-buds forming the whorl. Should any of these escape injury it becomes the leading-shoot. But in such a case it often happens that a damaged shoot bends downwards before beginning to grow upwards; and such a bend at the damaged place is still recognisable even when the tree is mature. Pupation takes place at end of May or in June at the base of the hollow tunnelled in the shoot. The moth emerges about four weeks later.

Preventive and Exterminative Measures.—The only way of getting rid of this pest is to break off and destroy, from May till the middle of June, all shoots infested, and thus destroy the caterpillars and pupæ; but they must be looked for below where the twig breaks. Shoots attacked are easily seen.

3. **The Pine-bud Tortrix,** *Tortrix (Retinia) turionana.*—Like the Pine-shoot Tortrix, the attacks of this moth are practically confined to young Scots Pine (and occasionally also other Pine) woods of from 5 or 6 to 15 years of age. It is, however, a less common species throughout Britain.

This moth seldom occurs in such large numbers as the Pine-shoot Tortrix; and as it does not often happen that all the side-buds forming the whorl are injured, one of these generally assumes the place of a leading-shoot, thus materially minimising the actual damage done.

Appearance.—The Pine-bud Tortrix very much resembles the Pine-shoot Tortrix, but is smaller, having a wing-span of less than ¾ of an inch. The fore-wings are ruddy-brown, with wavy leaden-grey transverse bands and patches, and fringed round the edge with dark leaden-grey; the hind-wings are grey, with greyish-white fringes. Underneath, the fore-wings are blackish-grey, with patches of red towards the tip, and of greyish-white towards the upper edge; while the hind-wings are greyish-white underneath, but darker towards the upper edge.

The 16-legged *caterpillar* is less than ½ an inch long, and both caterpillar and *pupa* closely resemble those of *Tortrix buoliana.*

Life-history.—The moths fly about the end of May and in June, and lay their eggs singly on the terminal buds of young Pine-shoots, into which the tiny caterpillars bore when they hatch out. During the autumn and the following spring they hollow it out, so that the young shoot withers, becomes blackish-grey, and dies. About the end of April or in May the caterpillar pupates within the hollowed bud, which it fills with the fine threads of its cocoon. From this the moth emerges late in May or early in June.

Preventive and Exterminative Measures consist merely in careful revision of the thickets during April and early in May, and breaking off and destroying buds infested. They are easily known by their small size and dark colour.

4. **The Pine Resin-gall Tortrix,** *Tortrix (Retinia) resinella,* is very common in Central and Northern Scotland, where damage is often reported from the caterpillars boring into shoots below the whorl of buds, and living inside the gall formed by the outflow of resin. Their presence is recognisable by the resinous outflow, the stunted side-shoots, and their liability to break off when touched. Branches attacked assume a twisted appearance.

Appearance.—The wings of this small *moth* have a span of hardly ⅘ of an inch. Head, body, and fore-wings are dark-brown or slate-coloured, with a coppery sheen. The upper wings have silvery or lead-grey transverse stripes, and a blackish feathery fringe, while the lower wings are dark brown-grey with light-grey fringe; and in both pairs the under side is dark brown-grey.

The 16-legged *caterpillar* is less than ½ an inch long, and yellowish-brown in colour, with a light-brown head. The *pupa* is ⅓ of an inch long, and very dark, almost black.

Life-history.—This insect is remarkable in having a two-yearly generation, which is uncommon among *Lepidoptera.* The moths appear in May, and the female lays her eggs singly beneath the whorl-buds of young Pines, and chiefly on the side branches. The caterpillar hatches out a few weeks later, and bores through the bark into the soft shoot. Resin flows from the wound and forms a small soft gall which grows to about the size of a pea, and in which the small, 16-legged, worm-like caterpillar hibernates during the following winter. In the second year the caterpillar resumes feeding, and the gall increases, with thick walls of resin, to the size of a cherry or a small nut, while internally it exhibits a well-marked partition formed by the gall of the previous year. The shoot is hollowed to the pith and enclosed within the resin-gall. In April of the second year the caterpillar pupates within the gall, and in May the moth emerges from the gall. The generation is therefore biennial.

Prevention and Remedy.—This Tortrix, on the whole, does not do very much damage, because the leading-shoots are seldom attacked, and are not always killed in consequence. But when allowed to multiply greatly, and especially in young woods growing on inferior soil, the damage may often be quite enough to make it advisable to collect the galls and destroy them while they still contain the caterpillars (before the end of the second autumn).

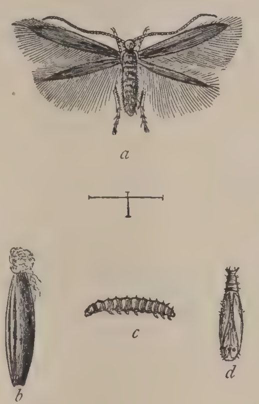
The chief danger from this insect is that in woods attacked by it there is always a chance of the two more injurious species, *T. buoliana* and *T. turionana*, also attacking the crops.

E. Leaf-mining Moths (*Tineidæ*).

Moths with long, narrow, pointed wings having long fringes; antennæ filiform or silky and brush-like, seldom pectinate. *Caterpillars* 16-footed, usually with 10 prolegs. *Pupa* thin and hairless, with long wing-cases extending almost to the tip of the tail. *Generation* annual.

1. **The Larch Mining-Moth**, *Tinea* (*Coleophora*) *laricella*.—This is a very injurious insect throughout the whole of Britain, and besides the great damage it directly occasions by defoliating young Larch-woods, the wounds made offer entrance-holes for the destructive canker-fungus. There is now never a year when the pest is not reported from some part or other of the British Isles (Figs. 162, 163), but the worst recent attacks have perhaps been those in and around Gloucestershire.—Experiments in Germany show that the caterpillars burrow readily into the needles of the Japanese Larch (*L. leptolepis*), but the long soft needles of the youngest shoots are too large to be conveniently used for making their larval cases; while the foliage of the Siberian Larch (*L. siberica*) seems to disagree with them, and to make them sicken and die.

Fig. 162.



The Larch Mining-Moth
(Coleophora laricella).

a. Moth (magnified three times).
b. Larval covering formed of leaf-case (magnified three times).
c. Caterpillar (magnified three times).
d. Pupa (magnified three times).

Fig. 163.

Showing the Larch Mining-Moth at work, and the kind of damage it does.

a. Larvæ in leaf-cases.
b. Naked larvæ.
c. Needles attacked and hollowed out.

Appearance.—*Moth* ashy-grey or greyish-black and lustrous, with a wing-span of less than $\frac{1}{2}$ an inch. *Caterpillar* with 16 feet (10 prolegs), dark ruddy-brown, and about $\frac{1}{5}$ of an inch long. *Pupa* also about $\frac{1}{5}$ of an inch long, dark-brown, narrow, and covered with fine bristly hairs.

Life-history.—The moth flies in the daytime about the end of May and in June. The female lays her small round yellow eggs (changing to grey in about a week) singly on Larch needles, usually in plantations of from 10 to 40 years of age, and chiefly on the lower branches of 10- to 14-year-old poles freely exposed to the sunlight. But older woods and also saplings and young plants are also sometimes attacked when the moths swarm in great numbers. The caterpillar hatches out in three to four weeks, bores its way into the needle, eating out the contents, and using the empty leaf-case as a protective covering, in which, when full-grown in September, it hibernates, the empty leaf-case now becoming a little yellowish-brown sack, firmly fastened to twigs, bark-fissures, &c. Next spring it again feeds on the new needles, but carries its sack about with it, and finally pupates in this (Fig. 162 *b*). The needles attacked by the young and the old caterpillars at once turn yellow and withered as if frost-bitten, and the damage is often so serious that entire defoliation takes place, especially in the case of young Larch-trees near the edges of green lanes, &c. Whole plantations sometimes look as if their foliage had been badly nipped by late frost. As new needle-tufts are formed in the centre of the damaged rosettes, however, they gradually recover and develop short shoots which take the place of the long shoots destroyed.

Damage of this sort is often repeated year after year on young Larch growing near the edges of plantations, and they gradually sicken and die in consequence.

Preventive and Exterminative Measures.—Small birds like tomtits, and various *Ichneumonidæ*, prey on the caterpillars. Late frosts and heavy rainfall at the time of swarming kills off many of the moths. The only active measures that can be taken are to thin Larch-woods in winter or early spring, and remove the thinnings before the moths emerge in May. Pruning the lower branches of Larch-trees in infested areas removes material specially attractive as breeding-places. Mixed woods are far less exposed to attacks than pure Larch plantations.

F. Wood-boring Moths (*Cossidæ*).

Moths with thick bodies covered with short hairs, and large wings; antennæ brush-like or pectinate. *Caterpillars* 16-legged, large and round, either smooth or with a few scattered hairs. *Pupæ* large and long, with rings of spinal processes on the abdomen; cocoons formed of bore-dust and wood-chips. *Generation* two or three years.

This family includes two genera, the caterpillars of which do a very considerable amount of damage throughout Britain among orchard- and broad-leaved trees, though seldom attacking any conifer. They make timber often useless for technical purposes, by riddling it with big holes.

1. **The Goat-Moth** (*Cossus ligniperda*).—This large moth (Fig. 164), so named from the goat-like smell of its caterpillar, also called the "Augur-worm" in Scotland and the "Carpenter-worm" in England, is one of the worst of enemies to Elm, Oak, Willow, Poplar, Ash, Alder, Birch, Beech, and Lime, and in orchards to Apple, Pear, and Walnut. The caterpillars drill holes through the bark into the timber, and finally throw the trees into a sickly condition. It is most common in the warmer parts of England, but is also found all over Scotland and Ireland. As the holes are large, trees attacked are often killed outright. The caterpillars are often found deeply embedded in large Willow and Poplar, as they prefer to bore into softwoods; and in many cases such trees become riddled with holes. But they also bore into the hardest wood, and are common in Oak- and Elm-trees. Badly-bored trees are often thrown during storms. Unless exterminative measures be adopted,

trees attacked become regular breeding-places for this insect. Badly infested trees "bleed" freely, and emit the characteristic goat-like odour.

Appearance.—The moth has a span of about 2½ to 3 inches for the male, and about 3 to 3½ or nearly 4 inches for the female. The fore-wings are greyish-brown, mottled with ashy-grey marks, and with numerous irregular dark-brown streaks and marks; the hind-wings are ashy-grey to greyish-brown, and the thorax is

Fig. 164.

The Goat-Moth (Cossus ligniperda)—*natural size.*

a. The female moth.
b. Caterpillar, not yet full-grown.
c. Pupa.
d. The cocoon, after the moth has emerged.

densely haired, with a blackish band across it behind, and brown and grey in front. The large heavy abdomen is long and blunt, and with dusky-brown and grey bands. The 16-footed caterpillar is, when full-grown, about 3 to 3½ inches long. It is at first reddish-yellow, and turning brownish-red later on, with brown head and shield, darker above than below, naked, and having an offensive goat-like smell. The *pupa* is thick and ruddy-brown, and has rings of prickles on the abdominal segments.

Life-history.—The moths fly and pair in June and July, when the female lays her eggs, to a total of about 25, in bark-crevices of Oak, Elm, and most soft-woods, usually on the lower part of a tree-trunk. The caterpillars hatch out in July, and at first feed under the bark, but soon bore into the solid wood, where they form long tunnels, in which they live for two to three years. Sometimes the caterpillars leave the trees and crawl about on the ground. When mature they usually pupate just inside the entrance to their burrows (and sometimes in the ground), the large reddish-brown pupa lying in a cocoon of rough wood-chips. Previous to the moth emerging in June or July, the pupa pushes its way partly out of the tree. The life-cycle extends to two or three years.

Preventive and Exterminative Measures.—Little can be done to prevent attacks of the Goat-moth. Trees attacked show, even at an early stage, bore-dust and excrement at the opening of the bore-holes. Syringing the holes with carbolic acid and other poisonous substances has been tried, but without much success, as the caterpillars are usually too well protected by bore-dust and wood-chips for the poison to reach them. Putting bits of cyanide of potassium in the holes has, however, been found successful. Badly infested trees should be felled, and branches cut, and the caterpillars destroyed. The lower parts of the trunks of trees attacked may be smeared early in June with a thick dressing of mud and paraffin to prevent egg-laying. Bats, owls, goat-suckers, titmice, and other small birds are useful in clearing off the eggs, and woodpeckers extract the caterpillars from infested trees, while many birds feed on the moth itself.

The following is a recipe quoted by Nitsche as in use on the Continent, with good results not only against *Cossus ligniperda*, but also other insect enemies of the woodlands (MacDougall, in *Trans. High. and Agri. Socy. Scot.*, vol. xii., 1900, p. 297) :—

Infuse 5 lb. of tobacco in half a pailful of warm water, and allow this to stand for twenty-four hours ; then strain. Mix the infusion with half a pailful of bullock's blood, and add one part of slaked lime and sixteen parts of cow's dung. Allow this mixture to remain for a short time in an open cask so that it ferments, and stir several times daily. Clean the base of the stem, removing some of the earth at the bottom, and paint on the composition. Repeat the painting three days in succession, and a crust is formed on the stem which rain does not wash off, and which does not harm the tree.

2. **The Wood Leopard-Moth** (*Zeuzera æsculi*) also damages timber technically like the Goat-moth. It chiefly attacks young stems of Maple, Sycamore, Ash, and Lime among forest-trees, but in orchards it is found on Pear, Cherry, Apple, and Plum trees. Although called *æsculi*, it attacks other woodland species as well as orchard-trees, far more frequently than the Horse-Chestnut.

Appearance.—It is only about two-thirds of the size of the Goat-moth. The wings are almost white, with numerous round black or steel-blue irregular spots ; and there are six similar spots in two rows on the upper part of the body. The abdomen is dull-white or grey, striped alternately with blue-black and white bands. The *caterpillar* is yellowish, with little black warts, and nearly 2 inches long when full-grown. The *pupa* is bright brown, nearly an inch long, and has rows of sharp spikes along its back, which serve to retain the empty cocoon in the mouth of the gallery during the emergence of the moth (see below).

Life-history.—The moth flies from June till August, and lays large numbers of orange-coloured oval eggs on the stems and branches of trees. In a few days the acterpillars hatch out and bore into the bark. They remain feeding in the sapwood till winter, when they bore deeper, tunnelling upwards into the stem. They continue in the larval state for two years, feeding continuously. In May or June of the second year they return to near the bark and pupate within the sapwood, to emerge as moths in June or later. Its generation is therefore biennial. The bark just over the pupal-chamber is left so thin by the larva that the pupa can easily force itself through it, and the empty cocoon is found protruding from the hole after the moth has emerged.

Preventive and Exterminative Measures.—As for the Goat-moth.

G. Clearwing-Moths (*Sesiidæ*).

Moths with narrow and more or less transparent wings (like Hymenopterous insects) and thickish body; antennæ brush-like. The moths fly about in the daytime during bright sunshine. *Caterpillars* 16-footed, with 10 prolegs; yellowish-white, cylindrical, and sparsely sprinkled with fine hairs. *Pupæ* with rings of prickly spines on the abdomen, in a cocoon formed of bore-dust and wood-chips. *Generation,* two years.

1. **The Hornet Clearwing-Moth,** *Sesia apiformis* (*Trochilium apiformæ*), the largest and most important of this group, damages the butts of young Poplar stems up to about 20 years of age (and especially Black Poplar and Aspen) in much the same way as the Poplar Longicorn and the Goat-moth. The caterpillar feeds for two years, and often riddles with holes the butts of Poplars. It does most damage in avenues and nurseries.

Appearance.—The *moth* has transparent wings, with rust-red edges and veins, and a span of about 1½ to 1¾ inch. The *caterpillar* is rather flat, dirty- or yellowish-white, with a large brown or red-brown head, and a dark dorsal line; it has 16 feet (3 pairs of true legs, and 5 pairs of suckers or prolegs). Its head and legs easily distinguish it from the larva of the Poplar Longicorn, along with which it is often to be found at work (compare Fig. 157, p. 100). *Pupa* brown, with prickly dorsal spines on the abdomen and at the tail-end.

Life-history.—The moths fly in June and July, and lay their brown eggs in bark-fissures near the base of Poplar stems. The caterpillars hatch out in July and August, bore into the stem, and live there for two winters, then come out and pupate, either near the mouth of the bore-hole or else on or near the ground in cocoons formed of bore-dust and wood-chips. The moths emerge in June, the generation thus extending over two years.

Preventive and Exterminative Measures.—Catching and killing the moths on the Poplar stems (June, July); cutting and removing infested poles; smearing with patent tar or cart-grease the butts of young Poplars where the pest is known to exist; and as for Poplar Longicorn (see p. 100).

Several other Clearwing-moths perforate the branches of deciduous trees in a similar way to the above. Such are the Red-belted Clearwing (*Sesia culiciformis*), which attacks the Birch; the Red-tipped Clearwing (*S. formicæformis*), common in Osier-beds; and the Hornet Clearwings (*S. bombiciformis,* and *S. tipuliformis*) common to various kinds of broad-leaved trees.

III. Membrane-winged Insects (*Hymenoptera*).

The main distinguishing characteristics of this order are the four transparent wings, and the facts that the anterior and posterior wings are hooked together during flight, and that the females have an appendage at the tail in the form of a sting, awl, or ovipositor. Several of them are destructive to trees.

A. **Sawflies** (*Tenthredinidæ.*—These are transparent-winged insects, whose females lay their eggs in holes sawed in leaves by means of an ovipositor (hence "sawfly").

Flies having wings with many veins; fore-wings with one or two well-defined long bays near apex, and three or four rhomboidal bays at edge; antennæ filiform or brush-like; prothorax short; abdomen consisting of 8 segments; female with movable ovipositor. *Larvæ* very active, with 8, 18, or 22 legs, usually bright in colour, and moulting several times. *Pupæ* soft; pupation in an oblong or oval and leathery cocoon. *Generation* generally double, and sometimes treble in a year.

1. **The Pine-Sawfly** (*Lophyrus pini*).—This is one of the most destructive insects among conifer crops throughout Britain (see Fig. 165). It chiefly attacks the leaves of the Scots and Austrian Pine, devouring them down to the bottom of the leaf, and completely disfiguring the branches. The damage is done by the caterpillars, numbers of which appear on one branch, and then proceed to others until the tree is almost or entirely defoliated. They attack the trees about May, and continue until September (second brood). Their power of reproduction is wonderful; and were it not for useful and predatory insects which feed on them, and fungous diseases which become epidemic among the caterpillars, they would soon entirely destroy extensive woods. They very often attack young plantations, and frequently confine themselves to one spot at a time; but they are also found upon older trees.

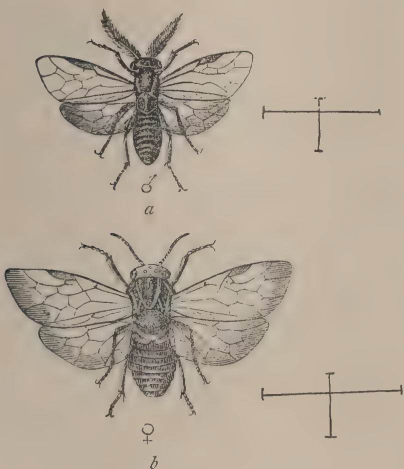
Appearance.—The wings of the female fly have a span of about $\frac{2}{3}$ to $\frac{3}{4}$ of an inch. The antennæ are short and bristle-like. The head is black, the body yellowish with black spots on thorax and abdomen, and with three black rings or sections on the abdomen. The male has a span of about $\frac{3}{5}$ of an inch. The body is black, the legs yellowish, and the antennæ combed or double-feathered. The dirty yellowish-green tailed *caterpillars* have 22 legs, and a brown or black shining head, and black dots on the segments of the body. When touched they raise their heads like a snake. They are about 1 inch long when full-grown. All parts of the fly are already recognisable in the *pupa*. The pupal state is passed in a tough, oval, brownish-yellow cocoon formed in bark-fissures, or attached to twigs and needles, or under moss and dead foliage on the ground. The cocoon opens by a circular lid.

Life-history.—In dry warm seasons there may be two broods in the year. The sawflies appear late in April or during May, when the female lays about 120 eggs on the edges of the Pine-needles, after lacerating them with its saw-like ovidepositor. From 10 to 20 eggs are laid in one needle, each wound being sealed up with frothy slime. The caterpillars hatch out (in about a fortnight) in May and June, and collect in clusters on the whorls of young Scots Pine, especially near rides and green lanes, or on suppressed and dominated stems. At first the tiny caterpillars usually feed in pairs on each needle, eating the edges and leaving the midrib standing; but as they get stronger and nearer their full growth (when they are about 1 inch long) they eat all the needle except a short stump. Fortunately they only feed on the old leaves, and not on the new ones of the last year. They moult several times, and leave their cast skins sticking to the twigs. In July they pupate in their peculiar leathery cocoons formed between bark-scales, twigs, and needles, &c. In two or three weeks the sawflies emerge, pair, and lay eggs for a second brood. The caterpillars of this second brood hatch out in August, and often feed until well on in autumn, when they descend and form cocoons under moss or dead leaves on the ground. Within these they hibernate as larvæ, and only become pupæ in the following spring, about three weeks before emerging as sawflies.

The above life-cycle is not constant and regular. Sometimes single broods remain for a whole year or longer in the cocoon before emerging as sawflies.

Prevention and Extermination.—Numerous animals prey on the Pine-Sawfly. Insectivorous birds devour the larvæ, and should be encouraged to breed in nesting-cases ; squirrels and mice extract the larva or pupa from the cocoon ; and swine eat the caterpillars, but not the cocoons. Ichneumon-flies,[1] parasitic flies (*Tachininæ*),

Fig. 165.



The Pine-Sawfly (Lophyrus pini).
a. Male Wasp (twice magnified).
b. Female Wasp (twice magnified).

Pine-Sawfly Caterpillars at work. An unopened cocoon is also shown on the right-hand side (*natural size*).

Twig of Scots Pine damaged by the Pine-Sawfly (*natural size*).

and beetles (*Carabidæ*) attack the caterpillars, which are also rather sensitive to frosty, cold, damp, or unseasonable weather. Although it is not always easy to detect their dirty yellowish-green colour against the Pine-branches and

[1] When the pupa has been devoured by an ichneumon-fly, the cocoon-lid does not open, but the fly issues through a small hole in the centre of what would have been the lid, thus $\odot$.

leaves, the caterpillars, when collected in clusters, may be crushed by pulling the gloved hand firmly along the twigs from below upwards (so as not to damage the leaves), or perhaps even more expeditiously with a Büttner's *double brush* (see p. 19). Or the caterpillars may be shaken down, if the poles are strong enough to stand this. It is difficult to collect cocoons below moss on the ground, because, being small, they are not easily noticed. In parks and gardens ornamental trees may be freed from this pest by spraying with hellebore wash (1 oz. to 2 gallons of water), or arsenate of lead or Paris-green (1 oz. to 15 gallons of water); but these poisons require careful handling. Small ornamental plantations may also be cleared by sprinkling naphtha on the larvæ with a brush.

Board of Agriculture Leaflet No. 103 deals with *L. pini* and *L. rufus*.

2. **The Fox-coloured Sawfly** (*Lophyrus rufus*) is often found working along with *L. pini*. It did great damage in Argyllshire in 1890, and in Ross-shire in 1898. Scots Pine 2 to 6 ft. high are most subject to attack.

Appearance.—The female is reddish-brown or reddish-yellow, with black spots on the thorax, and with yellow to reddish-brown legs; the male is smaller, and glossy black, but the first abdominal ring and the feet (except the claws) are red or reddish-brown. It flies in August and September.—The larvæ are dusky greenish-grey with black heads, a pale longitudinal stripe along the back, and a dusky line with a pale one on each side of it above and below; the spiracles are placed in the lower pale line. The sucker, feet, and under side of the body are pale-green. When full-grown they are rather more than ½ an inch long. It has the same habit as *L. pini* of rearing its head when disturbed.

Life-history.—The larvæ hatch out about the end of May, and feed till middle or end of June, when they pupate in an oval, pale yellowish-brown, parchment-like cocoon, formed amongst needles and heather, or in the earth, &c., beneath the trees. Like the common Pine-Sawfly, this species also collects in colonies, and two are usually at work on each needle. The cocoon is lighter in colour and not so tough as that of *L. pini*. On the Sawflies emerging, they pair, and lay their eggs in August and September in the needles, in the same way as *L. pini*, where they remain all winter and hatch out in May.

Preventive and Exterminative Measures.—As for *Lophyrus pini*.

B. Wood-Wasps (*Siricidæ or Uroceridæ*).

Wasps long and completely veined; body long and cylindrical; antennæ filiform or brush-like; abdomen consisting of nine segments; ovipositor elongated. *Larvæ* 6-legged, soft, white, cylindrical. *Pupæ* soft and white. *Generation* never less than two years, and often more.

Wood-Wasps (*Siricidæ*)—among the largest and most striking of Hymenoptera—are technically injurious, as the deep borings of their large larvæ often honeycomb stems, and thus render timber unfit for many technical purposes. The two species common in Britain attack coniferous timber, but a third also bores into the Willow.

Life-history of Sirex *Species.*—The female, by her long and strong ovipositor, bores quickly (in about four minutes) through the bark and into the sapwood of sickly trees and felled or windfall timber, and lays her eggs singly in the wood of the stem, usually at the depth of the second or third last annual ring of wood. Rotten wood it avoids. The wasp only lives for about six or seven days, during which time it bores and lays from 100 to 150 eggs, one egg being laid in each bore-hole. The round whitish grub, which is over an inch long when full-grown, has three pairs of small thoracic feet, strong biting jaws, and a characteristic spine on the last segment.[1] It bores first of all in the softer sapwood, but generally works in deeper and hibernates. During the second year it is stronger and bores still deeper, and again hibernates. In the spring following the second winter it bores its way towards the surface of the trunk, and forms a pupal chamber in the sapwood at a depth of about ½ an inch usually. Between July and September the complete wasp bores a round hole straight through to the surface, and emerges for pairing and reproduction. The borings are circular, like the larvæ.

Their generation is never less than two years, and is often longer, for the wasps occasionally emerge from beams and scantlings some considerable time after they have been converted and worked up.

1. **The Giant or Yellow Wood-Wasp** (*Sirex gigas*) bores into Spruce, Silver Fir, Larch, and rarely Pine. It is blackish in colour, with a yellow patch behind each eye. In the female, which may attain 1½ inch in length, the first two and the last three segments of the abdomen are yellow, while in the smaller male all the rings of the abdomen are reddish-yellow, except the first and the last, which are black.

2. **The Steel-blue Wood-Wasp** (*Sirex juvencus*) bores chiefly in Pine (Fig. 166), but also in Larch. The female has a steel-blue body with reddish legs, and varies up to 1½ inch in length, while the male is usually smaller in size, and with yellowish-red rings from the fourth to the seventh segments of the abdomen.

Preventive and Exterminative Measures of any practical use against wood-wasps consist merely in at once cutting out any sickly or damaged stems likely to serve as breeding-places, and in keeping the woods properly thinned and supervised.

The handsome Ichneumon, *Rhyssa persuasoria*, is parasitic on *Sirex juvencus* larvæ. *Rhyssa* bores with its long ovipositor into a tree where the wood-wasp larvæ are at work, and lays an egg in the tunnel of the wood-wasp. When the *Rhyssa* grub hatches, it proceeds to feed on the grub of the wood-wasp, which is thus destroyed. The ovipositor of *Rhyssa* is very long, and sometimes this Ichneumon is captured fixed to the tree, from which it has been unable to withdraw its ovipositor (MacDougall, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xv., part iii., 1898, p. 312).

3. **The Willow Wood-Wasp**, *Sirex* (*Xiphydria*) *dromedarius*, sometimes bores into Willows in the fen district. The wasps begin to emerge from the wood in June. It is a rare insect, and it is not yet known if it attacks sound wood, or merely sickly and moribund trees.

C. Gall-Wasps (*Cynipidæ*).

Gall-wasps, with fore-wings having six or eight bays, with one long bay at apex and two or three rhomboidal bays at edge—but sometimes with aborted wings only, or none at all; abdomen compressed and shorter than wings (when present); antennæ filiform; male usually much smaller than female. *Larvæ* generally thick and fleshy, smooth, whitish, and incurved. *Pupæ* thick, smooth, and whitish. Several gall-wasps are parasitic on the larvæ of injurious insects.

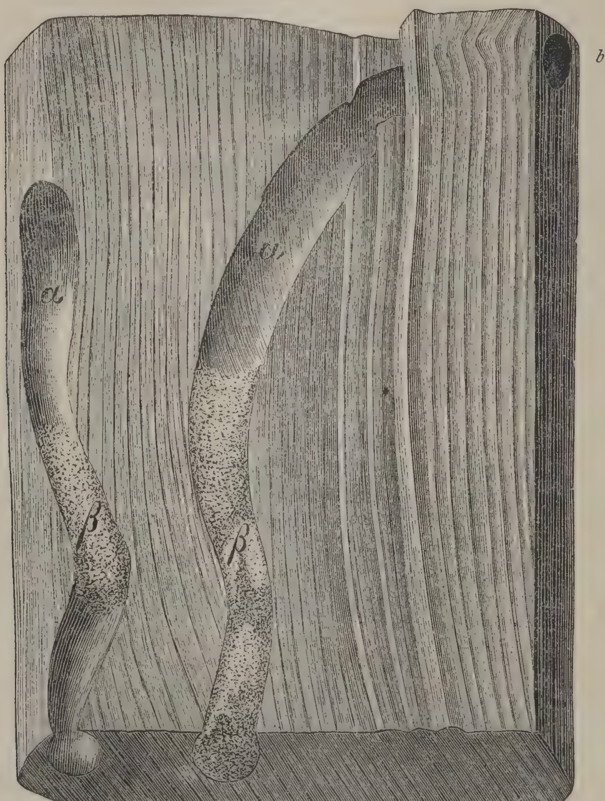
The *Cynipidæ* are of great interest in having, like many fungi and also the plant-louse *Chermes*, an alternative generation. Winged insects develop a wingless, hibernating, sexless form, which reproduces itself parthenogenetically ("virgin birth"), and whose brood reproduces the original form, in which the pairing of male and female is necessary before ovideposition. Thus, *Cynips fecundatrix* produces *C. pilosa*, whose virgin-brood reproduce *C. fecundatrix*; *Cynips terminalis* breeds *C. aptera*, which, after forming galls on the roots of Oak-trees, lays virgin-eggs from which *C. terminalis* is reproduced. Here *C. terminalis*, produced at the tips of the crown twigs, migrates to the roots to lay her

[1] This spine and the cylindrical form of the grub distinguish it from the flattened and spineless grubs of the long-horn beetles (*Cerambycidæ*, see p. 99).

eggs, while the sexless *C. aptera* migrates back to the summit of the crown to reproduce the sexual form there. A winged sexual generation thus alternates with a wingless parthenogenetic generation to complete the full life-cycle.

The Gall-wasps chiefly attack Oaks of different species. There are many species (some 50 being said to occur on the Oak), and they are all provided with an ovipositor, which is entirely concealed except at the extremity. They bore holes with this into the buds, leaves, or small

Fig. 166.



Borings of the Steel-blue Wood-Wasp (Sirex juvencus) *in Scots Pine—natural size.*

a. Larval borings, partly filled with bore-dust (β).
b. A circular exit-hole.

branches, and lay their eggs there much in the same way as is done by the Sawfly. Some time afterwards, when the young larvæ hatch out, the disturbance they cause leads to "**oak-galls**" being formed. These enclose the larvæ, which remain and feed within the gall until they emerge as wasps.

The Oak-Apple Gall-Wasp, *Cynips* (*Dryophanta*) *querci*, is the chief and the commonest of Gall-wasps that attack Oak foliage. It occasions the well-known large green and red "Gall-apples," about as large as a cherry, found on the lower side of Oak-leaves.

Preventive and Exterminative Measures consist in collecting and destroying the galls. Small birds pick the grub from the gall.

Other common species include—

The Oak-Cone Gall-Wasp, *Cynips* (*Aphilotrix*) *fecundatrix*, which forms the small, woody, cone-like excrescences near the tips of Oak twigs. These woody-galls, often formed in clusters, are at first greenish and soft, but turn brown as they harden.

The Oak-Rose Gall-Wasp, *Cynips* (*Teras*) *terminalis*, causes the large, rose-coloured, spongy galls at the tips of Oak twigs. They are generally formed at the terminal bud, where the "roses" are sometimes as big as a potato; and they consist of several larval chambers clustered together.

The Marble Gall-Wasp (*Cynips Kollari*) often attacks young Oak in nurseries.

The Acorn Gall-Wasp (*Andricus glandium*) is another common gall-wasp which attacks acorns of the Turkey Oak and the Cork Oak. In S.E. Europe, Turkey Oak-galls are a commercial product.

IV. Two-winged Flies and Midges or Gnats (*Diptera*).

Various midges cause malformation of shoots, and malformation of buds like that occasioned by gall-wasps. Gall-midges often do considerable damage in Osier-beds, as the nodes or swellings formed make the rods useless for weaving. The damage done to other kinds of trees (Beech and various conifers) is very trifling.

Gnats or *Midges* with very small bodies and two comparatively large and often iridescent wings, with three to five longitudinal veins, round and broad at apex, but narrow at lower end; antennæ thread-like or pearl-shaped; abdomen cylindrical, with eight segments, pointed in female, and often provided with a movable ovipositor. *Larvæ* long legless maggots or "strigs," mostly pale-yellow or reddish, without horny mouth-parts, but with a horny holdfast embedded ventrally. *Generation* annual.

The most important injurious insects of this order are the Osier Gall-midges belonging to the family of *Cecidomyidæ* or gall-gnats. These lay their eggs on Osier-shoots, and when the larvæ hatch out and begin to suck the sap, nodes or swellings are formed which make the withes useless.[1]

1. The Large Osier Gall-Midge (*Cecidomyia salicis*).

Appearance.—This midge is small, blackish, and long-legged, being only $\frac{1}{8}$ to $\frac{1}{7}$ of an inch long; its abdomen is ringed with red, and has whitish hairs.

Life-history.—The eggs are laid on young shoots (mostly on *Salix purpurea*)

[1] The Gall-gnat family is a large and interesting one, numerous in species. The flies of the family are small and extremely delicate; the hairs on body and wings are very easily rubbed off, and this makes determination of the species a matter of great difficulty, and, because of this, examples of the galls (in the gall-making species) are always desired as an aid to identification. The larvæ or maggots, which hatch from the eggs of the female flies, are found in very diverse places according to the species—*e.g.*, under bark, in fungi, in flowers and fruits, and in galls on leaves or stems. Some of the best known and most injurious are not found in marked swellings or galls—*e.g.*, the Hessian-fly maggots, so destructive to the stems of wheat and barley, and the maggot of the wheat midge, injurious to the young grain. The gall-making species are the commonest, and the galls inhabited by the maggot are to be found on many different plants, both herbaceous plants and trees. More than one species may attack the same tree, and it is not common for the same species to lay on plants far apart in relationship.

Of the gall-gnats whose galls are found on trees, several are not uncommon on the Willow, the galls being found on the youngest shoots, or in 2-year-old and older twigs, or in the bud at the apex of the twig, or on the Willow leaves, or on Willow flowers (MacDougall, in *Trans. Roy. Scot. Arbor. Socy.*, 1905, p. 210).

in May, and again in July. When the reddish-yellow maggots or strigs begin to suck they cause spindle-shaped swellings which spoil the withes. Pupation takes place within the swelling.

Prevention and Extermination.—From May onwards, twigs infested should be cut off and burned before the maggots come to maturity. A natural enemy of the gall-gnats is a beautiful little 4-winged *Chalcis* fly. This lays its eggs in the galls, and on hatching out the larvæ feed on the maggots of the gall-gnat.

2. **The Small Osier Gall-Midge** (*Cecidomyia saliciperda*).

Appearance.—This midge is still smaller, being only $\frac{1}{12}$ to $\frac{1}{8}$ of an inch long, with blackish-brown body, and milk-white wings.

Life-history.—During May the eggs are laid in a long string on the bark of young Willow-shoots (chiefly on *Salix alba, S. viminalis, and S. acutifolia*), and in June the reddish-yellow maggots eat their way inside. From July till the following April they bore irregular vertical galleries, which cause spindle-shaped nodes or swellings that ultimately become scabby from the bark bursting. Pupation takes place within these nodes.

Prevention and Extermination as for *C. salicis*.

3. **Cecidomyia heterobia** (Fig. 167) in 1903 and 1904 caused much damage to Osier-beds at Castlecomer (S.E. Ireland) by attacking the best varieties of *Salix triandra* (Black Norfolks, Black Mules, and Spaniards), and forming galls on the terminal shoots (see *Trans. Roy. Scot. Arbor. Socy.*, vol. xviii., 1905, p. 211).

4. **The Beech Gall-Midge**, *Cecidomyia* (*Hormomyia*) *fagi*, produces the long, hard, conical green and red galls often to be seen on the upper side of Beech leaves.

Appearance.—This midge is only about $\frac{1}{12}$ of an inch long, and has a blackish-brown body with flesh-coloured abdomen, and brownish wings with grey hairs.

Life-history.—The midges fly in April, when the female pierces holes in the tender cuticle on the upper side of the young Beech leaves, and lays an egg in each hole. Above the puncture the green cone containing the maggot forms, and gradually hardens and changes from green to deep red in colour. About October it drops to the ground, and early in the following spring pupation takes place within the gall lying on the ground, the midge emerging in April to pair and reproduce itself.

Prevention and Extermination consist in collecting and burning leaves infested.

The species found on conifers include the Pine Gall-midge (*Cecidomyia brachyntera*), the Spruce Gall-midges (*C. piceæ* and *C. abietiperda*), the Larch Gall-midge (*C. Kellneri*, Fig. 168), and the Yew Gall-midge (*C. taxi*); but none of these does any serious damage.

V. Half-winged Insects (*Hemiptera*).

The metamorphosis of Hemiptera (as also of Orthoptera) being incomplete, the larvæ which hatch out of the eggs are already more or less like the perfect insect. They moult their skin several times, the last moult freeing the wings of the perfect insect. Any *definite* larval or pupal stage is wanting. Two families of this order are of special interest to the forester—Plant-lice (*Aphidæ*) and Scale-insects (*Coccidæ*), which are both very often destructive.

A. **Plant-Lice** (*Aphidæ*) form a very destructive family. The *Aphidæ* emit honey-dew, for which some kinds are regularly milked by ants. This they extract from the sap of the leaves, and afterwards eject it in a purified state. Plant-lice possess an extraordinary power of multiplication; hence they easily become very destructive to any kind of plant they attack.

Fig. 167.

Galls of Cecidomyia (Rhabdophaga) heterobia *on the apex of the terminal shoots of* Salix triandra (*Castlecomer*, 1904).

Aphides with membranous wings, often wanting in the female; antennæ long and thread-like or silky; head usually with a well-developed proboscis; legs generally long and thin. *Generation* many times within the year, and very prolific.

The genus of importance in woodlands is *Chermes*, various specific forms of which infest conifer plantations.

The genus **Chermes** includes the plant-lice which attack Spruce, Larch, Pine, and Silver Fir.[1] By means of their proboscis they prick the leaf-buds which then form galls, or they pierce and bend the needles, or they suck the sap from the bark. Whichever means of attack is employed, the tree gradually sickens and may die off.

The *Chermes* infesting different conifers are not really different species, but only specific forms in the generation of one species (analogous to similar changes in the generation of the fungus *Melampsora* on Willow or Birch, and *Chrysomyxa* on Larch and Pine). Thus, from Spruce-galls a generation of lice may issue, which attack Larch, Pine, or Silver Fir, and look as if they were an entirely different species.

Fig. 168.

Galls produced on a twig by the Larch Gall-Wasp (Cecidomyia Kellneri)—*natural size.*

a. Infected buds, rendered abortive.

There are three kinds of galls made on the Spruce by members of the genus *Chermes*—viz., *C. abietis*, *C. strobilobius*, and *C. coccineus*. In the case of the first two the plant-lice from the galls migrate to the Larch, and sometimes to the Pine, where the next stages in the life-history are passed. *C. coccineus* is also thought to have a migrant generation, which moves from the Spruce to the Silver Fir and becomes the woolly aphis *C. piceæ*.

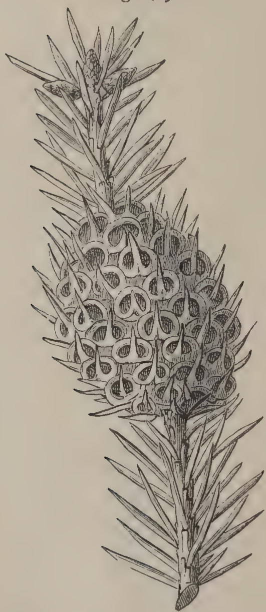
Much remains to be learned about the difficult life-history of these insects, but the following details are well established as to the common *C. abietis*:—Small, wingless, grey-green aphides, which have passed the winter on the Spruce, and which may be found under cover of cotton-like threads, undergo several metamorphoses in early spring and in warm weather prick Spruce buds and lay their eggs. The bases of the leaves swell and a gall is formed (Fig. 169) like a small fir-cone, with the tops of the needles projecting all over the gall. The gall is hollow, and small yellowish lice hatch out there and wander into its various chambers before these become closed by growth. Development takes place inside, and in August the galls, at first green and now brown, open at the edges and winged aphides with black heads and yellowish bodies emerge and lay eggs on the needles of the Spruce under cover of downy threads. From these eggs wingless forms hatch out, which form the galls on the Spruce in the following

[1] Interesting details concerning the genus *Chermes* and the results of spraying experiments made in East Lothian will be found in an article by MacDougall in *Trans. High. and Agri. Socy. Scot.*, vol. xii., 1900, pp. 298-303, from which the following details are taken. See also Board of Agriculture Leaflets Nos. 34 (*Woolly Aphis*) and 104 (*Aphides or Plant-Lice*).

year. In such a case, where the life-cycle is confined to the Spruce, there are two generations (a winged and a wingless) in one year. In this whole life-cycle only females are found, so that the reproduction is a parthenogenesis or "virgin birth."

But simultaneously with the above simpler life-history there may be a more complex life-cycle spread over two years, and consisting of five generations. *Generation i.* of this cycle passes, as before, the winter on the Spruce, and lays its eggs in spring. *Generation ii.* hatches out from these, lives at first in the cone-like galls, and ultimately becomes winged. Some of these winged summer forms migrate from the Spruce to Larch (and sometimes also to Pine), and deposit their eggs on the Larch foliage. This form is then known as *C. laricis.* Soon *Generation iii.* hatches out from these last-laid eggs, small yellow larvæ appearing which suck the Larch-needles for a short time in autumn and then crawl to the bark, where they hibernate in fissures and under bark-scales. They become adult in the following spring and lay their eggs on the young Larch-needles. From these ova *Generation iv.* is hatched out in the form of yellowish woolly aphides (the woolly form of *C. laricis*), which pierce and suck the middle of the Larch-leaves and make them crick or knee. They afterwards get wings and fly back to the Spruce, where they lay their eggs. *Generation v.* hatches out from these, and consists of both males and females, —males being thus produced for the first time in the life-cycle. After pairing, the fertilised ova of Generation v. are deposited and hatch out in late summer and autumn as the wingless females forming Generation i. above described, which pass the winter on the Spruce and produce the cone-like galls in the following spring. —(MacDougall, *op. cit.*, pp. 299-301.)

Fig. 169.



Cone-like gall produced by Chermes abietis *on a Spruce twig—natural size.*

Prevention and Extermination[1] consist in collecting and burning as many of the galls as possible. Useful birds should be encouraged. Spraying with pure paraffin kills the lice after the eggs have hatched out, but does not seem to affect the eggs much (it also kills Pine-sawfly larvæ); but this scorches the foliage of Larch and Spruce, though they recover during the summer, while Pine-leaves are not thereby damaged. Spraying in June with 1 lb. of soft soap dissolved in every gallon of water kills off the insects, but this wash also scorches the young shoots of Spruce, though it does not seem to affect the Larch or Pine foliage. A milder spray, less likely to damage the foliage, and also fairly satisfactory, may be formed of an emulsion of hard soap $\frac{1}{2}$ lb., soft water 1 gallon, and paraffin 2 gallons. The soap is dissolved in boiling water and at once added to the warm paraffin, the two being churned till they form a buttery mass. This stock may be diluted with from eight to ten times its volume of water.

1. **The Spruce-gall Aphis** (*Chermes abietis*) is common all over Britain, and does not seem to receive the attention it deserves (Fig. 169).

Appearance.—This louse is only about $\frac{1}{12}$ of an inch long, and yellowish-green to light-brown, with (when present) white wings and whitish bloom.

Life-history.—It bores into the buds of young Spruce of 10 to 20 years old, and lays about 20 to 30 eggs on the edges of the scales. On hatching out the

[1] *It is only by collecting and destroying the galls of* **C. abietis** *on Spruce, that the Larch aphis* (**C. laricis**) *can possibly be exterminated.*

young lice suck the sap, and a cone-like gall (false-cone) is formed by the compressed needles. This false-cone (Fig. 169) is at first green, but turns ruddy-brown. After it has opened at the edges of the leaf-bracts to let the fully developed louse emerge in July and August, it becomes dry, hard, and dull-brown. Side-shoots are much more attacked than leaders; and this is fortunate, because punctured shoots become curved and bent. If badly attacked, the poles soon become sickly and unhealthy.

Prevention and Extermination consist in cutting off the galls, and drying and burning them.[1]

2. **The Larch Aphis** (*Chermes laricis*), though small, occurs in such large numbers sometimes that it does great damage to plantations (Fig. 170). According to Loudon, it was first observed on the Larch at Raith (Fifeshire) about 1785, and it appeared in the Athole plantations in 1795. It generally attacks unhealthy trees and plantations, and is seldom found in healthy and thriving woods. Its attacks might be far less frequent and destructive if the Larch were grown in mixed woods. The aphis usually appears, and most frequently on trees of 10 to 20 years old, about the beginning of May, and soon seems to be enveloped in a whitish coating like filaments of cotton. The lice are sometimes found in such numbers as to make the trees look white all over. During the whole season they go on producing eggs.

Fig. 170.

Damage done by the Larch-Bug or Larch Aphis (Chermes laricis) *—natural size.*

a. The lice at work sucking out the sap from the leaves, which consequently get bent at these places.

Appearance.—A small, oval, purplish-black or blackish-brown louse, less than $\frac{1}{12}$ of an inch long, and covered with fluffy white woolly down, but becoming dirty-green when it gets wings. This is merely the sexless form of *Chermes abietis*. It has a long bristle-like sucker, with which the louse penetrates the Larch-needles to feed on their sap.

Life-history.—Towards the end of April this sexless form of aphis lays 40 to 50 eggs on the twigs. On hatching out the young lice scatter themselves over the needles, and do not live enclosed in a gall. At first very minute, they grow quickly, and get covered with whitish woolly down from the honey-dew exuded from their pores. When these swarm in large numbers, the trees look as if covered with scattered snow-crystals. From about June till August they get wings and fly about and lay eggs, from which further broods are produced till the autumn. This aphis may attack Larch of all ages, but is most frequently found on poles of 10 to 20 years of age. It is often also troublesome in nurseries.

Prevention and Extermination.—By far the best measure is to collect and destroy the galls of the Spruce aphis (*C. abietis*), the sexual form of the insect. Otherwise spraying with insecticides, such as soft soap and paraffin emulsions, &c., is the only remedy to try and kill off the pest while in its sexless form on the Larch (see footnote on opposite page).

[1] Where this aphis is abundant, the formation of mixed woods of Spruce and Larch must provide the most favourable conditions for breeding this pest on these two trees.

3. **The Red Spruce Aphis** (*Chermes coccineus*) is smaller than *C. abietis*, and brownish-red with a white downy spot behind. Its life-history is similar, but its development is quicker, so that three to four generations in one year are common. The false-cones are much smaller than those of *C. abietis*, and are usually found at the tip of twigs without any shoots above them. Green at first, they afterwards turn red and then brown.—The galls should be collected and destroyed.

Various aphidæ are found on broad-leaved trees, where they do far less harm than on conifers. These include **The Elm-gall Aphis** (*Tetraneura ulmi*), causing the formation of small club-like galls about the size of a pea or bean on the upper side of Elm-leaves. **The Elm-blister Aphis** (*Schizoneura lanuginosa*) produces large hairy galls on the tips of Elm shoots and foliage. During the summer these blister-galls, at first green and red, but turning brown as they dry and harden, contain a sticky viscous fluid in which the lice live from June till August. **The Ash Aphis** (*Chermes fraxini*) produces canker-like spots on the bark of the Ash. **The Thorn-Fly** (*Aphis cratægi*) is found on young Thorn-hedges, and on Thorn plants in nurseries.

B. **Scale or Blight Insects** (*Coccidæ*).—It is to this family that the felted scale of the Beech belongs, and other scales common on many kinds of woodland trees, the **Scale** being a small insect found clinging to the bark.

The females are minute imperfectly formed insects, and never have wings. They attach themselves to bark or leaves, and cover themselves with a felty scale, beneath which they feed on the sap, lay eggs, and die. The adult males are usually winged, but live only a short time.

The Beech, when old and weakly, or after severe attacks of the Beech weevil (*Orchestes fagi*) or heavy mast years, is apt to be attacked by the **felted Beech-Scale** (*Cryptococcus fagi*)—formerly erroneously called the **Beech Aphis** (*Chermes fagi*)—but the attacks seldom take place on trees in vigorous growth. When badly attacked, the bark loosens and the tree dies. Where the bark has been punctured small round galls form, which swell and burst, while the gall-tissue in the cortex becomes brown and dies. The canker-fungus (*Nectria ditissima*) very often attacks Beech-trees at the same time as this insect. Trees badly attacked usually die within a few years. The Beech-Scale is now a serious pest, and is increasing.

The adult female is lemon-yellow, and about $\frac{1}{25}$th of an inch long. The male has not as yet been discovered. The best *preventive and exterminative measures* are brushing with paraffin emulsion, or winter-washing with caustic alkali wash. See Board of Agriculture Leaflet No. 70 (*Winter-Washing of Fruit-Trees*).

Young Ash-trees after heavy thinning, or when growing on light gravelly soil, are exposed to attacks of the **Ash Coccus** (*Apterococcus fraxini*), while both Ash and Willow suffer from attacks of the **felted White-Scale** *Coccus* (*Chionaspis*) *salicis*. In this latter case, where soil or situation is at fault, the trees affected are never likely to thrive; but where they appear to have been injured by too severe thinning, the case is different. Such trees may be strengthened by scraping off the outer bark with the scale, or by applying a caustic alkali solution—or a strong emulsion made of soft soap (dissolved in hot water) and paraffin, or of ½ pint paraffin to 1 gallon coal-tar—with a hard brush to destroy the eggs.

The scale is easily distinguished by the appearance of the insect upon the surface of the bark. It presents itself as very numerous small white felty spots, and if a stone be taken and drawn roughly along the bark, it will be tinged red with the blood of the insects. If scraping and washing have not been effective, the young insects may be sprayed with paraffin emulsion in May, when they are seeking their feeding-places.

A black variety of Scale is produced on the bark of branches and twigs of young 5- to 15-year-old Spruce by *Coccus racemosus*, and on Silver Fir by *Coccus corticalis.*

VI. **Straight-winged Insects** (*Orthoptera*).

The insects of this order have (like the Hemiptera) only an imperfect metamorphosis. The wingless larva closely resembles the complete insect; while the pupa only differs from the latter in having rudimentary wings, not strong enough to fly with. During all these three stages of development the insect crawls about and continues to feed. For the forester, the most important family in this order is the Crickets (*Gryllidæ*).

Fig. 171.

The Mole-Cricket (Gryllotalpa vulgaris)—*natural size.*

a. Imago when full-grown (natural size).
b. c. Larva at different stages of early development.

Crickets (*Gryllidæ.*)

Crickets with cylindrical bodies and strong fore-legs adapted for burrowing; hind-wings folding lengthways and extending beyond the wing-cases, but often absent or aborted; by rubbing the wing-cases together a chirping sound is produced; some kinds with, and some without, a long ovipositor; antennæ long and bristly; head free and thick. *Generation* annual.

The Mole-Cricket (*Gryllus gryllotalpa*, syn. *Gryllotalpa vulgaris*).

The mole-cricket is for the most part carnivorous, and it is thus sometimes useful in destroying noxious insects, such as cockchafer-grubs and other larvæ. But in forming its underground runs it is also destructive of seedlings in nurseries, for in making its runs (of about the breadth of a finger) it bites through all roots in its way, and makes seedlings and transplants wither and die. Damage of this sort is usually worst in Pine and Spruce seed-beds.

Appearance.—This insect is easily recognisable by its powerful hand-shaped fore-legs with strong claws, formed like a mole's for digging. The wingless larva resembles the fully developed insect, and there is no distinct pupal stage, gradual changes taking place at each time of moulting the skin. The pseudo-pupa (*nymph*) only differs from the perfect insect by having rudimentary instead of as yet completely developed wings; it crawls about and feeds like both larva and imago (Fig. 171). The cricket is $1\frac{1}{2}$ to $1\frac{3}{4}$ inch long, ruddy or dark-brown above, and lighter below; the short wing-cases, veined with black, do not cover the whole of the hind-wings; abdomen with two long tail-processes; fore-legs strong, and armed with claws for burrowing.

Life-history.—Pairing takes place in May and June, when both the male and female chirp underground. The female lays up to about 150 to 200 pale-yellow eggs, about the size of hempseed, inside a nest-hole hollowed out of a clump of earth as big as a fist, cemented with slimy saliva, and formed about 3 to 4 inches deep in the ground.

The larvæ hatch out in July, in about two to three weeks. At first whitish, but turning brownish, and then darker later on, they soon wander throughout the soil and feed. In October or November they hibernate under ground (after three moults), and in all moult their skin four times before the "nymph" or masked form of pupa finally develops into the perfect insect in the following May or June. The female cricket keeps careful watch over the entrance-hole of the nest containing her eggs, but at the same time also actually devours a large number of her progeny.

Prevention and Extermination.—The eggs may be taken from the nests in June and July, if these be found by tracking the converging runs that go deeper into the ground as they get near the nest. The runs are marked by air-holes in the soil, about the size of holes made with the point of a walking-stick, and by the withering and dying seedlings ; yet it is not easy to find the nests, as they often lie about 10 inches deep.

Laying out ordinary flower-pots (with the bottom-holes stopped with cork) about 6 feet apart, and stretching lath-like pieces of wood from pot to pot, sometimes traps crickets wandering after nightfall during the pairing-time. Being forced to go along the edge of the lath they tumble into the pots, where they can be collected and destroyed.

When the mole-crickets are chirping and calling to each other while pairing in May and June, they can often be caught by cautiously approaching the place whence the chirping comes, and then suddenly dislodging the insect by lifting a clod with a hoe.

As the freshly-formed runs are easily distinguishable after rain, a spoonful of petroleum, oil, or tar may be poured into them, and then water added until the runs are full. Whenever the cricket is touched by the oil it at once ascends for fresh air, and then can easily be caught and killed.

Mites (*Acarina*), a low order of the *Arachnida*, constituting a sub-class of the *Arthropoda*, and including scorpions, spiders, mites, &c., include at least one species which often infests the bark and leaves of many trees, the so-called **Red Spider, Spinning Mite,** or **"Fire-blast Insect"** (*Tetranychus telarius*), found under the bark and upon the leaves of Elm, Poplar, Lime, Spruce, and Scots Pine. It causes the leaves of trees attacked to turn brown ("fire-blast"), and generally to fall off altogether ; so that in this way many trees are weakened and their bark injured by these pests. They abound chiefly in dry warm weather, and are seldom to be found during a wet season.

This Mite spends the winter in crevices of wood (living or dead) and under stones, then emerges about middle of May, and attacks leaves of woodland and orchard trees and shrubs, sucking the sap, and clogging the pores with a finely-spun web. Within this web it lays its eggs, which soon hatch out and multiply quickly. The young are 6-legged at first, but afterwards have 8 legs. In hot dry years the larvæ collect like red dust on the lower side of the leaves ; but heavy rain kills them in large numbers.

Prevention and Extermination.—Washing with a strong emulsion of soft soap and paraffin, or spraying with a lye formed of boiling 1 lb. of flour of sulphur and 2 lb. fresh lime in 4 gallons water, sprayed on from time to time till the pests are destroyed. 2½ lb. of sulphide of potassium (liver of sulphur) dissolved in 100 gallons of water is a good spray on hops. See also Board of Agriculture Leaflet No. 41 (*Red Spiders*).

Two other genera of Red Spiders (*Bryobia, Tenuipalpus*) are destructive to fruit-trees and berry-bushes.

CHAPTER V.

PROTECTION AGAINST WEEDS AND PARASITIC PLANTS.

Plants of various kinds may interfere with the growth of timber crops, either by overrunning the soil as *weeds* overtopping seedlings and plants in young plantations, or else as *epiphytes*, or as *parasites* and *fungi* growing on or in trees, and frequently causing disease. Fungous diseases, often epidemic, always damage the buds, leaves, roots, or timber of trees attacked, and may cause the death of single trees or of large blocks of plantations.

A. **Weeds** comprise all vegetation interfering with the vigorous growth or regeneration of timber crops. Natural regeneration is often rendered difficult, and sometimes even impossible, when the soil is overgrown with rank weeds, the roots of which mat the ground, thus preventing the rootlets of young plants from ramifying throughout the soil, besides intercepting rain, and interfering with the aeration of the soil. Special measures have then often to be taken to destroy the weeds before sowing or planting has any fair chance of succeeding. On moorland covered with heather the thick close network of roots often mats the soil, so that the cost of planting is often much heavier than it otherwise would be, owing to stout transplants being required.

A dense soil-covering of weeds extracts from the soil large quantities of soluble salts, part of which, at any rate, might have gone to nourish the timber-crops. Unless the weeds are removed and used as manure, litter, &c., the mineral nutrients are, it is true, returned to the soil on decomposition; but they are again withdrawn by a fresh growth of weeds, so that they are practically lost to the timber-crop. Weeds also hinder light rainfall from penetrating into the soil, because much of it is caught on the leaves and quickly evaporated.

Grass and other quick-growing weeds soon outgrow and top young plants in plantations, and then at once interfere with their growth by withdrawing light, air, and dew from them. And when the weeds die in autumn they often overlay the young plants and press them down to the ground during heavy snow-storms, sometimes smothering them completely. Spreading weeds like brambles, and creepers like honeysuckle, convolvulus, and wild hops, often completely overgrow the young plants and gradually suffocate them. Swamp-mosses increase the soil-moisture to an excessive degree and cause the formation of bogs; while in other places a strong growth of rank grass may soon cause the soil to become dried up, owing to rapid transpiration of moisture from the upper layers. For this reason plantations are often backward when there is a rank growth of grass. Through rapid transpiration and radiation of heat in spring plants standing among grass often suffer from late frost, while similar plants growing on similar soil, but not surrounded with grass, remain undamaged. A dense mass of tufts of grass also harbours mice, voles, and insects, which may sometimes do a great deal of damage in young plantations.

The trees most likely to be interfered with and hindered in growth by weeds are, of course, light-demanding kinds which are of slow growth while young. Quick-growing and shade-enduring kinds are less exposed to danger. Thus Oak, Ash, Elm, and Sweet-Chestnut among broad-leaved trees, and Silver Fir and Spruce among conifers, are, owing to their slow rate of growth at first, more liable to injury than most other trees, while Birch, Willows, Poplars, Larch, Pines, and Douglas Fir are quickest in outgrowing the reach of weeds, and thus getting clear of danger.

Weeds may, however, under certain circumstances, be of considerable use. They are undoubtedly useful in holding together the soil on very steep slopes, in binding drifting-sand, and in protecting very young plantations against frost and insolation if the weeds (such as furze, broom, and juniper) are high enough and not too thick. Heather often affords protection to Scots Pine seedlings during natural regeneration; and many a self-sown Oak owes its existence to the acorns having dropped by chance among holly or other prickly shrubs, that have protected it against the bite of cattle. Sometimes weeds can also be used as fodder, litter, or manure (heath, heather, bracken, broom, furze, dry grass), or it may sometimes even pay to have their fruits collected for sale (whortleberry, cranberry, raspberry, brambles).

The more important Weeds.—When timber-crops are grown in close canopy, the amount of light reaching the soil is seldom sufficient to admit of a dense growth of weeds overrunning the soil. But when the leaf-canopy becomes interrupted (*e.g.*, as in old Larch- and Pine-woods, or in Beech-woods undergoing natural regeneration), or when mature timber is cleared, a thick growth of weeds soon makes its appearance. When any densely-shaded woodland area (like a Spruce or Silver Fir wood in close canopy) is thus suddenly cleared, it is extraordinary how rapidly the soil gets covered with a strong growth of weeds of all sorts, whose extremely light seeds, carried in the excreta of birds or provided with wings and feathery crowns making them easily wind-borne for a great distance, have perhaps long been lying undeveloped on the soil, and unable to germinate through want of sufficient light.

The fresher and the more fertile any soil is, the more likely is it to be overrun with weeds, the stronger is their growth, and the greater their variety and number. On poor soil the reverse is the case, so that sometimes one weed, like heather, dominates extensive areas. Where many different varieties of weeds are to be seen, this is always the sign of a fairly good, and particularly of a fresh soil. Climatic conditions, of course, also regulate the growth of weeds, as the mountain flora is different from that of the lower hills and plains. And the amount of light obtainable also determines both the kinds of weeds that grow, and the extent to which they cover the ground. Thus whortleberry, for example, grows best and thickest in half-shade, while grass, heather, furze, and broom grow most luxuriantly in full exposure to light.

The forest weeds may be *herbaceous*, like grasses, epilobium, foxglove, &c., which die down annually, or they may have *woody-fibrous* stems that are perennial; and in this latter case they may either be dwarfish plants, like heather, heath, and whortleberry, or else shrubs like hawthorn, dogwood, and dwarf elder. And a number of quick-growing softwoods, prone to spring up in large numbers and strong in growth where not wanted, must also at times be reckoned as weeds. Aspen and Saugh, or even Birch and Alder, often thus prove exceedingly troublesome, and have to be treated more or less as weeds, even though at other times, and in their own proper place when wanted, they are cultivated as useful and profitable trees.

The following are the more important weeds usually found in woodlands, and they are here classified according to the class of soil they naturally prefer :—

1. **On Wet, Boggy, or Peaty Soil**: Peat-moss (*Sphagnum*), Hair-moss (*Polytrichum*), Bell-heather (*Erica tetralix* and *E. cinerea*), Cranberry (*Vaccinium oxycoccos*), Bog-whortleberry or Great-bilberry (*Vaccinium uliginosum*), Lousewort (*Pedicularis*), Dock (*Rumex*), Cotton-grass (*Eriophorum*), Horse-tail (*Equisetum*), and different species of Sedges (*Carex*), Bulrushes (*Scirpus*), and Rushes (*Juncus*).

2. **On Fresh, Fertile, or Humose Soil**: Raspberry (*Rubus idæus*), Blackberry or Bramble (*Rubus fruticosus*), Briar (*Rosa*), Foxglove (*Digitalis purpurea*), Willow Herb (*Epilobium angustifolium*), deadly Nightshade (*Atropa belladonna*), black Nightshade (*Solanum nigrum*), Balsam (*Impatiens noli-me-tangere*), stinging Nettle (*Urtica dioica*), Hemp-nettle (*Galeopsis tetrahit*), Vetch (*Vicia*), and Clover (*Trifolium*), Bracken and other ferns, as well as broad-leaved grasses.

3. **On Dry Loam and on Sandy Soil**: Ling or Heather (*Calluna vulgaris*), Whortleberry, Bilberry, or Blaeberry (*Vaccinium myrtillus*), Myrtle-Bilberry, Cowberry, or red Whortleberry (*Vaccinium vitis idæa*), Furze, Gorse, or Whin (*Ulex europæus*), Broom (*Sarothamnus scoparius*), Greenwood (*Genista*), Groundsel or Ragwort (*Senecio*), Mullein (*Verbascum*), Hawkweed (*Hieracium*), Spurge (*Euphorbia*), and various narrow-leaved meadow-grasses; while on very sandy soil characteristic plants include Sand-sedge (*Carex*), Lyme-grass (*Elymus*), Bent (*Agrostis*), and Marram-grass (*Ammophila, Psamma*).

4. **On Salt Soil**: Marsh-samphire (*Salicornia*), Salt-wort (*Salsola*), Sea-milk-worts (*Plantago, Glaux*), and similar plants.

Shrubs, most frequently to be found among hills and valleys with fresh soil, include Dogwood (*Cornus sanguinea*), Alder Buckthorn or Black Alder (*Rhamnus frangula*), Blackthorn or Sloe (*Prunus spinosa*), Hawthorn (*Cratægus*), Spindlewood (*Euonymus*), Guelder-rose (*Viburnum*), Barberry (*Berberis*), Holly (*Ilex*), Honeysuckle (*Lonicera*), Privet (*Ligustrum*), Elderberry (*Sambucus*); and on drier soil, Juniper (*Juniperus*). Sea-Buckthorn (*Hippophaë rhamnoides*) is characteristic of sandy soil.

Weeds not only give a general indication as to the nature of the soil, but also to a certain extent indicate its physical properties. The number of plants, however, that are more or less constant with regard to the mineral soil (so as only to be found on clay, lime, or sand, for example), is very limited, although general preferences of this sort are clearly noticeable in most weeds. Like our trees themselves, the woodland weeds are divisible into the two classes of *light-demanding* and *shade-enduring*. To the former belong heather, furze, broom, and most of the plants characteristic of poor and sandy soil; to the latter belong holly, dogwood, and many other shrubs; while whortleberry, bramble, raspberry, and grasses thrive in the subdued light of old woods.

Continental Note.—The moister and the better the soil, and the more light that falls on the ground, so much the more varied and luxuriant is the soil-covering; while on inferior soil, and where there is merely subdued light, only few weeds cover the ground,—mostly heather in the former case and whortleberry in the latter. The demands of the different kinds of weeds for light and for certain conditions of soil are often so very characteristic that the forester can draw important conclusions from their appearance. Thus, when a sprinkling of weeds is noticeable in Beech seed-fellings, this tells him that there is sufficient light for the future crop to germinate in, whereas in Oak pole-woods it is a sign that it is just about time when underplanting is necessary. Where heather grows rank, there is no use of trying to grow crops making high demands on the soil; while raspberries and nightshade indicate that the soil is still moist and fertile, and rushes point to stagnant water.—(Fürst, *Forstschutz* in Lorey's *Handbuch der Forstwissenschaft*, 2nd ed., 1903, vol. ii. p. 66.)

Prevention and Extermination of Weeds.—If undesirable Birch, Aspen, or Willow have to be got rid of, it is often far more effective (especially as regards Aspen) to cut a broad (12 to 15 inches) girdle deep into the wood, as this dries and exhausts the tree. This is often far more efficacious, as well as much cheaper and less troublesome, than waging a long warfare by way of cutting shoots and suckers. The growth of ground-weeds in such quantity as to injure young plantations, and other woods, can best be prevented by taking early steps to drain wet land previous to planting, and in keeping pole-crops and older woods in close canopy. The planting of woodlands as soon as possible after clearance, and the use of stout transplants in place of small seedlings, are both measures which of course tend to minimise risk from weeds.

There may already, however, be a strong growth of grasses or other weeds on the land to be planted; or they may at once overrun the ground as soon as the fall of the mature crop takes place; or they may spring up in blanks caused by fires, windfall, snow-break, or insects; and in all such cases the weeds have to be kept in check before young plantations can succeed in establishing themselves, and can begin to grow vigorously.

The removal of weeds can sometimes be arranged for without incurring outlay—*e.g.*, if heather, broom, or bracken can be used as litter or manure. But before planting operations can be carried out, clearance of the weeds is necessary in one way or another, even if only a partial clearance be made in strips, as answers well in the case of heather and berries, though this may have to be repeated. The burning of heather tracts and the cutting over of furze are often also advisable (see vol. i. Part III., *Sylviculture*, p. 422), although in some cases heather can be checked sufficiently in growth by herding sheep on it before planting. Where heather is burned as soil-preparation before planting, the block to be fired should have a 6- to 10-foot fire-trace cleared round it, and the burning should take place against wind on dry still days in early spring.

A strong growth of grass, apt to overshadow and choke young plants in summer, and to overlay and crush them in winter, can be removed by being cut with the sickle, or by being pulled out along with the roots in wisps. It is better to tread down or to smash and injure bramble-shoots with a bludgeon than to cut them back, as this only makes them throw out a strong flush of fresh shoots and suckers. Bracken on hillsides can best be checked in growth by lopping close to the ground with a switch-bill in spring, just when their brittle rolled-up young fronds are beginning to open.

Shrubs and other woody-fibrous plants should be cut through or hacked out of the soil with a hoe or mattock. This should be done about the middle of summer, because the shoots which may spring from the stool will then not only be fewer, but will also be more likely to get nipped by autumn and winter frost before the shoots ripen into hard wood. Blackthorn and hawthorn are often very troublesome; they are difficult to cut because of their thorns, and they have a strong reproductive capacity in shooting from the stool. If such shrubs, and also softwoods, are cut back in spring, piling heaps of earth (not too small in size) over the stools immediately after cutting often hinders their throwing out stool-shoots.

To obviate a strong growth of weeds in nurseries, the forester must avoid sites with damp soil, or near open areas from which the seeds of weeds can be wind-borne. Whenever available, old arable land free from weeds is preferable. Caution, too, should be used in manuring with compost formed from heaps of garden rubbish, as this often contains many weeds removed about their seeding-time; and as these seeds retain germinative power for a very long time, the use of such compost often leads to a very strong growth of weeds on the nursery seed-beds. Garden rubbish should therefore be burned and only the ashes thrown on the compost heap. So too, when leaf-mould is brought from the woods to pile on compost heaps, fungi (*Botrytis* especially) are often brought, which ultimately infect the seed-beds and cause much loss, among coniferous seedlings especially. When, in spite of such precautions, weeds make their appearance, they should be hoed after heavy rainfall or during damp weather, and all their roots removed. Spreading sawdust between the nursery-rows also prevents the growth of weeds and keeps the surface soil moist, while it also prevents the soil being lifted by frost.

B. **Epiphytic Plants.**—The chief plants of this kind usually found in British woodlands are Ivy, and Beard-mosses (*Usnea*) and other Lichens.

1. **Ivy** (*Hedera helix*) is a non-parasitic plant. It obtains its nourishment mostly from the soil, and the rootlets attached to stems and branches are mainly tentacles for support. Unless where desired for ornament, it should be cut through near the ground, the operation being repeated if necessary; because if allowed to grow unchecked, it soon interferes with the well-being of the crop.

2. **Lichens**, though not parasites, are produced on trees in consequence of damp air and flagging energy in growth. While the growth in girth is very slow, the bark is shed so gradually that lichens are able to fix themselves on this. And by mechanically closing the *lenticels* or air-holes of the bark through which the tree transpires and absorbs oxygen, the health of the tree is injured, and branches die off inside the crown. Unless checked this injury will often spread quickly and kill off a large number of trees. In the case of ornamental trees this can be remedied by scraping and pruning; but where bad cases occur to a large extent in woodlands, it is a sign that the situation is not well suited to the kind of crop grown on that particular spot.

3. **Beard-mosses** (*Usnea barbata*) and similar growths are also, like other lichens, due to dampness of the atmosphere, and are rather indications of want of vigorous growth and of unsuitable environment than actual symptoms of any diseased condition. Where they are plentiful, however, fungous diseases (*Æcidium*, &c.) will generally be found attacking the timber-crops in unusual numbers, due partly to the lowered vitality of the trees and partly to the dampness of the atmosphere.

Extermination.—Lichens and Mosses can often be destroyed by brushing with a 10 per cent solution of sulphate of iron (1 lb. to a gallon of water). Caustic Alkali Wash (1 lb. caustic soda and 1 lb. pearl ashes, each dissolved in 5 gallons water, then mixed, and ¾ lb. of soft soap added) is stronger and more effective, but must be used with care. (See Board of Agriculture Leaflet No. 70, *Winter-Washing of Fruit-Trees.*)

4. **Small Climbing Plants.**—The woody-fibrous Honeysuckle or Woodbine (*Lonicera*) and Traveller's Joy or Old Man's Beard (*Clematis*) do damage by twining round the stems of saplings and young poles, constricting the stems and often finally strangling them; while the climbing Bindweed (*Convolvulus*) and Wild Hops (*Humulus*) act as a dead weight in bending down slender stems in coppices and osiers-beds. They can only be exterminated by being dug out with all their roots.

C. **Parasitic Plants.**—With the exception of mistletoe and dodder, nearly all the parasitic plants in our woodlands are fungi, which cause diseases of various kinds, some of which extend in dangerous epidemic form.

Mistletoe (*Viscum album*) is commonest on Apple-trees (seldom on Pear-trees) in orchards, but is also found on Poplars, Lime, Willows, Birch, Maple, Scots Pine, and Silver Fir; rarely, if ever, on Oak, and never on Beech, Alder, Larch, or Spruce. It often forms large bushes with greenish-yellow leaves persistent throughout the winter. Its extension and reproduction are probably mainly due to thrushes. They feed on its white berries, and leave portions of them, containing some of the seeds, on the bark of the tree when cleansing their beaks from the sticky flesh of the fruit.

On seeds germinating on a smooth thin-barked branch some rootlet finds its way, under favourable circumstances, in through the bark of the tree to the xylem, and forms the first penetrating rootlet (*haustorium* or *sucker*). During the following year this rootlet gets overgrown and enclosed in the new annual ring formed. But it retains direct connection with part of the plant flourishing outside of the branch infected; and as the mistletoe grows, this first penetrating rootlet also enlarges and extends sidewards through the phloëm, annually throwing out new *haustoria* or suckers. As these live a long time and gradually become overgrown with many annual rings, they often extend as deep as 4 inches into the wood. And as they rapidly decompose when they die, the infected part is riddled with holes. The part of the branch above the swelling caused by the mistletoe usually dies some time afterwards. If the damage is confined to branches it is of no great consequence. But in woods of Silver Fir and Scots Pine mistletoe sometimes appears in large quantities, and when it manages to get into the stem it makes the bole swollen and deformed, while the holes render its timber useless for technical purposes.

The extermination of mistletoe is easy enough in orchards, if desired. In woodlands, branches infected should be pruned off, and stems attacked should be thinned out to prevent the spread of this parasite by birds; but cutting off the visible outside part of the plant is of little use, as the roots within the tree soon send out fresh shoots to elaborate the sap drawn from the host.

Dodder (*Cuscuta*), far more harmful to field-crops than to nurseries or plantations, sometimes attacks osier-beds and spoils the rods where the *haustoria* or suckers pierce them. Shoots attacked should be cut and burned about the end of June. As the dodder-seed retains germinative power for two or three years, when once the osiers begin to be attacked the damage may continue for the next year or two, so that a careful watch has to be kept and the cutting out of rods continued till the pest is eradicated.

Fungous Diseases.—Many of the organic disturbances in plants, varying from petty interference in vegetative processes up to serious disease, resulting in the death of trees, are directly due to attacks of parasitic cryptogamous plants called **Fungi**.

Neither fungous nor any other diseases of trees can be transmitted through seed collected from infected trees, though the plants raised from such seed may perhaps be found weakly and predisposed to attacks from insects and fungi.

Fungi are lowly organised plants consisting only of cells, which may sometimes become hardened. They do not assimilate like green plants. They have no chlorophyll, and consequently cannot elaborate carbon for themselves, but are dependent for carbon on the supplies they can withdraw from other organic combinations. Such essential nutriment they must therefore obtain from either living or dead animal or vegetable organisms.

Life-history of Fungi.—All the fungi which attack trees and damage them to a greater or less extent belong to the higher or filamental order of this class of plants, namely, to those whose vegetative portion (*mycelium*) providing nourishment, and living on in the substratum, consists of long branching filaments (*hyphæ*) capable of growing at their points, and whose elongated cells are (except in the *Phycomycetes*) divided into cell-rows by transverse walls (*septa*). The *mycelium* develops from the *spores* or reproductive organs. The conditions required for the germination of the spores are merely water, oxygen, and a slight degree of warmth; given these the germinal *hyphæ* can be produced anywhere, but darkness favours the growth of the fungus.

In many fungi the vegetative portion does not adhere merely to the typical simple form of *mycelium*, but assumes the more complex forms of compact bundles of mycelial strands (*rhizomorpha*) with branching root-like processes. The tissue of these strands differs from that of higher plants in their extreme ramification, and in the separate *hyphæ* gradually uniting to form the *rhizomorpha*. In fungi which contain little water, the *hyphæ* become filled with nutrients, and then unite to form tuber-like masses, with very much thickened cell-walls. These are called *sclerotia*, and fungi which develop *sclerotia* have always a long vegetative existence; they may lie dormant, and may for a long time appear dry and dead, but once given favourable conditions they resume active vegetation again, and proceed to grow and produce spores.

The protoplasm of fungi usually contains a large proportion of water and a good deal of oil, but no starch and no organs for providing chlorophyll. The cell-wall does not consist of cellulose (except in the *Saprolegniaceæ* and *Peronosporaceæ*), but to a greater or less extent of chitin (the substance of which the wing-cases and outer covering of insects consist), together with considerable quantities of substances containing little or no nitrogen (but not true cellulose), and of other carbohydrates used for constructing cell-walls.[1]

Usually from about a quarter to a half of the ash of fungi is found to consist of potash and phosphoric acid; but otherwise it contains much the same constituents as the ash of green plants, except lime, sufficient supplies of which the fungi can always obtain from its host.

The *mycelium* of parasitic fungi lives either *epiphytically* on the surface of the parts of plants attacked, or else *endophytically* in the interior of its host. Epiphytic fungi obtain their nourishment by means of special side-branches extending between the walls of the epidermal cells; whereas, on the other hand, endophytic fungi either extend their *mycelium* intercellularly (e.g., *Uredineæ* or *rusts*), or again by means of special *haustoria* or suckers, when they withdraw the cell-contents by pure osmosis, or else intracellularly, when they pierce the living cells of their host. As the growing-points of the *hyphæ* extend they generate and give off various crude ferments which enable them to bore through the cell-walls and imbibe their nourishment. By means of these ferments the cellulose and the pectine contained in the cell-walls is dissolved, the woody tissue is broken up and the cellulose consumed, and the various glucosides (such as coniferin, salicin, amygdalin, &c.) are transformed into carbohydrates serving for the nourishment of the fungi, while albuminoids, starch, and oils are all likewise dissolved.

Fungi which complete the whole of their life-cycle upon one host-plant are called *autoxenous* or *autœcious*, while *metoxenous* or *heterœcious* fungi are those which spend one part of their life on a second kind of host; and in this latter case the second host is usually quite a different genus of plant from the first, while the fungus during this intermediate stage appears as if also belonging to quite a different genus (see p. 171 below).

Parasitic fungi may either attack only one particular kind of tree, or they may infest different kinds and portions of trees, and in different stages of growth and conditions of health. But seedlings, saplings, poles or trees predisposed to infection by unsuitable soil or situation, insufficient light (dominated stems, &c.) or weakly condition (after insect attacks, &c.), are of course far more liable to infection than healthy plants growing under normal conditions, and with favourable environment. Some fungi only attack live tissue during the non-vegetative winter period of rest of a plant, while others infest it during the vegetative period. Some fungi can only penetrate into the seed-leaves, so that plants outgrow danger on shedding their cotyledons; others can only attack foliage while the leaves are

[1] Klein, *Forstbotanik*, in Lorey's *Handbuch der Forstwissenschaft*, 2nd ed., 1903, pp. 382-411. This excellent and most recent *résumé* of the fungous diseases of trees has mainly been utilised in bringing the following pages up to date.

still without the protection of a good tough cuticle. Mild damp weather increases danger of fungous infection; and in this respect our mild moist climate, with its long spring and autumn, and its comparatively mild winter, is most distinctly favourable to the dissemination and the growth of parasitic fungi, and the spread of the serious epidemic diseases they often cause in timber-crops. The more destructive of these sometimes in Continental woodlands destroy the whole of extensive natural regenerations, sowings, and replantations. The effects on pole-woods in Britain are only too well known in the case of the Larch-canker; and even old woods can be seriously injured, as in the case of the Pine-canker. But the results of destructive fungous epidemics are always greatest when infection precedes, is simultaneous with, or follows attacks by insects.

The Fructification of Fungi takes place by means of well-defined spore-producers (*sporangia*) found on special branches (*sporophores*) of the *hyphæ*, which produce vast numbers of germinative cells of different kinds, called *spores* generally, or *sporidia* when they are secondary spores formed on a promycelium formed by the germination of hibernating or resting-spores, and *gonidia* or *conidia* when formed at the points of *hyphæ* usually growing erect. On being set free all these different kinds of spores can, under suitable climatic and atmospheric conditions, develop into a new generation of fungi.

Those *spores* which are produced sexually through the union of two cells or energids are termed *ovispores* (*oospores* or *zygospores*), and are "resting-spores" well provided with nutriment, by means of which they can germinate even after lying dormant for a very long time (up to three or four years). Those produced asexually are called *conidia* or *gonidia*, and (except the *chlamydospores*) perish in a few days unless they find, on being scattered far and wide in enormous numbers by wind, insects and other animals, water, &c., conditions favourable to their germination. These asexually-formed *conidia* are usually much more minute, and are produced in far greater number than the sexually formed *oospores*; but in both cases fructification is usually most common in autumn, about October.

The *conidia* are formed singly, or in rows at the end of simple *sporophores* (special *hyphæ* or mycelial filaments which usually grow erect). At first they are usually 1-celled, but in most cases they become many-celled through subdivision.

When the *mycelium* produces no *conidia*-bearers, but is wholly or partially divided into short pieces like *conidia*, the spores are called *oidia*; while they are termed *chlamydospores* when the membrane of such *oidia* becomes thickened and reserve-nutrients are stored up in it. A fungus can have more than one form of fructification, and then it is said to be *pleomorphous*.

Spores usually retain life for a longer period than the *mycelium*, and especially during time of drought, when many spores have great power of withstanding the effects of high temperature. And at the same time most spores can stand almost any degree of cold, whereas low temperature often kills the *mycelium*, especially if it be soft and oily (but not when it forms hard *sclerotia*).

Most **fungi** are fortunately **saprophytic**, and only a comparatively small number are **parasitic**.[1] Saprophytic fungi only live on dead and decomposing substances, and are therefore merely an accompaniment or consequence of disease, and not its cause. Parasitic fungi, however, attack healthy living plants, and are a direct cause of disease, often ending in death; but many parasitic fungi continue

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[1] The only known cases in which fungi are of use to trees are those in which the *mycorhiza* or thickly-matted mycelium of root-fungi underground give symbiotic aid in accumulating stores of nitrogen from the soil. They are especially active in the root-nodules of all leguminous plants, and also of the Alder. Similar fungi are also found on the roots of Beech, Oak, Willows, and conifers, &c., assisting in nutrition, and useful in aerating the soil. The *mycodomatia* inhabiting the bacteriads utilise the free nitrogen of the air, and do not form a mycelium.

to grow saprophytically when once they have killed the plant attacked. Few of the *slime-fungi* (*Myxomycetes*) are parasitic, most are saprophytic ; and most of the *Ascomycetes* and *Hyphomycetes* are also saprophytic, whereas all the *Uredineæ* or *rusts*, *Erysipheæ*, *Peronosporaceæ*, and *Exoasceæ* are parasitic. In wound-parasites (e.g., *Polyporus*), the fungus is usually first saprophytic, before becoming parasitic.

"When any spores settle on plants and find the conditions (damp and warmth) favourable to their development, germination follows—*i.e.*, they throw out delicate, thin-walled, mostly colourless, tube-like processes (*mycelial filaments* or *hyphæ*), sometimes containing a golden-yellow oily fluid. These tubes, though often undivided, are as a rule divided into separate cells (septated), their contents being protoplasm and cell-sap. With the exception of the mildew-fungi, which merely vegetate on the exterior, the infection of leaves, fruits, bark, and wood always commences from the outside by the *hyphæ* pushing their way either through the stomata or the epidermal cells of young leaves or bark, or effecting an entrance into the interior of the plant through the unprotected portions of the roots, or at any wound-surfaces like those of broken branches.

"These *hyphæ* either insinuate themselves between the cellular walls of the parenchym or the prosenchym, and vegetate in the intercellular spaces or the resin-ducts, whilst they send single short off-shoots or suckers (*haustoria*) into the interior of the cells, or else they bore through the cell-walls, and thus force their way from one cell to another. By extending in length, and at the same time throwing out side-processes—less frequently by dividing—they at length form a filamentous network or **mycelium**, which represents the complete vegetative body of the organism. Masses of mycelium form **sclerotia**, containing stores of food-supplies (chiefly proteids and oil) which, under favourable conditions, produce either new mycelium or sporophores of the fungus.

"*Sporangia* or *spore-producers* spring from the mycelium and produce the reproductive organs, the spores. One and the same fungus often produces sporophores of the most varying shapes, and the form of these is much more characteristic (*e.g.*, mushrooms, toad-stools, &c.) than the hidden mycelium, which is much alike in all fungi.

"When the sporophores are only single threads from the mycelium they are called *spore-hyphæ*, but in other cases the sporophores and *sporangia* are of the most varying forms, and have different names. *Carpospores* are a form of resting-spores which produce a second generation differing from the original form, whilst *gonidia* or *conidia* only reproduce the form on which they occur. Conidia therefore multiply one form of fungus very rapidly within the annual period of vegetation, whereas carpospores perpetuate the species from one year to the other."—(*Studies in Forestry*, 1903, p. 277.)

Fungous diseases may either spread from root to root underground by mycelial infection (e.g., *Agaricus melleus*, *Trametes radiciperda*, and *Rosellinia quercina* in nurseries and plantations), or by means of spores and gonidia carried by wind, animals, or other agencies (e.g., *Phytophthora omnivora* on seedlings, attacks of *Trametes radiciperda* at the base of the stem, and smut caused by *Ustilago*, bunt due to *Tilletia*, or rust on wheat, oats, &c., due to *Puccinia*).

The manner in which the host-plant reacts against the fungous infection differs according to the fungus and the host. Only in the case of leaf-fungi, of minor importance generally, does the point of attack remain localised and circumscribed within narrow limits. In other cases the action either causes destruction or some sort of transformation, or else both combined. The life of leaves and other organs is shortened ; the form and anatomical structure of the parts attacked are changed, and the host becomes more or less diseased. Infection with fungous spores or *hyphæ* interferes first of all with normal vegetation (*e.g.*, transpiration and decomposition of the carbonic acid in foliage infected). This gradually leads to cell-walls being destroyed and the cellular substance and contents being consumed ; then chemical disturbance and physiological alteration result, generally accompanied by *hypertrophy* or morbid enlargement to a greater or less extent, and finally ending in the death of the part attacked. These hypertrophic changes vary greatly in character, according to the part of the tree infected. Fungus-galls are thus produced (*e.g.*, by *Exoascus* and *Æcidium*) on the leaves, flowers, and fruits of Poplars, Alders, Spruce, &c.; or a morbid growth of twig-clusters ensues (forming the so-called "Witches' brooms" in Germany), as specially notable on Silver Fir and Birch; while the pathological condition induced also leads to chemical as well as anatomical and morphological changes in the diseased cells, which result in the diminution or the total disappearance of chlorophyll, the formation of red or yellow colouring matter dissolved in the cell-sap, the disappearance of starch or its formation in abnormal quantity, the secretion of oxalate of lime, &c. Such hypertrophic enlargements influence to a greater or less extent the vigour of the parts of the tree above them, and when the diseased tissue extends all round the stem and destroys the cambium, the death of the upper portion necessarily results. Later on the mycelium produces its own generic and specific kinds of spore-bearers, either on the leaves or twigs, or on the bark, or at old branch-holes, or even from exit-holes of bark-beetles. Vast numbers of spores are produced, and are scattered by wind, &c., to create new centres of sporadic infection. In many cases the tissue infected remains alive, at least until the fungus ripens its spores (e.g., *Uredineæ*), or the fungous mycelium retains life for several years in the stem and roots of the host (e.g., *Taphrina*, *Nectria*, *Peziza*, &c.). Thus many fungi complete their life-cycle within a few weeks or months, while in others the spores either hibernate or the mycelium retains its vitality up to about three or four years. Most of the fungous diseases of trees belong to this latter class.

Many fungi are *polymorphic*, that is to say, their spores produce an individual which looks quite different from the parent fungus; and the spores of this individual may also again produce what seems a third species not like either of the two previous forms of the fungus. Ultimately, however, the spores produced in the second or the third form throw back to what was the original or parent type, and the cycle recommences.

Changes in Generation.—It has now been clearly ascertained by experiments that many fungi previously considered different genera and species are merely intermediate stages in the development of well-known species. Those fungi are not necessarily the most highly organised, in which fructification arises from some sort of sexual process. The constant change in intermediate form is called *change of generation*, while the change in the shape of the regenerative organ is known as *pleomorphy;* and the change in the choice of the *host* or the plant infected is termed *metoxeny* or *heterœcy* (see table on p. 148, *Uredineæ*). This is somewhat analogous to the *alternation*, or change of generation among certain *Cynipidæ* (see chap. iv., p. 125).[1]

The outbreak and increase of fungous diseases may be greatly favoured by climatic and local conditions. Dampness and warmth are requisite, whereas light is not required (and is often, indeed, a hindrance). As the assimilative process is carried on in fungi without chlorophyll, they cannot, as green plants do, assimilate carbonic acid; and if light were necessary to fungi, they could not grow deep in the ground or in the inside of trees, as is very often the case. Damp localities and moist seasons favour the spread of fungi more than windy situations and dry years. As the protoplasm and the contents of the mycelial *hyphæ* contain a large proportion of albumen, fungi grow readily in nitrogenous substances. Thus all wood containing much nitrogenous matter is soon attacked and destroyed by fungi (*Merulius lacrymans*, &c.), and on this account Beech is far less durable than Oak or Pine. But if wood contained no albumen, or could be rendered and kept quite

[1] Rust occurring in the form of lines of yellow spores seen on the leaves of wheat is occasioned by *Puccinia graminis*, which assumes the intermediate form of *Æcidium berberidis* on the leaves of the Barberry; and *P. coronata*, the oat-rust, becomes *Æ. rhamni* on the common and the Alder buckthorn. These shrubs should therefore be cut out of all hedges, &c., throughout corn-growing districts.

dry, fungous decay would not be possible, moisture being necessary for the growth of fungi.

When fungous disease breaks out epidemically in timber-crops, this is due to unfavourable conditions of soil, situation, or climate for the kind of tree attacked; and in this case further damage can generally only be prevented by changing the crop to some more suitable species. Where, however, disease only occurs here and there it can usually be exterminated by cutting out the infected plants or trees to prevent the ripening and scattering of the spores. Whether they attack the *Foliage*, or the *Stem and Branches*, or the *Roots and the base of the Trunk*, fungous diseases (like the noxious insects) do far more damage to crops of coniferous trees than to those of broad-leaved trees. This may no doubt be partly attributable to the greater number of wounds and weak spots occasioned by insects, weight of snow, strain of winds in winter, &c., through which the fungous spores can obtain entrance into their host; but it is also probably partly due to the much weaker recuperative power possessed by conifers than by broad-leaved trees.

Prevention and Extermination of Fungous Diseases.

The late Prof. R. Hartig, one of the highest authorities on the diseases of trees, considered that—

"*The best preventive measures* against the outbreak and spread of fungous epidemics is the formation of mixed woods. Infection above or below ground is best obviated when each tree is, as it were, isolated by neighbours of different species. *A change in the kind of timber-crop* may even seem advisable, under certain circumstances, on soil taken possession of by root-parasites, or containing Teleuto-spores which retain their vitality for years. So far as possible, *prevent fungus spores being conveyed by men and animals*, especially during operations in young woods. *The remedies that can be adopted* after any outbreak of fungous disease occasioned by root-parasites consist partly in the timely pulling or *digging up* of the sickly plants, and partly in isolation of the infested patch by means of *narrow trenches*. But the best and most important general measure to be recommended is the immediate *removal of all diseased plants* from the woods, so as to hinder further infection being spread by fungous spores. *Keeping the woods clean* is essential for maintaining their health."

There is no *cure* for fungous diseases in trees. Each individual case requires more or less drastic surgical treatment with pruning-knife, saw, or axe; and often the whole plant or tree attacked has to be removed altogether, root and branch. The life-history of the more highly-organised fungi causing serious diseases among trees shows how advisable it is to maintain close canopy in woods, in order to hinder the growth of weeds, which may act as host-plants for heterœcious fungi. And equally apparent is the security gained by keeping the woods clean and free from sickly or damaged trees and dominated or suppressed poles already predisposed towards, and little able to withstand, insect and fungous attacks. The softwoods (Aspen, Birch, Willow, Poplar, &c.) should also be treated as weeds and cut out when they are growing in admixture with, or in the vicinity of, conifer woods infected with fungous disease of the foliage. All the sylvicultural measures which assist in protecting woods and plantations against the attacks of injurious insects (see p. 63) are at the same time useful in preventing outbreaks of fungous diseases in either sporadic or epidemic form.

The chief fungous diseases of woodland trees may conveniently be classified artificially as follows, for ready reference, the more destructive kinds being thus marked * (*Studies in Forestry*, pp. 282-284):—

I. On Foliage.

A. **Of Conifers:—**

1. **Lophodermium* (*Hysterium*) *pinastri*, Pine scab or scurf. Mainly attacking Scots Pine.

2. *Chrysomyxa abietis*, Spruce needle-rust or blight. Mainly attacking Spruce.

3. *Coleosporium* genus (including the disease formerly known as *Peridermium pini*, var. *acicola*), Pine-needle rust or blight. Mainly attacking Pines.

4. **Trichosphæria parasitica*, Silver Fir needle-blight. Mainly attacking Silver Fir and Spruce.

Minor disorders are occasioned by *Lophodermium nervisequium* on Silver Fir, *H. macrosporum* on Spruce, *Cæoma laricis* on Larch, *C. abietis pectinatæ* on Silver Fir, *Æcidium columnare* on Silver Fir, *Æ. abietinum* on Spruce, and *Æ. strobilinum* on the bracts of Spruce cones.

B. **Of Broad-leaved Trees** :—

1. **Phytophthora omnivora*, Beech-seedling fungus. Mainly attacking Beech, Maples, Ash; Spruce and Scots Pine (in nurseries and young seedling growth).

Minor disorders are due to *Melampsora Hartigii* on Willows (especially *S. caspica*); *M. tremulæ* on Aspen, *M. betulina* on Birch, and *M. salicina* on Sallow, also *Rhytisma acerinum* on Maples and Sycamores.

II. On Stems and Branches (in the bark or in the wood).

The cankerous diseases which belong to this section may be divided into two main groups. In the first of these are comprised all such diseases of the bark and the cambium as cannot be healed without human interference, because of their influence annually extending, so that when it has encircled the stem all above this zone dries and dies off. And in the second group are comprised disorders which only, as a rule, spread through the bark during a single period of vegetation; but if within that time the disease has not completed its circuit round the stem the infected place becomes cicatrised and heals over. Unfortunately the only one of the chief cankerous diseases below mentioned which belongs to this latter group is *Nectria cucurbitula*.

A. **Of Conifers** :—

1. **Trametes pini*, Pine fungus. Mainly attacking Scots Pine, Spruce, Larch, Silver Fir.

2. **Cronartium* genus (including the disease formerly known as *Peridermium pini*, var. *corticola*), Pine-canker or bark-fungus. Mainly attacking Pines.

3. *Cæoma pinitorquum*, Pine-shoot fungus. Mainly attacking Pines.

4. *Æcidium elatinum*, Silver Fir fungus. Mainly attacking Silver Fir.

5. *Nectria cucurbitula*, Spruce-bark fungus. Mainly attacking Spruce.

6. **Peziza Willkommii*, Larch-canker. Mainly attacking Larch.

Minor disorders are occasioned by *Cladosporium entoxylinum* and *C. penicillioides* on Scots Pine, and *Pestalozzia Hartigii* on Spruce and Silver Fir (seedlings in nurseries).

B. **Of Broad-leaved Trees** :—

1. **Nectria ditissima*, the canker of broad-leaved trees. Mainly attacking Beech, Ash, Oak, and other broad-leaved trees (and especially Apple-trees in orchards).

Minor disorders are due to *Nectria cinnabarina* on Maples, Elm, Lime, and in particular Horse-Chestnut, and *Polyporus sulphureus* on Oak, Poplar, Tree-Willows, Birch, and Larch.

III. On Roots and Base of Trunk.

A. **Of Conifers** :—

1. **Agaricus melleus*, the Honey fungus, an edible mushroom. It mainly attacks conifers, but especially Spruce, or Scots and Weymouth Pines.

2. **Fomes* (*Polyporus*) *annosus* Fries (*Trametes radiciperda* Hartig.), the Pine root-fungus. It mainly attacks Scots and Weymouth Pines, Spruce, and Silver Fir.

B. **Of Broad-leaved Trees** :—

1. *Rosellinia quercina*, Oak-seedling fungus, occurring in 1- to 3-year-old Oaks principally.

In describing the appearance and life-history of these and some other important fungi, however, it seems preferable to deal with them severally according to their natural orders and families, in the following manner,[1] those causing the more destructive diseases being marked thus * :—

Order of Fungi.	Family.	Genus and Species.	Trees usually attacked.	Parts usually infected.	Details on page
A. *Phycomycetes.*	I. *Peronosporaceæ.*	1. **Phytophthora omnivora.*	Beech especially; Maple and Sycamore; other trees.	Seedlings.	150
B. *Ascomycetes.*	I. *Exoascaceæ.*	1. Genus *Taphrina.*	Birch, Hornbeam, Alder, &c.	Branches.	151
		2. *Phoma abietina.*[2]	Silver Fir.	Branches and leaders.	153
		3. *Phoma pithya.*[2]	Douglas Fir and Scots Pine.	Branches.	153
		4. *Pestalozzia Hartigii.*[2]	Spruce, Silver Fir.	Branches, twigs.	153
		5. *Septoria parasitica.*[2]	Spruce and Menzies Spruce.	Leaders of trees up to 30 years old.	153
		6. *Cercospora acerina.*[2]	Maple and Sycamore.	Seedlings.	154
		7. *Cercospora microsora.*	Lime.	Foliage.	154
C. *Pyrenomycetes.*	I. *Hypocreaceæ.*	1. **Nectria ditissima.*	Beech and Ash especially, and other broad-leaved trees.	Stems, branches, twigs.	154
		2. *Nectria cinnabarina.*	Horse-Chestnut, Elm, Lime, and Maples.	Branches.	156
		3. *Nectria curcubitula.*	Spruce chiefly.	Bark and wood of small stems and branches.	156
	II. *Sphæriaceæ.*	1. **Trichosphæria parasitica.*	Silver Fir; Spruce, Tsuga.	Twigs and foliage.	157
		2. **Rosellinia quercina.*	Oak.	Roots of 1-3-year-old plants.	158
		3. *Sphærella laricina.*	Larch.	Foliage.	158
	III. *Hypodermataceæ.*	1. **Lophodermium pinastri.*	Scots Pine.	Foliage of 1-5-year-old plants.	160
		2. *Lophodermium macrosporum.*	Spruce.	Foliage in 10-40-year-old woods.	162
		3. *Lophodermium nervisequium.*	Silver Fir.	Foliage.	162
D. *Discomycetes.*	I. *Phacidiaceæ.*	1. *Rhytisma acerinum.*	Maple and Sycamore.	Foliage.	163
	II. *Pezizaceæ.*	1. **Peziza Willkommii.*	Larch; Scots Pine, Silver Fir.	Stems of 10-20 (and up to 40) years; branches of older trees.	163
		2. *Peziza resinaria.*	Spruce; Larch.	Ditto.	168
		3. **Botrytis cinerea.*	Silver Fir, Spruce, Douglas Fir; Larch and Pine.	Foliage and young shoots; but it is mostly saprophytic on dead needles on the ground.	168
		4. *Cenangium abietis.*	Austrian and Corsican Pine.	Shoots of plants over 5 years old.	169
E. *Basidiomycetes.*	I. *Uredineæ.* (a) *Melampsoriaceæ.*	1. *Melampsora pinitorqua.* *Cæoma pinitorquum.*	Aspen and White Poplar; Pines (change of generation).	Foliage. Young shoots of 1-10-year-old plants.	172

[1] The classification here followed is that adopted by Klein, *op. cit.*

[2] These are some of the unclassified fungi, the full life-history of which is not yet known, and in the meantime they are classed with the *Ascomycetes* on account of their fructification in *asci*.

Order of Fungi.	Family.	Genus and Species.	Trees usually attacked.	Parts usually infected.	Details on page
E. *Basidiomycetes*—continued.	I. *Uredineæ*—continued. (a) *Melampsoriaceæ*—continued.	*Melampsora laricitremulæ.* *Cæoma laricis.*	Aspen and White Poplar; Larch (change of generation).	Foliage. Foliage.	173
		Melampsora laricipopulina. *Cæoma laricis.*	Black Poplars; Larch (ditto).	Foliage. Foliage.	173
		2. *Melampsoridium betulinum.* *Cæoma laricis.*	Birch; Larch (ditto).	Foliage. Foliage.	174
		3. *Melampsorella cerastii.* *Æcidium elatinum.*	Cerastium, Stellaria, &c.; Silver Fir (ditto).	Foliage. Branches & stem.	174
		4. *Calyptospora Göppertiana.* *Æcidium columnare.*	Whortleberry; Silver Fir (ditto).	Foliage. Lower side of foliage.	175
		5. *Thecopsora padi.* *Æcidium strobilinum.*	Wild Cherry; Spruce (ditto).	Foliage, lower side. Cone-scales.	175
	(b) *Coleosporiaceæ.*	1. Genus *Coleosporium* (including disease formerly called *Peridermium pini acicola*).	Groundsel and other plants; Pines (ditto).	Foliage. Foliage of 3-10-year-old plants, and older poles.	176
	(c) *Cornartiaceæ.*	1.**Cronartium* genus (including disease formerly called *Peridermium pini corticola*).	Host-plants not yet known; Pines (ditto).	... Bark and wood.	177
		Cronartium ribicolum (ditto *Peridermium strobi*).	*Ribes* genus; Weymouth Pine (ditto).	... Bark and wood.	178
		2. *Chrysomyxa abietis.*	Spruce.	Foliage.	178
	II. *Hymenomycetes* (*Autobasidiomycetes*).	1. **Trametes pini.*	Pines, Spruce, Larch, Silver Fir.	Stems of trees about 40 years old or more.	181
		1.**Fomes annosus* (syn. *Trametes radiciperda*).	Scots and Weymouth Pines, Spruce, Silver Fir.	Roots, and then the lower part of the stem.	182
		2. *Fomes ignarius.*	Willows, Oaks, and most broad-leaved trees.	Wound-surfaces; the commonest of wound-parasites causing white-rot.	183
		3. *Fomes fomentarius.*	Beech, Elm, Oak.	Wound-surfaces; causes white-rot.	183
		1. *Polyporus sulphureus.*	Oak and Birch chiefly; but also other broad-leaved trees and conifers.	Wound-surfaces; causes red-rot.	184
		2. *Polyporus vaporarius.*	Spruce and Silver Fir.	Ditto, ditto.	184
		1.**Agaricus melleus.*	Principally conifers, but also most broad-leaved trees.	One of the commonest of saprophytic fungi on old stumps and roots, whence it extends as a parasite to the roots of conifers (especially Pines and Spruce). But it is also a wound-parasite on Maples and Oak.	185
		2. *Agaricus adiposus.*	Silver Fir.	Stem, especially at canker-spots.	187

Description of the chief disease-producing Fungi.

A. Phycomycetes.

The fungi included in this order are lowly organisms (somewhat like the *Siphoneæ* among *Algæ*), whose mycelium is usually *not* septated by transverse walls before the reproductive organs are formed. Reproduction takes place either sexually by oospores or zygospores, or asexually by means of conidia, and the spores are often capable of moving in drops of water.

I. Peronosporaceæ.

This family lives endophytically, and is distinguished by forming oospores. The only fungous disease caused on trees by this family is that originated by *Phytophthora omnivora.*

1. *Phytophthora omnivora,* **the Beech-seedling Fungus.**—This disease chiefly attacks Beech-seedlings, the stalks of which become covered with brown patches, the roots turn black, and the cotyledons and primordial leaves become spotted with brown, then wither, die, and rot quickly during rainy weather. Within about a week of the first signs of the disease its full effect is noticeable when May and June happen to be wet months, while in dry seasons it takes a little longer for the seedlings to assume the characteristic scorched, blackened appearance. It occasionally during warm, damp, spring weather does great damage among seedling crops in natural regeneration of the Beech, and also in seed-beds in nurseries. As, besides being wind-borne, the spores are easily conveyed on the boots and clothing of men, and by horses and carts, dogs, game, and vermin, the disease is often noticeable along paths running through Beech-woods undergoing natural regeneration. Next to Beech, it chiefly attacks seedlings of Ash, Maple, and Sycamore; but it is more or less "omnivorous" when once it has asserted its influence. Sometimes the disease only appears at the tip of the seedling, and in such cases the plant may recover from the attack; but when the rootlets are infected and discoloration appears on the stem, the seedling is doomed. Conifer seedlings are often attacked in nurseries, when whole seed-beds may be destroyed before the germinating seedlings even begin to show above ground.

Life-history.—Infection primarily occurs by the germination of oospores that have been resting in the soil. As the mycelium is formed (at first unseptated, but septated subsequently), it mostly grows intercellularly with small button-shaped *haustoria*, and spreads throughout the whole stalk as well as within the cotyledons; while numerous conidia-bearing *hyphæ* either pierce the epidermis or else break through the stomata, and on reaching the outside produce a large, terminal, lemon-shaped conidium. Below this the conidiophore usually throws out a short side-process, at the end of which another conidium is formed, which presses the first to one side. After the detachment of the lemon-shaped conidium the receptacles become prolonged and again form conidia; whilst the older ones drop off and either at once germinate, or scatter in all directions the conidia which they contain. The conidia fall off and germinate during damp weather, either germinating at once or else becoming zoosporangia and releasing a number of 2-ciliated spores moving in water (rain), which soon come to rest and throw out a tube-like germinating process. If germination happens to take place on any Beech cotyledon *not yet protected by a cuticule*, this tube-like germinating process pierces the epidermis and quickly develops into a mycelium which soon produces conidia and sporangia. Numerous oospores are also subsequently produced (by sexual fructification) inside the leaf, which form resting-spores, falling to the ground with the dead foliage in autumn. These either germinate in the following spring or else remain dormant for several years until conditions arise favouring their germination. This fungus multiplies so rapidly during rainy weather, and in close damp situations, that new sporangia-bearers are formed within three or four days of the first signs of infection. When once this disease obtains a foothold in nurseries or areas being naturally regenerated it may do serious damage, owing to the infectious ovispores being easily conveyed by wind and animals, and to the mycelial filaments spreading below ground and piercing the rootlets of neighbouring seedlings.

Prevention and Extermination.—Infected seedlings should be carefully removed and burned while the disease is still only sporadic. Infected seed-beds should for the next two or three years only be used for bedding transplants, and preferably only for a different kind of tree than the seedlings already attacked. Watering the seed-beds with a solution of 4½ lb. of bluestone (copper vitriol) and one quart of ammonia in 50 gallons of water prevents the disease spreading.

B. Ascomycetes.

The fungi forming this order have from the very first a septated mycelium. In the lower, less highly organised genera, club-shaped or tubular sporangia, called *asci*, are produced directly, while in the genera with more complex organisation they are produced in sporophores. In these *asci* (which are generally club-like), after repeated subdivisions of the central part, a certain definite number of cup-like *ascospores* are generally produced, the number varying according to the species of fungus. The whole plasma of the *ascus* is not generally used for producing spores. The spores are always at first 1-celled, but in many species they afterwards become many-celled by septation. They are sometimes scattered by being shot out of the top of the *ascus* when it opens. In the fruit-receptacles, which are usually formed asexually, the *asci* produced, and often intermixed with sterile *hyphæ*-ends (*paraphyses*), form a homogeneous layer (*hymenium*), wholly or partially enclosed within a closely-woven covering (*peridia*) of filaments.—In addition to this typical fructification, however, reproduction can also take place by means of many different kinds of conidia and chlamydospores.

Until complete knowledge is obtained of the life-history of what are still unclassified fungi (*fungi imperfecti*), these are meanwhile included among the *Ascomycetes*, on account of their fructification taking the form of conidia and pycnidia (see footnote, p. 148).

I. Exoascaceæ.

This family consists entirely of parasitic fungi, and those attacking trees are contained within the comprehensive genus *Taphrina* (including *Exoascus*). It has no sporophores, but the *asci* (usually 8-spored) break out in compact masses and large numbers on the upper side of the part of the plant attacked. The mycelium may either live as an annual directly below the cuticle of the leaves attacked, or it may perenniate in buds, twigs, branches, or leading-shoots. In the latter case, during the annual period of active vegetation it develops subcutaneously in the foliage or the fruit a single layer of interwoven *hyphæ*, from each of the cells of which an *ascus* appears.

1. The genus *Taphrina* (including *Exoascus*) produces deformities of various kinds, which may be grouped and classified as follows, but which do no serious damage in woodlands:—

(*a*) *Those which form tufted twig-clusters* (*called* "*Witches' brooms*" *in Germany*), *and develop their* asci *on the leaves*,—

(1) *T. turgida*, on the common Birch, forming large and very thick-branching twig-clusters with pendulous twigs and somewhat crinkled leaves covered with grey bloom on the lower side. (2) *T. betulina* on the pubescent Birch, forming tufted twig-clusters with

grey bloom on the lower side of the leaves. (3) *T. carpini* on the Hornbeam, often forming very large, thick-tufted, and thickly-foliaged twig-clusters with crinkled leaves, having a grey bloom on their lower side. (4) *T. epiphylla* on the white Alder, often forming numerous very hypertrophied but sparsely-branched twig-clusters on one tree, and showing the greyish-white film of *asci* on both sides of the leaves. (5) *T. cerasi* and *T. insitiæ* producing twig-clusters on various species of Cherry-trees, and coating the lower surface of the leaves with a grey or greyish-white *ascus*-film.

(*b*) *Those which cause malformation of the shoots, though at same time forming* "Bladder-growths" *and producing their* asci *on the foliage,—*

(1) *T. ulmi*, producing spots on Elm-leaves, and bladder-like swellings. (2) *T. Janus*, producing pale-red bladders on Birch-leaves, with *asci* on both upper and lower side of leaf. (3) *T. Tosquinetii*, common on Alder, thickening the shoots and deforming the leaves by large bladders, and coating the foliage with grey-white *ascus*-film. (4) *T. cratægi* on Hawthorn, producing crinkled leaves with red spots. (5) *T. celtis* on *Celtis australis*, producing spots on leaves, and slight swellings.

(*c*) *Those which only produce* "Bladder-growths," *spots on leaves, or smooth* ascus-*films, without causing malformation of the shoots,—*

(1) *T. betulæ* on Birch, producing white or yellow spots on leaves. (2) *T. carnea* on the pubescent Birch, producing flesh-coloured bladder-growths. (3) *T. cœrulescens* on Oaks, producing irregular greyish or bluish spots on leaves. (4) *T. acericola* on Maple and Sycamore, producing spots on leaves. (5) *T. Sadebeckii* on Alder, producing round yellowish- or greyish-white spots on leaves. (6) *T. aurea* on Poplars, producing large bladder-growths on the leaves, with a golden-yellow *ascus*-film on the concave lower side of the leaf. (7) *T. bulbata* on Pear-trees, producing bladder-growths on the leaves.

(*d*) *Those which cause deformities of the ovary or other parts of the fruit-producing organs,—*

(1) *T. Johansonii* on Aspen, and *T. rhizophora* on White Poplar, which both produce bladder-plums and turn the ovary yellow. (2) *T. alni* on Alder (chiefly white Alder), causing the cone-bracts to swell into long, curved, red bladders. (3) *T. pruni* on Cherry and Plum trees ("bladder-plums"), and *T. Rostrupiana* on Blackthorn.

Prevention and Extermination in all the above cases can only be effected by cutting off and burning the parts infected.

The **Mildew Fungi** (*Erysiphaceæ*) and the **Soot Fungi** (*Perisporiaceæ*) are two families which both belong to the order *Ascomycetes*, and are characterised by forming fruit-receptacles (*Carpoasci*). They frequently occur on the foliage of trees, but the damage they do in woodlands is hardly perceptible.

The **Mildew-fungi** (*Erysiphaceæ*) all live epiphytically on leaves and young twigs, and extend their *haustoria* into the cells of the epidermis. Numerous *hyphæ* of the mycelial film develop into oval spores (*oidia*), and the infected parts then look as if covered with mealy dust. The covering of the small sporophores scattered over the mycelium is closed on every side, and often grows into characteristic thread-like appendages. The ascospores are freed when the covering of the fruit-receptacles decomposes and rots.—There are three genera distinguishable according to their fruits, and but few species of any special interest to the forester. Of these three genera (*Podosphæra*, *Uncinula*, and *Phyllactinia*) the chief species are:—

(1) *Podosphæra oxyacanthæ*, which chiefly attacks Apple-trees, and also Hawthorn and Mountain-Ash.

(2) *Uncinula aceris*, producing white spots on Maple and Sycamore leaves. Leaves become dwarfed and shrivel up if infected while still developing. 2. *U. salicis*, producing either white spots or thick films on Willow, Poplar, and Birch leaves. 3. *U. Tulasnei* on foliage of Willow, Poplar, and Birch, but forming a more regular fungous film over the leaves. 4. *U. clandestina* on Wych Elm foliage. 5. *U. Prunastri* on Blackthorn foliage.

(3) *Phyllactinia suffulta*, producing white spots and films on Beech, Oak, and most other broad-leaved trees, and sometimes causing premature drying of the foliage in Beech-woods.

The **Soot-fungus** (belonging to the *Perisporiaceæ*), common on the leaves of many trees and shrubs, is caused by the much-septated, thick-walled aerial mycelium of the genus *Apiosporium* (syn. *Capnodium*, *Fumago*). Attacks of black-smut fungi are generally worst when preceded by any marked increase in plant-lice (*Aphides*), as the fungi then live saprophytically on the "honey-dew" exuded by the lice. Although covered above by the black smut, all the lower side of the leaf remains green; but if the fungus is in large numbers the leaves gradually die. Only two species are to be found on woodland trees,—(1) *Apiosporium salicinum* on Willows and Poplars; and (2) *A. pinophilum* on Silver Fir, often covering with black smut the needles and twigs of whole branches.

The fungi remaining as yet unclassified (see p. 148), which are in the meantime included among the *Ascomycetes*, include several genera and species destructive in nurseries, young plantations, and older woods. These may thus be summarised, following the enumeration given in the table on p. 148:—

2. *Phoma abietina* causes a cankerous disease on Silver Fir twigs and branches. Among the young undergrowth in Silver Fir-woods, branches, twigs, and leading-shoots with dead foliage adhering to them are often found above a broad constricted ring where the bark is burst, and where numerous small black pycnidia appear, whose spores are scattered in August and September. Next spring the infected 1-year-old twigs die without any constriction of the bark, which is only effected in the case of larger branches when growth in girth is continued for one or more years above and below (but chiefly above) the dead ring of bark reaching down to the cambium.

3. *Phoma pithya* occasions a cankerous disease on twigs and branches of Douglas Fir and Scots Pine, not unlike that produced on Larch by *Peziza*. It is now, unfortunately, found attacking Douglas Fir plantations in many parts of Britain. The fungus destroys the bark and produces constriction right round the stem, while above and below this contracted part an effort is made to heal the wound by cicatrisation. This failing, death ensues. When the fungus only partly destroys the bark and does not completely ring the stem, a callus is formed round the cankered part. As is also usual in the case of the Larch-canker, the infection usually takes place near where branches grow from the stem. At St Quinox, in Ayrshire, fully 10 per cent of a large number of Douglas Fir recently planted had to be cleared (1897) within three years because of this disease.

4. *Pestalozzia Hartigii* causes a similar constriction of the periderm on the twigs of almost all kinds of young plants. But this fungus chiefly attacks Spruce and Silver Fir in nursery-lines and young plantations. It also kills them in patches on seed-beds, bending them down just above the ground. Among the broad-leaved trees it is more frequently found on Beech, Ash, Maple, and Sycamore than on the other kinds. The young stem infected can be seen to be more or less constricted close to the ground, and this first of all makes the foliage wither, and then causes the plant to wilt and die. On examining the part where the periderm is constricted a cushion-like *stroma* will be found with depressions where conidia are emitted. These conidia issue from the epidermis like small black cones.

5. *Septoria parasitica* is a disease which often causes the death of the leading-shoots of the common Spruce and the Menzies Spruce in seedlings, small plants, and poles up to thirty years old. The young shoots infected at their base begin to bend and hang down in a sickly condition about the end of May or early in June, and soon afterwards wither and die. During the summer the small black pycnidia break through the bark of the dead twigs, being usually most numerous on the needle-cushions, the base of the twig, and the needles at the extreme tip of the shoot. Shoots infected in spring die within one week to a fortnight.

6. *Cercospora acerina* causes a disease among Maple and Sycamore seedlings, which is often widespread in wet seasons, and much resembles that occasioned by *Phytophthora omnivora.* The cotyledons, primordial leaves, and stalks become spotted or wholly blackened, then wither. At the infected spots masses of short conidia-bearers appear and produce tufts of long many-celled conidia at their top-ends, while the intercellular mycelium swells and forms short rows of brown, thread-like, dormant mycelium (the simplest form of *sclerotium*), which makes the disease break out again in the following spring.

7. *Cercospora microsora* produces small black patches on the leaves of the Lime, and often occasions premature shedding of the foliage.

8. Other fungi of the above unclassified group include (1) *Fusomi pini,* which in May and June causes a disease in Pine and Spruce seed-beds, and also among Birch and Alder seedlings, scarcely distinguishable from that due to *Phytophthora omnivora.* Wet weather greatly favours its spread, as the mycelium then extends far beyond the seedling attacked and attacks neighbouring plants. (2) *Allescheria laricis,* also in May and June, and especially during damp weather, causes disease in the foliage of young Larch in seed-beds and nursery-lines. The needles become covered with brown spots and die. Thick, short conidia-bearers grow out of the pores, and septate into three or four cells, each of which produces a 1-celled, biscuit-shaped conidia. (3) *Brunchorstia pini* attacks the shoots of the Corsican Pine, the infection originating in the bark, and by summer spreading to the base of the needles, where the small pycnidia are developed, hidden under the leaf-sheath. (4) *Glœosporium nervisequium* causes an epidemic disease on the leaves, and sometimes also on the young shoots, of Plane-trees. During a wet spring it destroys many of the young leaves just while they are expanding, so that about the middle of May they become brown-spotted along the nerves, and later on dry and wither. (5) *Fusicladium tremulæ* kills the leaves and dries the shoots of the Aspen in spring; and the new shoots in summer are also often attacked. (6) *F. dendriticum* infects the leaves, twigs, and fruit of Apple-trees and Mountain-Ash; and (7) *F. pirinum* produces brown patches on those of Pear-trees, sometimes doing much damage.

C. Pyrenomycetes.

The *Pyrenomycetes* or fungi having a *perithecium* (hence the name) have spherical *ascus*-fruits, and are therefore really only a sub-class of the *Ascomycetes.* Their hymenium fills the interior of round or bottle-shaped *perithecia* having a narrow opening at the top; and it is from the base of these that the *asci* are produced. The *ascus*-fruits may consist of one single *perithecium*, but several are usually contained in a sporophore of characteristic shape, or in a flat or cushion-like layer (*stroma*).

I. Hypocreaceæ.

This family is characterised by soft, coloured *perithecia* united in one *stroma.* The only genus of importance to the forester is the very destructive canker-fungus *Nectria*, which produces yellow or red *perithecia* developing (usually in large patches) on a *stroma* of the same colour. The *asci* contain eight 2-celled spores.

1. *Nectria ditissima,* **the Canker of broad-leaved trees,** is very common in Britain, and attacks almost all kinds of broad-leaved trees (Oak, Alder, Maple, Sycamore, Lime, Hornbeam, Hazel, also Apple, Pear, and Plum in orchards), but principally Beech and Ash. When these are attacked, the mycelium spreads quickly and enters the wood; and many trees are covered with canker-spots all over the stem and branches (Fig. 172). It is this fungus which causes Ash to become "black in the heart" and valueless as timber. When once the disease gets a firm footing in any Ash plantation it soon becomes epidemic, and whole plantations are sometimes totally ruined, especially when growing on wet undrained land. This fungous disease is dis-

tinguishable, by the numerous dark-red globular sporophores on the cankerous spots, from any other diseased condition caused by sun-burn, frost, or plant-lice; but they are very minute and can only be found by careful examination.

Life-history.—This fungus grows only as a parasite, effecting its entrance at wounds, such as those made by insects, frost, hail, &c. It attacks crops of all ages

Fig. 172.

$\frac{2}{3}$ natural size.

Canker at fork of a young Oak caused by Nectria ditissima.

$\frac{2}{3}$ natural size.

Canker on a young Beech stem, due to Nectria ditissima.

a. Clusters of red *perithecia*, as seen during the winter months.
b. Canker-spots, exposing the dead wood.

Fig. 173.

$\frac{2}{3}$ natural size.

Showing nature of damage done to a young Spruce stem by Nectria cucurbitula.

a. Sporophores (*Perithecia*) hibernating on the dead bark.

from young poles upwards, and is even found on 1-year-old shoots. The mycelium lives chiefly in the bark, killing the infected portions, and gradually extending its infection. Canker-spots then arise as the tree each year tries to cicatrise the dead parts, which gradually increase in size. The conidia-cushions are white, and the *perithecia* red.

The infection often begins at the fork of young branches, from which the mycelium spreads up and down the stem, turning the diseased wood brown in Beech and black in Ash. The canker deepens with the growth of the mycelium, and as the edges become raised by the repeated attempts at cicatrisation, a hypertrophic condition follows, resulting in spindle-shaped excrescences along the cankered part. The stem and branches gradually become more and more cankered, till the pole or tree is killed outright.

Prevention and Extermination.—Infected saplings, poles, or trees should be thinned out; and during thinnings, or when felling and removing trees from areas regenerated naturally, care should be taken to avoid making wound-surfaces by injuring the bark on the poles or trees left standing as the crop.

"*Prevention and Remedies* recommended for orchards, where this is the most destructive canker on Apple-trees, are as follows:—Young branches that are attacked should be cut off, as they are certain to be girdled and killed at an early date.

When thick branches are diseased all the wounded parts should be cut away and the cut surface luted with clay or protected with a coat of gas tar. If the disease has spread from the original point of infection, and appeared at the surface in other places, the branch should be cut off.

It is very important that grafts should not be taken from diseased trees, as parts that appear to be sound may contain the fungus in their tissues.

The white stage of the fungus can be killed by applying with a brush a solution of sulphate of iron—1 lb. to a gallon of water. This mixture will also destroy lichens and moss growing on the trunk and branches."—(*Board of Agriculture Leaflet*, No. 56.)

2. *Nectria cinnabarina*, **the Coral-spot or Horse-Chestnut Fungus**, is one of the commonest saprophytes on dead branches of broad-leaved trees; but it is also parasitic on the buds, twigs, and branches of Horse-Chestnut, Lime, Maple, Sycamore, and Elm, destroying the sapwood in rings and killing the parts above those infected. (See also Agricultural Leaflet No. 115, *Coral-spot Disease.*)

Appearance and Life-history. — On parts attacked saprophytically great numbers of small brick-red conidia-cushions break out of the bark, upon which the vermilion and dark-red *perithecia* appear during the autumn and winter. But the mycelium can, as occurs most frequently on Horse-Chestnut and Elm, extend parasitically from wound-surfaces into living branches. It soon spreads quickly in the vessels of the woody tissue, and kills the branches by preventing the upward flow of the watery sap. The fungus then decomposes and consumes the starch contained in the wood-cells, and leaves behind a greenish substance which soon causes the wood to turn black and discoloured.

Prevention and Extermination.—Dead or damaged branches should be pruned, and the wound-surfaces tarred; and all infected parts should be cut off and burned. These protective operations should be carried out before the spores scatter in autumn and spring, when the risk of infection is greatest. Spraying with caustic soda solution in winter is also recommended.

3. *Nectria curcubitula*, **the Spruce-bark Canker** (Fig. 173), occurs chiefly as a wound-parasite on young Spruce poles, but is also found on Silver Fir, Pines, and Larch. It is common in Britain, though generally only as a saprophyte on dead branches. It is prevalent in damp frosty localities, where twigs nipped with frost or injured by insects, hail, &c., enable it to effect its entrance in weakly young trees of 3 to about 15 feet high. On young trees in vigorous growth it remains saprophytic, the progress of the disease being stopped and a corky layer being formed that cuts off the diseased tissue, which then dries and is shed. But in weakly young trees the canker is able to extend, killing the cambium and penetrating the sapwood.

Appearance and Life-history.—The first signs of the disease are bleaching of the needles, and drying and browning of the bark and cambium, especially near wounds caused by insects, &c. The mycelium spreads quickly in the bark, especially throughout the sieve-tubes of the phloem, and the development of the fungus is mostly confined to the winter period when the tree rests from active vegetation. It kills the bark, and often also the wood of young twigs and stems, so that the leaders are often killed on plants in young Spruce plantations (mixed as well as pure). When the disease encircles the stem, the crown and often the whole plant dies; but if a strip of bark remains sound, active vegetation of the young tree can proceed, and the cankered spot may in course of time become completely cicatrised. The sporophores can only develop when the dead bark is always kept moist. White and yellow conidia-cushions are first of all formed about the size of a pin's head, and on these numerous groups of scarlet concave *perithecia* containing the tube-spores are afterwards produced. So long as the host is in vigorous growth the fungus cannot penetrate beyond the resting parts of the bark, as the living cells of the cambium grow and divide normally; but if unsuitable soil or situation, or injury of any sort has predisposed the young tree to disease, the cortical tissues, the cambium, and even the sapwood are attacked, so that the upward flow of water is stopped and the whole of the part above the infected place dries up and dies.

Prevention and Extermination.—Young plants or parts of plants attacked should, during the autumn and early winter, be cut off and burned, as the spores easily scatter when infected parts are shaken; pruning-shears should be used whenever practicable, and care taken to avoid scattering the spores.

II. **Sphæriaceæ.**

This family is characterised by dark *perithecia*, which either stand quite free on the conidia-cushion or are surrounded by a thread-like layer; but they are never embedded in a true cushion-like *stroma*.

1. *Trichosphæria parasitica*, **the Silver Fir Needle-blight Fungus,** is a very common and destructive parasite, which very often in damp localities attacks thriving young poles and the lower branches of 20- to 40-year-old Silver Fir, and sometimes also Spruce and Tsuga. It does a good deal of damage on the Continent in natural regenerations and thick young plantations. When twigs are attacked the needles turn brown, become loosened from the twig and hang down, but are prevented from falling by the fine mycelial threads. The mycelium perenniates, and trees attacked never shake off the disease.

Appearance and Life-history.—The thin colourless mycelium is generally found on the lower side of the last sprays of Silver Fir, where it forms numerous white pustules on the two silvery grooves along the needles. As the needles turn brown and hang down, the pustules also turn brown; and about November small, round, blackish-brown, hairy *perithecia* are formed, containing dirty-grey spores which scatter and germinate on Silver Fir foliage. But besides scattering myriads of spores to spread the infection, this fungus never, before killing the young tree attacked, relaxes the hold it once attains on it. The mycelium hibernates on the lower side of the spray and needles (which generally die during the year following infection), and extends to the new shoots flushed in spring, attacking first the needles on the older spray that may have escaped in the previous year, then killing at once the needles not yet fully developed at the base of the new shoot, and afterwards gradually infecting those on the middle and upper portions of the twig. Sometimes young shoots are in spring thickly covered with mycelium and all the leaves are dead, so that the whole twig dies off. The black *perithecia* which appear on the small, white, and afterwards brown, conidia-cushions on the lower side of the leaves can hardly be distinguished by the naked eye. They have tufted wisps of hair on their upper half, and the *asci* contain eight bright-grey 4-celled spores capable of germinating immediately.

Prevention and Extermination.—Infected twigs should be carefully pruned so as not to scatter the spores, and should be burned.

2. *Rosellinia quercina*, **the Oak-seedling Fungus**, attacks and kills the roots of 1- to 3-year-old Oak-seedlings, more especially in seed-beds and nursery-lines during damp warm spring and summer weather; but plants are still liable to attack up to about ten years of age. The terminal leaves of infected plants gradually fade and dry up, and then this drying-up process is continued downwards.

Appearance and Life-history.—The infected tap-root becomes covered with finely-woven mycelial filaments near which the bark-tissue turns brown; while small, round, black pustules about the size of a pin-head appear on the tap-root, and especially where the first tiny side-roots branch off. From these small black pustular *sclerotia* numerous fine thread-like rhizomorphs (*rhizoctonia*) proceed, at first whitish then turning brown, which surround the roots and extend throughout the soil, spreading infection from root to root, very much in the same way as *Agaricus melleus*, see p. 185), while the white mycelium sometimes also grows above ground among the grassy soil-covering. By means of these small black pustular fruits (*sclerotia*) the fungus perenniates and hibernates, retaining vitality from year to year, and also outliving periods of summer drought in which any ordinary form of mycelium would perish; and when the atmosphere becomes damp again these *sclerotia* develop a thick, whitish-grey, mould-like mycelium, which in turn again produces numerous brown rhizomorphs (*rhizoctonia*).

As the tap-roots of the Oak-seedlings are protected by an outer corky layer against infection, the mycelial filaments have to effect an entrance through the less protected side-rootlets, whence they can extend unhindered into the whole of the inner tissues of the roots and stem. Infection can also, however, be effected by the conidia produced by the mycelium above ground, as well as by the spores scattered from the black pustular *sclerotia* developing on the surface of the soil or on the stems of the diseased seedlings. These different kinds of mycelia penetrate the living bark through the tips of the rootlets or through the lenticells, especially at the base of the side-rootlets, where small swellings appear at the infected parts, from which mycelial filaments extend to the inside of the roots during damp, warm, favourable conditions of soil and atmosphere. The bark-cells become filled with thick mycelium (*pseudoparenchym*) and then die, and finally the mycelium extends right into the centre. The roots soon turn black, and then assume the characteristic look of white-rot. The conidia formed in summer are borne on whorled branching sporophores, entirely different in appearance from the round black *perithecia* produced either on the surface of the infected rootlets or in the vicinity of the rhizomorphs rising to the surface of the soil.

Prevention and Extermination.—Diseased plants should be at once removed from the seed-beds and nursery-lines and burned. Young plantations or parts of natural regenerations infected should be isolated by digging narrow trenches about 1 foot deep all round them, to prevent the rhizomorphous mycelium spreading subterraneously.

White Root-rot (*Rosellinia necatrix*) attacks wild cherry-trees and crabs in woods and hedgerows. (See Agricultural Leaflet No. 64.)

3. *Sphærella laricina*, **the Larch Leaf-shedding Fungus**, has on the Continent proved a very destructive disease at low elevations. About the end of June (those attacked by *Chermes* even earlier), or in July, the needles become spotted with brown and soon fall off. In wet years most of the foliage is shed by August; but in dry seasons the disease only occurs in low-lying damp

situations where Larch is interspersed among evergreen conifers, on the foliage of which the infected Larch-needles of the previous year have remained hanging, and have produced ascospores. At low elevations the Larch thrives best when underplanted with, or interspersed among, Beech, because the infected Larch-needles are shed before the Beech-leaves, and the latter completely cover the former and prevent the spores being scattered.

Life-history.—The mycelium lives intercellularly. The conidia-cushions break through the epidermis of the infected needles still hanging on the twigs, and appear as tiny black spots with sausage-shaped conidia, which are very liable to be washed off during rainfall, and then quickly spread the disease during wet weather. These small black dots are minute spherical cavities (*sphærellæ*) sunk in the leaf-tissue and surrounded by a dark cellular investment. In the following spring the *perithecia* and isolated *pycnidia* appear as still smaller black spots in great number on the fallen needles.

Prevention and Extermination can only be effected by cutting out and removing infected poles or trees, and burning the diseased foliage.

4. *Sphærella taxi* attacks Yew foliage in the S.W. of England. The leaves infected show numerous small black spots, which are little spherical cavities in which the *asci* are produced. As Yew-needles have a hard and firm epidermis, when spores land on them and germinate the germ-threads can only enter by the stomata. The disease is therefore slow in spreading, but twigs and branches attacked should be pruned off and burned.

5. *Aglaospora taleola* sometimes attacks the branches and stems of young Oaks as a wound-parasite, and then spreads and produces a destructive cankerous disease, causing the smooth bark to die and burst open, after which cicatrisation gradually takes place. The mycelium also enters the wood, turning it brown superficially. On the diseased bark, which is thrown off later, the *perithecia* are grouped together with long necks under the periderm and perforating this, but only the mouth of the *perithecium* extends above it. The *asci* have eight 2-celled spores with thread-like appendages. But besides these, 1-celled, sickle-shaped conidia are also released from the quasi-*stroma*, near the mouth of the *perithecium*.

6. *Ceratostoma piliferum* is a saprophyte which occasions bluish discoloration in coniferous timber (especially Pine). The brown mycelium enters into the dead stems from without, and quickly spreads throughout the sapwood, but does not usually penetrate into the heartwood.

III. Hypodermataceæ.

This family, the **Scurf-Fungi**, has flat or elongated sporophores, called *apothecia* (like those of the *Discomycetes*), whose tough, leathery, black envelope is intergrown with the substratum-layers, and bursts lengthways when the spores are ripe. In damp weather the edges of this fissure open wide, but in dry weather they close again after scattering the spores. The closed *apothecium* is filled with densely-packed paraphyses, between which the 8-spored *asci* are embedded. The spores are mostly thread-like, with a gelatinous membrane which expands with moisture. The *apothecia* are produced on the dead tissues some little time after the mycelium has killed these; but small 1-celled conidia can also be formed in pycnidia. Two genera, *Hypoderma* and *Lophodermium*, attack trees.

In the genus *Hypoderma* the spores are not long and thread-like, but are always 2-celled when ripe, and much shorter than the tubes.

Hypoderma strobicola kills the needles and young shoots of the Weymouth Pine, sometimes entirely defoliating large clumps of plantations. The needles turn brown in summer, then the *apothecia* appear as narrow black lines, and the foliage is shed in winter. The ascospores are ovally elongated.

In the genus *Lophodermium* (*Hysterium*) the ascospores are elongated, 1-celled, and thread-like, while the paraphyses are partly septated by transverse walls, and thickened like knobs at the end, or bent like a hook. The spores of all the species effect their entrance through the stomata of the leaves; and the wetter the weather, the sooner they ripen.

1. *Lophodermium* (*Hysterium*) *pinastri*, **the Pine Leaf-Scurf or Leaf-shedding Fungus.**—Like *Botrytis cinerea* (see p. 168), this fungus is very common as a saprophyte on dead Pine foliage, but it is also a most destructive parasite. Young Scots and Austrian Pine in particular, and also most other evergreen conifers, are liable to have their foliage wither suddenly and then shed. This may occur after sharp frost, or during severe drought in summer, or during bright sunny days in winter when transpiration is induced through the foliage, whilst the frost-bound soil does not permit the rootlets to imbibe moisture and replace the water transpired, or it may also be caused by excessive transpiration in spring. But in addition to these physical and climatic causes of damage, an outwardly very similar disease is very commonly produced by the parasitic fungus *L. pinastri*. In the vast majority of cases the disease is due to this last cause, which often occasions great loss in nurseries and young plantations. The disease chiefly attacks and kills 1- to 4- or 5-year-old plants, although it may also be found on others up to about 20 years of age; but on plants over 5 to 7 years old the damage is comparatively slight. During late summer and autumn the young needles become speckled with small brownish-red or brown spots, containing the mycelium of this fungus. Early in the following spring (during March or April) the leaves wither, turn red or brown, and die off, the dead primordial leaves of 1-3 year old usually adhering to the young shoots, while the older needles generally fall off ("leaf-shedding"). Plants attacked in seed-beds are of no use for putting into the nursery-lines; and transplants attacked in the nursery-lines are useless for planting in the open, as their constitutional vigour is always sapped by the disease. If the winter has been mild and open, and has been followed by a wet spring, black fruits (*apothecia*) appear early in spring, but only burst and scatter their spores if the weather continues wet. These spores, however, do not convey infection to other trees, the disease being spread by ascospores produced in larger black ascophores, usually formed during the second or third year. These spore-cases contain *asci*, which only rupture and liberate the spores in wet summers, or after continuous rain. Like all the other scurf-fungi, the development of *L. pinastri* depends to a very great extent on a damp condition of the air, because its reproductive organs are only formed in the dead needles, and moisture is therefore essential for their development. Dry summers, cold winters, and dry spring weather greatly check the spread of this epidemic; while a moist summer, followed by an open mild winter, is very favourable to its increase. Damp misty localities provide favourable conditions, hence it is more frequent and destructive in young plantations in shut-in valleys or low-lying places than on hillsides and uplands. The disease is very apt to become epidemic in moist localities, as the spores are wind-borne in vast numbers and germinate freely.

Wherever the air is smoke-laden, Pine pole-woods are specially liable to attacks and get covered all over with the disease.[1]

Life-history.—It was formerly thought that young needles became infected in May, but von Tubeuf's investigations have shown that young plants are not infected before August. The attack is therefore made on mature fully-developed needles, and not on immature foliage only in process of development. The primordial needles on 1-3-year-old shoots only die in September at earliest, and the needles on the short shoots probably later. During damp weather the numerous small black pycnidia appear during the first autumn, and are succeeded by large numbers of flat black *apothecia* on the same needles. In sufficiently damp weather these *apothecia* are formed in a few weeks on the dead foliage perforated by the mycelium. They usually ripen only on needles that have fallen to the ground, and not on those that still remain hanging to the twig. The *apothecia* are mostly ruptured by April; but the ripening of the individual *asci* takes place very gradually, so that from April onwards, throughout the summer, and often also throughout the winter, spores can be liberated to spread the infection.

Prevention and Extermination.—The best protective measure is to spray the Pine seed-beds and nursery-rows in July or early in August each year with the copper solution "Bordeaux mixture."[2] This does not injure the plants, but the effect of the solution only lasts for one year, and the spraying has therefore to be repeated. Theoretically, though often out of the question in practice, Scots Pine nurseries should only be made in places free from the disease (though there can now only be few such places where the fungus is not at least saprophytic), or in broad-leaved woods. In nurseries infected plants should be pulled up and burned, and new seed-beds should, so far as possible, only be sown to the windward of those in which the disease has already appeared; and seed-beds of other conifers should alternate with those of the Pine. Where the presence of the disease is suspected, particular attention should be paid to the seed-beds after a wet summer and an open winter, because it is important to eradicate it before it can become epidemic. If it be desired to protect seedling-beds or young nursery-lines against frost, moss-dust or the foliage of broad-leaved trees should be used, and not conifer foliage, which is almost always more or less infected with saprophytic *L. pini* or *Botrytis cinerea*; and from saprophytes these can always turn to destructive parasites. All dead needles should be removed from the seed-beds for the same reason. In suspected localities it is also well to transplant the seedlings into the nursery-beds as soon as practicable, as this diminishes the risk of infection.

Continental Note.—At the Hessian Forest Conference (Cassel, July 1903), one of the three themes proposed for discussion was "The Leaf-Shedding Disease, and the best means of combating it." The discussion was of course introduced by considering the three known possible causes of this disease (frost, winter transpiration, *Lophodermium pinastri*), and it was accepted that the fungus was the chief cause. The results of many thousands of experiments made in all parts of Germany have shown that spraying the plants with solutions of copper is the only effective method. Spraying has only proved

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[1] From this cause over 10,000 Scots Pine of 12 to 20 years of age had to be felled on the Pollok estate (Renfrewshire) in 1902.

[2] This useful solution, known as "*bouillie bordelaise*" in the French vineyards, consists of 2 lb. sulphate of copper (bluestone or copper-vitriol) dissolved in 10 gallons of water, and 1 lb. of freshly-burned lime added. Also good is 1 lb. potassiate of copper dissolved in 10 gallons of water. If 2-year-old Pine seedlings are syringed once or oftener with either of these solutions between June and September, as required, this will generally (though not always) be found to check the disease. But spraying of the youngest seedlings (in their first year) with either of the above has not, in Germany, been found effective, as the liquid rolls off their wax-coated surface.

ineffectual in the case of young Scots Pine when they are just about one year old; and, according to v. Tubeuf, this is due to the primary needles of the Pine being covered with a thick waxy coating from which the fluid rolls off. The Bordeaux mixture is the best to use, at least 2 lb. of copper-vitriol (bluestone) being added for every 10 gallons of water. Spraying should take place between 1st July and 15th August, and repeated annually till the plantations are four to five years old, and the cost may vary from about 3s. to 8s. an acre. Plants grown from Scandinavian seed seem to suffer far less in Germany from this disease than those grown from German seed.—(Nisbet, in *Trans. Roy. Scot. Arbor. Socy.*, 1905, p. 173.)

2. *Lophodermium macrosporum*, **the Spruce Leaf-Scurf**, attacks the foliage of 2-year-old shoots in plantations of 10 to 30 or even 40 years of age, turning the needles red, and often doing a good deal of damage. The action of the disease may be twofold, as it either takes the form of a rust-like leaf-scurf or else causes leaf-shedding. In the former case the needles of the last year's shoot turn brown in spring and produce *perithecia* in July, which during damp weather ripen in the following April and May (the foliage being then two years old). In the latter case the needles only turn brown on the 2-year-old twigs in October, and the first *apothecia* are produced in the following June (on the rising 3-year-old needles), while the spores only ripen in March or April of the next year, when the foliage is nearly 3 years old. Sometimes, however, this infection is also accompanied by shedding of the browned 1-year-old needles, on which small isolated spore-pustules form. The *apothecia* gradually develop as long shiny-black excrescences on both of the two lower sides of the 4-sided Spruce-needles. The spores are twice as long as those of *L. nervisequium* on the Silver Fir.

3. *Lophodermium nervisequium*, **the Silver Fir Leaf-Scurf**, is not an important disease unless a large number of needles turn brown and die. On infected branches the 2-year-old needles (just about to enter their third year) turn brown in May (or somewhat later), and some months afterwards black *pycnidia* appear on the upper side of the needles in the shape of two wavy, crinkled, black, longitudinal, pustular swellings. Later on, usually in April of the following year, the *apothecia* are produced as numerous, dark-brown, longitudinal pustules along each side of the midrib on the lower side of the leaf, and these are ripened only on the foliage of the 3-year-old twigs. Most of the infected needles are shed before that, and the sporophores are then developed on the dead foliage on the ground.

4. *Lophodermium abietis* also attacks Spruce and Silver Fir foliage, but forms no long pustules. It first produces yellow spots and then large black dots, while the needles meanwhile turn brown.

D. Discomycetes.

This family of fungi has usually sporophores (*apothecia*) which are at first closed, but later become disc- or cup-shaped when ripe, and on the surface of which the *asci* are extended with their paraphyses (*hymenium*). The main portion of the sporophores is formed of the *hypothecium* lying below the *hymenium*.—*Discomycetous* parasites are to be found in the families *Rhizinaceæ*, *Phacidiaceæ*, and *Pezizaceæ*.

I. The *Rhizinaceæ* have flesh-like, wavy, stalkless sporophores, a non-depressed *hymenium* lying altogether free, and *asci* with a cap which bursts open. The only species attacking trees is *Rhizina undulata*, a root-fungus living saprophytically where fire has passed through the woods, and then becoming parasitic and attacking the roots of conifers of different ages. When young plants are infected they lose their needles; and later on the dark-brown, velvety, flat, morchella-like sporophores, from ½ to 2 inches long, appear round about them. Each *ascus* contains eight canoe-shaped spores, and the mycelium produced by them grows intercellularly in the bark-parenchym and in the lumen of the sieve-tubes. Rhizomorphous strands and mycelial filments extend from the infected roots and spread the disease.

II. Phacidiaceæ.

This family is characterised by thick-membraned sporophores which burst raggedly down the middle, and which are depressed in the black stroma adhering to the substratum. Three genera (*Rhytisma*, *Scleroderris*, and *Cryptomyces*) concern the forester.

1. *Rhytisma acerinum*, **the Maple and Sycamore Leaf-Scurf**, breaks out in damp weather during July as round yellow spots about $\frac{1}{4}$ to $\frac{1}{2}$ an inch in diameter on the lower side of the leaves of the common or Norway Maple, and less frequently on the Sycamore and the Field Maple. By August these spots enlarge to about $\frac{1}{2}$ or $\frac{3}{4}$ inch in diameter, and turn inky-black with a lighter margin, the black parts being flat *sclerotia*. The leaves infected are usually shed prematurely. In the following spring these hardened *sclerotia* become thicker on the dead leaves, and the rather prominent worm-like *apothecia* make these look wrinkled and bulging. In wet weather the *apothecia* burst lengthways in May or June, and expel their highly gelatinised thread-like spores with considerable force. Borne by the wind to new foliage, the spores stick to the leaves, and about three weeks later the yellow infection-spots make their appearance.

Prevention and Extermination consist in collecting and burning all the dead infected foliage; but this is only practicable in parks and gardens. The disease is a blemish, but is not perceptibly injurious in woodlands.

2. *Rhytisma punctatum* infects Sycamore leaves, forming small black sporophores surrounded with green, while the rest of the leaf turns brown in autumn; *Rh. salicinum* causes black spots on the foliage of different kinds of Willows; and *Rh. symmetricum* is a common parasite on *Salix purpurea*, whose sporophores appear on both sides of the Osier-leaf, and can even ripen before the leaves die and are shed in autumn.

3. *Scleroderris fuliginosa* infects many kind of Willows, and kills not only small twigs, but also large branches. A black crust forms on the bark, and small, stalked, plate-shaped *apothecia* appear in great numbers. The fungus kills the bark, the cambium, and the sapwood near it, so that hypertrophic swellings occur on large branches before these die.

4. *Cryptomyces maximus* also attacks various Willows, and forms a broad black crust on the twigs, when the part above that dies. During rain this mass of sporophores swells like a jelly, and in drying again it shrivels up and tears great rents in the bark. The oval spores infect the young twigs at once, and the mycelium developed hibernate there. On Osier-beds it attacks the best varieties of *Salix triandra*, those known as "Norfolks," "Black Mules," and "Spaniards."—"The presence of this fungus is first indicated by the appearance of yellow spots on the epidermis of the shoot, later black centres, due to the formation of the fruit-bodies of the fungus, appear in these spots, and finally the spots become covered by black cushions. In these black cushions arise the spores by which the disease is propagated and spread. It is necessary that a sharp look-out be kept on the beds, and any plants which show the first symptoms of the disease should be removed and burned" (A. W. Borthwick, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xviii., 1905, p. 212).

III. Pezizaceæ.

This very destructive family is characterised by having flesh-like or waxy sporophores (*apothecia*), shaped like a plate or cup, and often highly coloured. Three genera are destructive in woodlands—*Peziza*, *Sclerotinia*, and *Cenangium*.

(*a*) The genus **Peziza**.

1. *Peziza Willkommii* (also regarded by some botanists as synonymous with *Peziza calycina*, *Dasycypha calycina*), **the Larch-Canker or Blister-Fungus**,[1] has proved the most destructive of diseases in our woodlands (Fig. 174). This fungus is now very prevalent all over the United King-

[1] Exhaustive articles on *The Larch Disease* will be found in the *Trans. Roy. Scot. Arbor. Socy.*, vol. xvii., part i., 1903, pp. 19-56, and vol. xviii., 1905, pp. 213-218.

dom, and attacks Larch chiefly, though it is also found on Scots Pine and Silver Fir. The attacks take place most frequently in young plantations of 7 to 15 years of age; but at no age is the Larch immune from attacks, though after about 20 years (when thick, hard bark-formation begins), and on trees of about 30 years old or more,[1] the attacks are confined to the young branches in the crown, the fungus then having little or no chance of entering the stem, well protected by thick bark. The earlier the attack, the more serious it is. Although a sickly and therefore more or less diseased condition can be induced in the Larch by frost, plant-lice (*Chermes laricis*), or the mining-moth (*Coleophora laricella*), yet there can no longer be the slightest doubt that this fungus is the primary cause of blister or canker. Damage due to the above or to other causes certainly weakens young Larch-poles constitutionally and predisposes them to fungous infection, but the fungus is the only enemy that can produce this destructive disease. Poles of 7 to 12 years are usually either killed outright or else badly deformed. On older trees canker-spots may dry up completely and become partially cicatrised, but wherever situated the diseased part of the stem is completely spoiled as timber. How widespread and destructive the disease is in Great Britain and Ireland may be judged from the fact that there is probably not a

Fig. 174.

Canker of the Larch, caused by Peziza Willkommii.

a. Dead wood appearing at a canker-spot with outflow of resin.

b. Cup-shaped sporophores of the fungus *Peziza.*

[1] The Larch disease has only become noticeable during the last 20 years in the south-east of Ireland. The appearance of the disease is no doubt mainly due to the fact that the plantations formed between 1870 and 1881, and most of those made since then, have been chiefly, and sometimes entirely, of Larch. In nearly every one of the pure plantations of Larch, and in a good many of those which consist of about half or more of this tree, I found in 1903 that the canker-fungus unfortunately appears to have gained a very firm foothold, which it is never now likely to relax. In this respect the Larch plantations of south-eastern Ireland are in no way different from those in England, Scotland, and Wales, though the disease is fortunately, as yet, much less prevalent than in most parts of Great Britain. In none of the old Oak-woods interplanted with Larch and other conifers did I find any cases of canker on the stem; and in mixed conifer woods also the attacks, when noticeable at all, appear to be confined to the tops and branches produced during the last 20 years. But, on the other hand, I found that hardly any young plantations formed entirely, or mainly, of Larch during the last 20

plantation formed during the last 20 years, and consisting wholly or chiefly of Larch, which has escaped infection. Sometimes nearly every pole becomes blistered and cankered, and it has often been found necessary to clear-fell the poles at 12 or 15 years of age and replant with some different kind of tree.

This fungus is a wound-parasite, which can obtain entrance to any tree only at damaged parts—such as punctures made by insects (principally tree-lice and the mining-moth), hail, straining of the branches during gales or bending under pressure of snow or ice, exudation of sap after late frost, nibbling by rabbits, squirrels, or voles, wounds made at time of lifting or setting the plants, or from any other cause whatever. Of all such causes, probably the Larch-aphis is most to blame. It is quite certain, however, that some sort of wound is necessary before the fungus-spores can effect their entrance; and of course such opportunities are most frequent where the bark is thin and tender, and where sap and resin are most likely to exude. On wound-surfaces of any sort, however, the spores find a favourable germinating bed, from which the mycelium penetrates into the cortex during the non-active period of winter rest. Its growth is checked, whilst the Larch is in active vegetation, by the formation of a tough corky layer around the blister; but during the following autumn the mycelium again penetrates from the cambium into the bark, and enlarges the canker-spot. If this should finally extend all round the stem the whole of the upper part of the tree of course dies, though otherwise the struggle of the tree for existence may often be continued for very many years. But in large cankers the mycelium usually penetrates through the medullary rays into the heart-wood, and assumes proportions interfering greatly with the circulation of the sap; and when this takes place the tree begins to sicken and die. There is always danger of wind-break at cankered spots. Where large stems or thick branches are cankered, the remains of a dead branch or twig will almost always be found in the centre of the depression. This therefore shows that infection must have started near some strained or injured branch.

Dry, warm, breezy situations are not favourable to the ripening of the sporophores; while humid protected localities favour the maturing and germinating of spores. The disease is always most frequent in pure Larch crops,

years seem to have escaped this destructive disease. In many cases small plantations of pure Larch of 12 to 20 years old have been absolutely ruined; but the canker is also frequent in mixed plantations of about 7 to 10 years of age in which woodbine has been allowed to twine round and sink deep into the bark of young stems.—This is simply the effect of trying to grow Larch under different conditions from those which obtain in its alpine home, where its natural habit is to occur only as individual trees or in small family groups interspersed among other kinds of trees. Grown pure or forming the bulk of a plantation, as has been the tendency to grow it during the last 30 or 40 years, this has certainly rendered it less capable of resisting the insidious attacks of the canker-fungus, while the damp and comparatively mild climate at the same time favours the increase and spread of the disease.—Larch disease is comparatively infrequent in Co. Wicklow. This is attributable to the fact that the Larch has usually been grown here either interplanted among Oak scrub or else in mixed plantations along with a large proportion of Scots Pine, and sometimes also Spruce and Silver Fir.

and whenever the plantations are very thick. Artificial infection succeeds most easily in the month of May; and natural infection may perhaps also be most frequent then, because well-developed ascophores are then most abundant, injuries from insects and late frosts are also frequent or very recent, and there is a strong flow of sap which oozes to the surface of young shoots on the slightest puncture being made in the epidermis. In the sap exuding through any such chance wound, the spores, floating in the air after being discharged from the ascospores, can be caught, and may then germinate and effect their entrance into the living tissues.

Damp close localities, and low-lying undrained tracts where mists prevail and late frosts are frequent in spring, are specially favourable to the spread of the disease. Its prevalence in our woodlands is mainly due to our mild damp climate favouring a very luxuriant development of the fungus. The *Peziza* is, like the Larch, indigenous to the Alps; but the fruits of the fungus generally dry up there without ripening, while at the same time the Larch is very much better able to resist the parasitic attacks, because there is no doubt that the long alpine period of winter rest, with the short hot summer and little or no spring or autumn weather, likewise gives the Larch a hardier constitution than it acquires in our milder climate with a long, damp, variable spring. Here the Larch is more or less predisposed to any disease, and at the same time the fungus has very favourable conditions for its vegetation.

The first signs of the disease are smooth shining spots or slight swellings which appear on the stem or branches; then the bark splits and a slight outflow of resin takes places from the fissures. This fissuring of the bark soon becomes more general, bits of bark begin to scale from the stem, and small round or elliptical cup-shaped *apothecia* with felty white or grey edges and bright orange-red or yellow centres make their appearance at the fissures. The dead diseased parts gradually grow scurfy and black, while the canker wounds deepen as the bark curls up at the edges of the fissures, and gradually spread up and down and round the stem, killing the pole outright in the latter case.

Life-history.—When spores settle and germinate on wound-surfaces the many-branching septated *hyphæ* of the mycelium (which are only visible with a microscope) spread quickly in the soft cambium, growing partly in and partly between the cells and the sieve-tubes, browning and killing the tissues and penetrating the wood by the medullary rays and even entering the pith. The dead bark-tissue in summer becomes shrunk and depressed, and is separated from the living bark by an unusually broad layer of cork; but the mycelium (which is only capable of growing during the winter period when the Larch rests from active vegetation) in autumn makes its reappearance from the cambium or the woody-tissue, re-enters the living bast, and gradually, year after year, increases the size of the canker-spot. The cankered or blistered part is generally marked by an outflow of resin, which soon oxydises and becomes blackened; and there is usually a deep, and each year gradually deepening, depression in the middle where the oldest tissue has been first of all killed, while the stems become hypertrophic laterally.[1]

[1] "The tree endeavours to prevent a further spread of the parasite into its tissues by surrounding it with a thick wall of cork, but this barrier is of little use, since it can

Soon after the death of the bark-tissue the young sporophores appear as small yellowish-white pustules, about the size of a pin-head, round the edge of the blister. In a dry atmosphere these shrivel up and die; and it is only during continuously damp weather that these can ripen in August or September into the characteristic round or elliptical, white- or grey-edged, orange-yellow or orange-red *Peziza*-cups (ascocarps), varying up to about $\frac{1}{6}$ of an inch in diameter. These cup-shaped ascocarps also often appear on the dead bark, even when there are no blisters there.

In young plantations the ascocarps are produced in large numbers near the ground, where grass and weeds keep the soil and the foot of the little stems constantly damp, so as just to provide the conditions most favourable for the conidia or preliminary fructifications ripening into the mature spore-bearing ascocarps. And as this is just the part at which plants are liable to get slightly damaged when being lifted from the nursery or at time of notching or pitting the plants, this accounts for the disease being very prevalent in young plantations. Another common point of infection is in the angles of branches and twigs, where moisture collects, and where any strain from wind, snow-pressure, &c., can most easily rupture the bark and permit the entrance of the spore-tubes of germinating spores.

Prevention and Extermination.—When once infected, a cankerous tree never gets rid of the disease. Hartig found Larch-trees on the Alps on which the canker could be counted back for 100 years; but in our damp mild climate death usually ensues long before that time. And it is seldom indeed that any except purely ornamental specimens of Larch are ever here found of that age. As stems or branches infected always help to spread the disease, diseased poles or trees should (wherever practicable) be cut out and utilised, as the risk of infection ceases soon after the tree dies and dries up. Diseased branches should be removed from the woods, and either utilised or else burned. The cleaner that plantations are kept, and the more regularly and freely they are thinned, the less favourable are the conditions for the spread of the fungus.

Pure Larch plantations formed now in any part of Britain, even on dry, lofty, breezy situations, are almost certain to be attacked, so ubiquitous has the disease become; and the only way of securing even partial immunity is to grow Larch only in admixture with other trees, and preferably only among broad-leaved species (Beech, if possible). Forming mixed woods of Spruce and Larch is more likely to spread the disease than to prevent it, if the Spruce gall-aphis should happen to be in the vicinity (see p. 131). In ornamental trees the blister may be cut out with knife or chisel and the wound treated antiseptically with tar. Scrubbing canker-spots with an antiseptic solution (see pp. 106, 140, 156) has also been found cheap and effective for interspersed Larch (2s. 6d. to 3s. an acre; Gayton Hall estate, Ross-on-Wye, Herefordshire).

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only be formed in the living bark, and the fungus can therefore gain access to the living tissues beyond through the wood. During the summer the fungus is held in check by the vital activity of the living cells and the cork layer, but when the tree has passed into the resting condition, and those cells have become dormant, the spread of the mycelium is unhindered, and the fungus is then able to increase the area of the blister. In this way the struggle goes on between the host and parasite from year to year. The cambium round the diseased area keeps on forming new annual rings, so that ultimately the canker appears as a flattening, or as a depression in the stem. The supply of food is diverted to the side remote from the blister, with the result that the cambium there, being better nourished, forms broad year-rings, thus causing a projecting or swollen part on this side. The tensions which are set up between the living and dead tissues cause ruptures here and there, which are followed by an outflow of resin."—(Borthwick in *Trans. Roy. Scot. Arbor. Socy.*, 1903, p. 39.)

The Japanese Larch (*Larix leptolepis*) has up to the present appeared far less liable to the attacks of the canker-fungus, the Larch-aphis, and the mining-moth, than the European species. But it is by no means immune from infection by this fungous disease, nor from the attacks of these two insects, which certainly predispose trees towards infection and produce the necessary wound-surfaces enabling the fungus to enter the living tissues.

2. *Peziza* (*Dasyscypha*) *resinaria*, **the Spruce Blister or Canker**, produces a disease very similar to the above. It is local in its distribution, and is most frequently found attacking Spruce in Central and Southern England. But it is also not uncommon on Larch, occurring either alone or along with the true Larch-canker; and it has recently proved very destructive to the *Pinus excelsa* in Wiltshire (Massee). Even when examined with a pocket-lens, it requires some practice to distinguish it from the Larch-canker fungus. This being so, attacks of *P. resinaria* may often be attributed to *P. Willkommii*, in which case this may be a more destructive disease than has hitherto been suspected.

P. resinaria is, like *P. Willkommii*, purely a wound-parasite, which can only enter the living tissues through wounds made by insects, wind, &c., or by another minute parasitic fungus, a species of *Exosporium*. About three months after becoming infected with *Exosporium*, fruits appear as numerous small black dots on the surface of the bark, which becomes fissured with narrow cracks filled with resin; and through these resin-filled cracks the germinating spores of *Peziza resinaria* are enabled to enter the living tissue of the tree.

After infection the outer bark soon breaks up and scales off in fragments through the pressure exerted by the inner bark becoming rapidly hypertrophied. With age the original depression made in the bark grows larger, but there is more swelling round the edges of the wound than with the Larch-canker, and the wound more frequently completely rings and kills the branch attacked. The flow of resin is also much more copious, and large pockets form in the wood, which become filled with hardened resin permeated with the mycelium. Resin-ducts form in large number in the wood near the wound, and the resin also often fills the cells lining them.

The ascophore or cup of this fungus is somewhat smaller than in *Peziza Willkommii*, and is more distinctly stalked. The disc is always yellow or pale orange, not orange-red; and externally it is white or greyish-white, and appears minutely velvety when examined with a pocket-lens. The immature conidia are small, elliptic-oblong, and of a dull orange colour. The spores are subglobose and much smaller than those of *P. Willkommii*.

Peziza (*Dasyscypha*) *subtilissima*, a closely-related species, also sometimes attacks Silver Fir and Larch in Britain.

(*b*) The genus **Sclerotinia**.

The genus *Sclerotinia* occasions several minor diseases on trees. From the *sclerotia* the sporophores or stalked cups characteristic of the *Peziza* family are produced if the air is sufficiently moist. *Sclerotinia betulæ* deforms the fruits of the Birch, and makes them heart-shaped in place of elliptical. *S. alni* does the same on the Alder, and also attacks the fruit of whortleberries. *S. aucupariæ* immunifies the fruits of the Mountain-Ash, and *S. padi* those of the wild Cherry.

3. But of far more importance to the forester than any of these is *Sclerotinia Fuckeliana*, because its conidia-form *Botrytis cinerea*, the common **grape-mould**, which is usually only a saprophyte, can during wet spring and summer weather become parasitic and very destructive. It then attacks the foliage and young shoots of Douglas Fir, Silver Fir, and Spruce, and some-

times also Larch and Pine. The previous year's shoots, too, are sometimes attacked in the Silver Fir. This fungus was at first thought to be a separate species (*B. Douglasii*), but it is now known to be as above described.

As a saprophyte it is everywhere to be found (like *Lophodermium pinastri*, see p. 160) infesting dead foliage in conifer woods; and if such litter be used for covering seed-beds and nursery-lines, then parasitic infection is only too likely to take place. *Botrytis cinerea* then causes a very destructive disease in nurseries, and many of the deaths occasioned in seedling-beds or nursery-lines, and attributed to frost, &c., are perhaps really due to this fungus. The parts infected are the top-shoots of seedlings and the tips of the lower branches of older plants and trees. The diseased shoots become twisted or curved downwards, and the leaves die off, though often still held by the brown cobweb-like mycelium.

It also attacks Larch, Scots Pine, and *Wellingtonia* seedlings, the leaves soon turning yellow and dying off, when they hang down, supported by the mycelial threads. It is probably chiefly due to this fungus, and perhaps also to *Lophodermium pinastri*, that enormous numbers of self-sown Scots Pine seedlings are killed year after year, making it now in many localities difficult to effect natural regeneration satisfactorily. It also sometimes attacks and destroys the leading-shoots of Douglas Fir plants in young plantations, more especially in those at low elevations and in humid localities.

Life-history.—If the spores alight on young leaves or shoots in damp weather, they soon germinate and enter the tissue. The mycelium penetrates intercellularly in the leaves and the young shoots, killing the tissues as it proceeds. Sporophores and sclerotia are formed, and the spores can remain dormant for a long time and then germinate when conditions are favourable. On germinating, however, the spore-tubes cannot pierce the bark of a 2-year-old seedling, except at a wound-surface caused by late frost, insects, &c., when the fungus destroys the cambium and kills the plant, the bark forming a loose sheath round the stem. Plants attacked in the nursery are always unfit for use, as the damage caused makes them bushy and stunted, and destroys the leading-shoots.

Prevention and Extermination.—As the *Botrytis* grows saprophytically on all kinds of dead and parasitically on dying plants, it is of importance to keep the nursery-beds clean by weeding. It spreads most abundantly in humid air, so that nurseries should not be made in damp spots.

The best way of preventing its spread is to spray frequently with "Violet Mixture," consisting of 2 lb. sulphate of copper, 3 lb. carbonate of copper, 3 oz. permanganate of potash, $\frac{1}{2}$ lb. soft soap, and 18 gallons of rain-water (the soap being dissolved in hot water). All the infected ground, and for some way beyond that, should be thoroughly wetted.—(G. Massee, in *Jour. of Board of Agriculture*, vol. x., 1903, pp. 17-20.) See also Agri. Leaflet No. 127 (*Sclerotium Disease.*)

(*c*) The genus **Cenangium.**

4. *Cenangium abietis* is usually only saprophytic, but can also become parasitic and do a considerable amount of damage. It chiefly attacks Austrian and Corsican Pine of 5 years of age or older (never younger plants), and causes their shoots to shrivel up; but only weakly individuals become infected. Infection only takes place during the winter period of rest from active vegetation. The mycelium grows chiefly in the bark, and in the following spring causes the death of the last year's shoot and the terminal bud. Before this takes place the needles

turn red and are shed, beginning from the base of the shoot and working upwards. Later on older shoots, or even the whole plant, can be killed, although the infection often remains merely local. This disease predisposes the trees to attacks from beetles, moths, and aphides, which are far more destructive than the fungus.

Life-history.—Numerous black, pustular sporophores (*apothecia*) appear in small groups or bands, chiefly on twigs several years old, though later on also to be seen on the 1-year-old shoots (and then generally found on the leaf-scars, seldom on the needles themselves). They vary in size up to about $\frac{1}{10}$ of an inch in diameter, and are almost entirely closed, only opening during rainy weather. The somewhat smaller *pycnidia* form conidia that are either 1-celled and staff-like, or else many-celled and sickle-shaped.

E. Basidiomycetes.

This order of fungi is characterised by having *basidia* or conidia-bearers of very definite form, size, number of spores, and place of production, which in the higher class develop a hymenium on the surface or in the interior cavity of sporophores produced asexually.

I. Uredineæ.

This family, the **Rust-fungi**, belongs to the lower class (*Protobasidiomycetes*) of the *Basidiomycetes*, and is characterised by transversely septated *basidia*, which are always produced from chlamydospores. They are called **Rusts** from the fact of their sporophores frequently assuming a reddish-yellow rusty colour. *They are entirely parasitic.* Their mycelium grows intercellularly, and its plasma contains drops of orange-yellow or orange-red oil.

The *Uredineæ* have five different kinds of spores—viz., *uredo-*, *teleuto-*, and *æcidio-spores* (which are all chlamydospores), *sporidia* (basidiospores), and *spermatia* (conidia). All these different forms of spores do not necessarily occur in each species of fungus, but the *teleuto*-form of resting-spore is never wanting, and is that in which most of these fungi hibernate. The *teleutospore* is always 1-celled; and wherever it may appear 2- or more celled, the fructification merely consists of rows of single-celled *teleutospores.*

On germinating, each *teleutospore* throws out a short mycelial hypha (formerly called the *promycelium*), which becomes septated into four cells, and is then called a septated *basidium.* From each of these four cells of the *basidium* a filament (*sterigma*) is developed, at the apex of which a basidiospore (*sporidium*) is produced. In some genera, however, the *teleutospore* itself becomes septated into four cells, and develops like the basidiospore. The basidiospores germinate in water, and their spore-tubes always obtain an entrance into their host-plant by piercing the epidermis. After about two to three weeks the pycnidia (*spermogonia*) appear mostly on the upper side of the leaf attacked, but their conidia (*spermatia*) seem to be reduced organs of no particular importance. Soon afterwards the *æcidiospores* make their appearance, always in an enclosed sporophore (*æcidium*) and separated in rows from the main part of it, and usually issuing in cup-shape from the lower side of the leaf.

The *æcidia* usually have an envelope (*pseudoperidium*) consisting of a single layer of sterile cells; and where this is wanting the *æcidium* is called a **Cæoma**. When the *æcidium* forms large bladders or cluster-cups which are rent open with one long tear, it is called **Peridermium**; but when it opens only in parts here and there, it is called **Roestelia**. These therefore form three *quasi*-generic names.

The *æcidiospores* likewise germinate in water, by throwing out one spore-tube. This enters the leaf of the host-plant by the stomata, and in about eight to fourteen days produces *uredospores*, which are mostly stalked and clustered in wisps or bands. These *uredospores* also at once germinate in water, but throw out several spore-tubes, which likewise effect their entrance into their host through the stomata of the leaves, and in eight to ten days produce a new crop of *uredospores*, which reproduce themselves in the same way. Among the rust-fungi, therefore, the *uredospores* are the chief form by which the diseases are conveyed; and a whole series of *uredo* generations may succeed one another, until at last the cycle of development is completed by *teleutospores* being produced in the *uredo*-layers or in a special matrix. The *teleutospores* appear mostly in the spring, and generally have a thick skin of a dark colour.

Before the life-history of the rust-fungi had been thoroughly investigated and the relationship of the *æcidiospores* to the *uredo-* and *teleuto-spores*, &c., had been ascertained, the *æcidium* stage was formerly looked upon as a separate genus of fungi (*Cæoma*, *Peridermium*, and *Roestelia*), as above indicated.

Life-history of Rust-fungi.—With regard to their attitude towards their host-plant, rust-fungi may be divided into two groups: (1) *autœcious*, which complete their whole cycle of generation on one species of host, and (2) *heterœcious* or *host-changing*, whose *æcidia* and *spermagonia* develop on one kind of host-plant, while their *uredo-* and *teleuto-spores* are produced on another host, generally belonging to an entirely different order of plant from the previous host. This heterœciousness is in many cases casual, and not strictly necessary, because many heterœcious rusts can hibernate in their *uredo* stage (as in the Silver Fir canker-fungus, *Melampsorella cerastii*=*Æcidium elatinum*).

Some species have also, however, a perenniating hibernating mycelium; and many of these produce considerable malformation of the host-plant, although some of the merely annual species also cause deformities to a certain extent.[1]

The rust-fungi are divided into four sub-families (*Melampsoriaceæ*, *Coleosporiaceæ*, *Cronartiaceæ*, and *Pucciniaceæ*), of which the first three are destructive in woodlands, while the fourth and last chiefly concerns the farmer and the fruit-grower.

The rust-fungi of most importance to the forester are those which attack conifers. On Scots Pine alone, at least twelve species of *Coleosporium* (formerly called *Peridermium pini acicola*) are known as needle-rusts, as well as several bladder-rusts on the bark (formerly called *Peridermium pini corticola*) belonging to the genus *Cronartium*, and also the Pine shoot-twisting fungus, *Cæoma pinitorquum*, belonging to the genus *Melampsora*. On Larch foliage there are at least six *cæoma*-forms (*C. laricis*) belonging to species of *Melampsora*, and one *æcidium*-form (*Æc. laricis*) of *Melampsoridium*. On Spruce foliage are to be found the *æcidia* of *Chrysomyxa rhododendri* and *Ch. ledi*, and the *teleutospores* of *Ch. abietis*, while the cone-scales are destroyed by *Æcidium strobilinum* and the less frequent *Æc. conorum*, both of which are the æcidial forms of *Thecospora padi*. The canker-spots and twig-clusters ("Witches' brooms") so common on Silver Fir, are caused by the æcidial form (*Æc. elatinum*) of *Melampsorella*, while the foliage is infected by the *æcidia* of *Calyptospora* and *Pucciniastrum*, as well as of *Melampsora* (*Cæoma abietis pectinatæ*). The orange-coloured *uredospores* and the dark *teleutospores* of various species of *Melampsora* are frequent on the foliage of Willows, Birch, and Poplars.

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[1] According to the number of spores produced, and the time the *teleutospores* take to germinate, distinctions are marked by prefixing the syllables *Eu*, *Hemi-*, *Micro-*, and *Lepto-* to the generic name; thus, in the genus *Puccinia*,—

Eupuccinia denotes a species producing *æcidio-*, *uredo-*, and *teleuto-spores;*

Hemi-puccinia denotes a species producing *uredo-* and *teleuto-spores* only;

Micro-puccinia denotes a species whose *teleutospores* only germinate after resting throughout the winter;

Lepto-puccinia denotes a species whose *teleutospores* germinate at once.

A large number of the rust-fungi described as "varieties" on their metoxeny or heterœciousness being proved, are not true varieties. They are merely forms morphologically similar or only differing slightly, but exhibiting such decided differences in their selection of a host-plant that they have been called "biological species." Critical infection-experiments are necessary to ascertain the exceedingly complicated conditions of such *metoxeny;* and the observations are rendered still more difficult by the fact that the various kinds of *teleutospores*, not at once distinguishable, are sometimes found on the same individual plant, and even on the same leaf (Klein, *op. cit.*, p. 399).

(*a*) **Melampsoriaceæ.**

This sub-family is characterised by having unstalked 1- to quasi-4-celled *teleutospores*, which are massed together on flat cushion-like layers, and which form a typical *basidium* (formerly called *promycelium*) and small spherical *basidiospores*. Several genera attack the foliage of trees.

1. *Melampsora.*—This genus has 1-celled *teleutospores* which form a compact pitch-black crust under the epidermis, and germinate with freely-protruding *basidia*. The cushion-like *æcidia* are without any envelope or *pseudoperidium*, and are known as *cæoma*-layers. The *uredospores* stand singly on stalks, and have a colourless membrane. They are mostly grouped in yellow pustules on the under-surface of the leaves, and are intermixed with the thickened paraphyses.

It is in this genus that heterœciousness is most manifold and complicated. The host-plant upon which the *uredo-* and *teleuto-spores* are produced exerts an influence on the relation of the fungus to the host-plant in its *cæoma*-form, and therefore controls the spread of the fungus. The specific names now given to the genus *Melampsora* are determined by the name of the host-plant of the *teleuto-spores*, while the name of the usual host of the *cæoma* is generally put before it. Thus, *M. larici-tremulæ* means that the *cæoma*-form (*C. laricis*) is found on the Larch, and the *uredo-* and *teleuto-spores* on the Aspen.

Many of the species of importance in woodlands are parasitic on Poplar and Willow foliage. Of those attacking **Poplar foliage** seven species are known, of which the chief is *Melampsora pinitorqua*, **the Pine shoot-twisting fungus**, which produces its *uredo-* and *teleuto-spores* in large numbers on the leaves of Aspen and White and Grey Poplars. After hibernating on the dead foliage, they infect the foliage and shoots of Scots and Weymouth Pine in spring, and appear on these in the *cæoma*-form as *C. pinitorquum* (Fig. 175). This destructive *cæoma*-form is mostly to be found on Scots and Weymouth Pine of 1 to 10 years old, but plantations are liable to attack up to about 30 years of age. The yellow *cæoma*-pustules vary up to over 1 inch in length, and burst lengthways. Except those on the needles of seedlings, they appear on the bark of young shoots not yet full-grown. Young 1- to 3-year-old plants are generally killed outright ; but on older plants the twigs bend down at the infected spots, and as the shoot gradually tries to resume its upright position again, it assumes an ∽-shape (Fig. 176).

The mycelium can perenniate for many years, each year forming new *cæoma*-pustules, which shrivel up in dry weather, but develop freely during a wet May and June, and kill many of the young shoots. Young plantations are sometimes very badly damaged by this fungus, but it gradually ceases its attacks when the plantations reach about 30 years of age. The *Melampsora* itself on the Poplar foliage is more of a blemish than anything else. Infection is most frequent on wet soil and after cold damp spring weather.

Life-history.—The mycelium develops in the green bark-parenchym of the youngest shoots, where it perenniates, and whence it enters the new shoots flushed in the following May. The woody tissue of shoots thus infected becomes brown and discoloured right into the pith. Before the shoots are full-grown, pale yellow spots, late in May or early in June, make their appearance between the middle and the end of the shoots. As the spores develop under the bark the light yellow spots turn reddish-yellow and rise in pustules, until finally the epidermis fissures longitudinally and the spores scatter. Each such rent in the bark produces slight hypertrophy; and as the living tissue dies down to the woody substance, the shoot bends and grows concave at the infected part, where an outflow of resin also takes place. If the damage be only slight, the wound cicatrises and may heal entirely in time ; but when pustules break out on alternate sides, as often happens, the characteristic ∽-twisted form of growth is assumed. When damp weather in May and June favours the recrudescence of the fungus during successive years, the shoots of young Pines are often completely deformed. Parts die off wherever the disease happens to encircle the shoot and stop the flow of sap, and the young plants look stunted as if frost-bitten. The side-shoots which try to replace the leading-shoots also usually become infected.

Prevention and Extermination.—Dry warm weather naturally retards and checks the disease; but when the spring and early summer are wet for several seasons in succession, the traces of the damage may never become obliterated.

Fig. 175.

Damage caused by the Pine shoot-twisting fungus (Melampsora pinitorqua) *in its cæoma-form* (Cæoma pinitorquum).

γ. Bent infected spots, which here happen to be both on the same side of the twig.

Fig. 176.

Showing the nature of the damage occasioned to the crowns of young Pines by Cæoma pinitorquum. *The abnormal bends are caused by the attacks of the fungus.*

The only things that can be done to try and prevent this disease are to see that the soil and situation are suitable for the Scots or Weymouth Pine, and to cut out all Aspen and White or Grey Poplar, on the foliage of which *Melampsora pinitorqua* may be noticeable. All Pine-shoots infected should be removed and burned.

Of the other six less important species of Poplar-*Melampsora* as yet known, only two infect conifers in their *cæoma*-form—viz., *M. larici-tremulæ*, with its resting-spores on Aspen and White Poplar, and its *cæoma* on the Larch (*C. laricis*), and *M. larici-populina* on Black, Canadian, and Balsam Poplars, and also on the Larch (*C. laricis*). In both of these cases the *cæoma* appears as small, bright, orange-yellow pustules on Larch-needles, and often destroys a large portion of the foliage.

On **Willow-leaves** fourteen species of *Melampsora* (Fig. 177) are already known, some of which are very destructive in osier-beds, causing the leaves infected to become black-spotted and prematurely shed. Only one of these, *M. amygdalina*, is autœcious, producing all its forms of spores on *Salix amygdalina*, and being the only *cæoma* found on a Willow.

M. larici-daphnoides on *S. daphnoides* and *S. pruinosa*, *M. larici-epitea* on *S. caprea*, *S. fragilis*, *S. viminalis*, *S. aurita*, and *S. cinerea*, *M. larici-caprearum* on *S. caprea*, and *M. larici-pentandræ* on *S. pentandra*, all have their *cæoma*-form on the foliage of the Larch, while *M. abieti-caprearum* on the Sallow or Goat Willow produces the *Cæoma abietis pectinatæ* on young needles of the Silver Fir, forming several long, bright-yellow pustules on both sides of the midrib.

2. *Melampsoridium betulinum* has *teleutospore* layers like the genus *Melampsora*, but has also (like the genus *Cronartium*) an envelope (*pseudoperidium*) covering the *uredo*-layer and the *æcidia*. The small layers of *uredospores* and of *teleutospores*, at first orange-red and then turning brown, are produced on the leaves of the Birch, while the bright reddish-orange *æcidia* are formed on the needles of the Larch.

Fig. 177.

Willow Rust, caused by Melampsora *on the Caspic Osier* (Salix pruinosa).

a. Green leaf with yellow pustular sporophores.
b. Portions of the leaf already dead and withered.
c. Sporophores on the stalk near the base of the leaf.

3. *Melampsorella cerastii* differs from *Melampsora* by producing *teleutospores* in the epidermis-cells, where they form a pale-coloured layer, and by having (like *Melampsoridium*) semi-globular envelopes (*pseudoperidia*) round the pustular orange-yellow groups of *uredospores*, which often cover the whole plant. This fungus infects the foliage of various *Alsineæ*, and especially of species of *Cerastium*, *Stellaria*, and *Holostea*, which form the long-sought host-plant (at length discovered by E. Fischer) upon which the resting-spore form of *Æcidium elatinum* is developed, which produces canker on the stem and twig-clusters ("Witches' brooms") on the branches of Silver Fir, and often interferes greatly with its growth and health.

The Silver Fir Canker breaks out on the stem and branches at all heights, forming spindle-shaped excrescences on one side of the tree, or all round the stem, which swell and burst the bark with numerous fissures going down to the wood and inducing rot in it. The mycelium pervades the bark-parenchym and the sapwood, and when two or three cankers are produced on different parts of the stem, as is often the case, it is greatly depreciated in value as timber. This disease is frequent on loamy soil and in damp situations, but it proves most destructive on high-lying sandy soil. During hot dry years it sometimes kills the infected tree outright, but usually it perenniates for many years.

Another form of the same disease consists in the appearance of yellowish-green orthotropous deformities or twig-clusters ("Witches' brooms") of a far more dwarfish and bushy character than the normal branches from which they protrude upwards at right angles. On branches thus affected the needles are stunted and turn a pale sickly yellowish-green, grow closely and all round the twigs, become dotted all over the lower surface with two rows of yellow and then brownish-orange *æcidia*, and are shed during the same autumn. These deformed twig-clusters are always found growing out of a cankerous swelling or node, within which the mycelium of the fungus infests the bark, cambium, and sapwood, within which it hibernates, and from which it annually extends to the young twigs and needles till the tree is killed or the disease finally dies out.

Whether a canker-spot or a twig-deformity will be produced by the fungus depends on where the spores happen to enter and the mycelium to develop ; but very often both are to be found on an infected tree. If infection takes place close to a healthy bud, a deformed twig-cluster results ; but if the shoots are already formed and the mycelium only infects the bark, canker is there produced. But in either case infection is only possible through some sort of wound-surface. The *æcidiospores* are produced in the diseased leaves of the youngest shoots in the twig-clusters, and appear from June till August on the lower side of the needles.

Life-history.—Infection takes place on the young spring shoots, and excites the cambium to increased local activity, so that a node or swelling appears where the wood and bark develop abnormally ; and this forms the canker-spot in which the mycelium perenniates and gradually extends the canker year by year. Whenever there is a bud at such an infected part, a twig-cluster forms in the following year in place of a normally-developing shoot. Its foliage is thick, close, pale-yellow, and deciduous ; and from June till August, according to the climatic conditions, the yellow or brownish-orange *æcidia*-cups break out in two rows on the lower side of the deformed needles. In course of time these twig-clusters become very thick and bushy, often growing thus for about 20 years, and then attaining a large size. Such twig-clusters usually originate on one of the young shoots at a whorl, and are seldom found on a leading-shoot. In the former case the mycelium extends to the stem and often produces large canker-spots there ; and when the bark fissures, wound-fungi (*Polyporus*, &c.) often enter and induce white-rot, after which the stem is very liable to be broken during some storm.

Prevention and Extermination.—If grown in mixed woods, the Silver Fir is less exposed to infection than in pure woods. Once it has acquired a foothold, the disease can only be eradicated by continuously cutting off and burning the twig-clusters in June and July before their spores ripen, by pruning infected branches, by thinning out cankered poles or trees, and by removing and burning the host-plants (*Cerastium*, *Stellaria*, *Holostea*) upon which the *M. cerastii* develops its resting-spores. Where the disease breaks out in young plantations, some trouble should be taken to try and get rid of it. When an old Silver Fir wood is badly infested, it is best to clear it and replant with a mixed crop.

4. *Calyptospora Gœppertiana* produces its resting *teleutospores* in the epidermis-cells of small twig-clusters formed on the Cowberry (*Vaccinium vitis-idea*). It perenniates there, and then in spring infects the foliage of Silver Fir in the form of *Æcidium columnare*, which produces *æcidia* having a very long white envelope (*peridium*), and ranged on two rows on the lower surface of the needles. The orange-coloured *æcidiospores* are separated from each other by very long thin partition-cells.—*Æcidium pseudo-columnare* is also found on Silver Fir needles, and forms white *æcidiospores* larger than those of the above. Its other host-plant and other form of growth are not yet known.

5. *Thecopsora padi* produces small *urdeo*-pustules on the lower side of the leaves of the Wild Cherry, and the layers of *teleutospores* form brownish-red incrustations, which afterwards turn blackish-brown, in the epidermis-cells on the upper side of the leaf. The æcidial-form, *Æcidium strobilinum*, causes a disease in the cones of the Spruce which prevents the production of seed. Large numbers of semi-globular dark-brown *æcidia* break out in clusters, chiefly on the inner side of the cone-scales, which open and stand apart even during damp weather. The thick

envelope (*pseudoperidium*) of the *æcidium* becomes woody, and opens with a transverse fissure, but usually only after the cone has lain all winter on the ground. Another similar fungus, *Peridermium* (*Æcidium*) *conorum piceæ*, forms two large, flat, irregular *æcidia*, from $\frac{1}{6}$ to $\frac{1}{4}$ of an inch long, on the outer side of Spruce cone-scales; but its *uredo-* and *teleuto-spore* forms are not yet known, though they also probably belong to the *Melampsoriaceæ*.

6. *Pucciniastrum epilobii* has a *uredo*-layer like *Melampsorella*, but the *teleuto*-spore layers form large blackish-brown incrustations under the epidermis on the lower side of the leaves of *Epilobium angustifolium*. The *æcidia* look exactly like those of *Æcidium columnare*, and also infect the foliage of Silver Fir.

(*b*) **Coleosporiaceæ.**

This sub-family forms one or two waxy *teleutospore*-layers covered by the epidermis. The unstalked *teleutospores* soon divide into four cells, ranged above one another, and from each of these one single filament (*sterigma*) is extended and produces a large *basidiospore*.

1. *Coleosporium.*—This genus has bladder-like pustular *æcidia*, whose envelope (*pseudoperidium*) opens with an irregular rent; they are therefore called *Peridermium*. The *uredospores* are produced in short rows (like the *æcidiospores* above described). The *teleutospores* are dark-red.

Peridermium pini acicola, **the Pine needle-blister, bladder-rust, or cluster-cup,** which was formerly considered a definite species, but has now been found to be merely one of a series of biological species, belongs to this genus.[1] This disease is mainly confined to Scots, Austrian, and Corsican Pine of 3 to 10 years of age, but may also be found in woods up to 30 years old, though always on needles of the last or previous years, and never on the new foliage.

During April and May minute orange-yellow blisters (*æcidia*) often appear in a row, either on one or both sides of the needles of 1- and 2-year-old shoots. These blisters turn brown before they burst in the middle and scatter their spores. The mycelium hibernates in the inside of the needle without killing it, and again produces *æcidia* in the following year. The foliage is only killed and shed in bad cases of extensive infection, when the marks of the disease may be traced by small, blackish, warty spots with light edging. Usually it does not kill the infected needles prematurely.

Life-history.—The mycelium extended from the germinating *basidiospores* forms pycnidia either in the same or the following year, according as infection takes place early or late. The *peridermia* (or *æcidia*) of the different species are indistinguishable even with the microscope, but all of them make their appearance in spring on the foliage of Scots and other Pines, in which it perenniates until the needles are cast off in the usual course of time.

Prevention and Extermination.—The best way of preventing attacks is to form mixed woods in place of pure crops of Pine, and to keep plantations well weeded and thinned. Infected twigs should be removed and burned. When nurseries or young plantations are infected, the disease may usually be eradicated by digging up by the roots in early spring all groundsel, ragwort, and other species

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[1] No fewer than fifteen different species of *Coleosporium* are enumerated by Klein (*op. cit.*, p. 403), as producing those various forms of *Peridermium* on Pines which were formerly thought to be one species, *P. pini acicola*. These occur on such different weeds and plants as *Senecio*, *Tussilago*, *Petasites*, *Inula*, *Sonchus*, *Euphrasia*, *Melampyrum*, *Campanula*, *Pulsatilla*, and *Clematis*. But the commonest and the best known of them all is *Coleosporium senecionis*, which produces its resting-spores on groundsel (*Senecio vulgaris*) and ragwort (*S. sylvaticus*), and then becomes *Peridermium oblongisporium* on Pine-needles.

of *Senecio* growing in the vicinity, and burning them. The 2-year-old weeds should be rooted-out in April before they flower; but unless the roots are entirely lifted, new stalks are soon produced. Deprived of such host-plants, the *Peridermium* form cannot develop.

2. *Ochropsora sorbi*, the only species of another genus belonging to this group, infects the foliage of Mountain-Ash and other Service-trees (*Sorbus*), and produces pale-yellow incrustations on the lower side of the leaves, but its *Peridermium*-form has not yet been discovered.

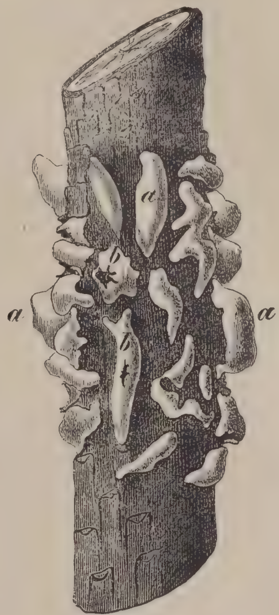
(*c*) Cronartiaceæ.

This sub-family has unstalked *teleutospores* ranged in rows. On ripening, these at once germinate with a typical *promycelium* and small spherical *basidiospores*.

1. *Cronartium.*—In this genus the simple 1-celled *teleutospores* are united both lengthways and transversely to form long, columnar, brown masses which extend freely like tendrils over the leaf-surface, and the short-stalked *uredospores* of which are enclosed in an envelope (*pseudoperidium*, as in *Melampsorella*, above described). To this genus belong the several **blisters** or **bladder-rusts** on the stems of Pine-trees, which were formerly believed to be due to one specific variety, *Peridermium pini corticola*.

This bladder-like **Pine-canker** or **bark-blister** (Fig. 178) is often very destructive throughout the whole of Great Britain and Ireland, especially in pure Scots Pine woods growing on poor soil, and with a hot S. or S.W. exposure, where it often occurs epidemically and rots a large proportion of the poles. Next to the Larch-canker, it is probably the most destructive disease in our woodlands.

Fig. 178.



Natural size.

A 5-year-old Pine-shoot, showing the bladder-like sporophores of Peridermium pini corticola *breaking through the bark.*

a. Blisters that have not yet burst and discharged their spores.

b. Ruptured blisters from which the spores have been partly scattered.

It attacks Pines in general, and Scots Pine in particular. Both poles and trees are liable to infection, but the attacks are mainly confined to young poles of about 15 to 20 years old; and all those parts of trees which are over 25 years old (stem, thick branches) seem to be immune from infection. The fungus appears first on parts of the tree that are of at least two years' growth, mostly at the whorls, and near the top of the crown. Young plants are quickly killed, while in older ones the rate of growth is interfered with, the wood becomes abnormally resinous, and the surrounding parts hypertrophied. On old branches and large stems, where the disease spreads up and down for many years, abnormal irregular furrows and twisted swellings are often formed, until at length the whole of the tree or the branch above the infected part dies through stoppage of the ascent of the watery sap.

It is often conspicuous on young Scots, Weymouth, and other Pines, when the semi-globular or oval pustules, filled with reddish-yellow spores, induce flow of resin and the formation of resin-pockets inside the stem, owing to the action of the mycelium. The growth of the tree then ceases at these places; and when this occurs to any great extent, the whole of the tree above the infected part dies.

Life-history (on Pine).—This fungus is purely a wound-parasite. It is only through some kind of wound in the bark that it can effect its entrance. The disease then first becomes noticeable by small bright, semi-globular or oval, orange-yellow or reddish sporophores (*æcidia*), breaking out as blisters on the bark of branches and stems in June, which soon enlarge, rupture, and scatter their spores. The colourless, septated *hyphæ* of the mycelium live intercellularly between the parenchym cells of the bark, the cambium, and the medullary rays and send their short side-branches into the cells to obtain nourishment.

The mycelium perenniates in the bark and the wood, and then in spring reappears forming large, compressed, bladder-like *æcidia*, filled with reddish spores and rupturing irregularly to release them. The mycelial filaments convert the starchy reserves into turpentine, which collects on the inner wall and saturates the tissue. This resinification interrupts the circulation of sap throughout the portions affected, and leads to hypertrophy and other important changes. The infection may not only extend far up and down the stem, but in large stems may also reach to a depth of 3 to 4 inches. As the mycelium, after hibernating, increases in size year by year, the highly resinified cankerous parts also extend; whilst the stem grows excentrically owing to the new annual layers of wood being formed only where the bark is still healthy. Sometimes the crown of poles is killed off within a year, when infection has nearly encircled the stem; but in the case of large trees it may be 10 to 20 years, or even much longer than that (sometime 50 to 70 on the Continent) before the crown is killed. Warm dry summers favour the progress of the disease by diminishing imbibition and stimulating transpiration, because then the merely partial supplies of sap ascending by the uninfected part of the stem are insufficient for the wants of the foliage above that.

Prevention and Extermination.—As soon as the first signs of this disease have been noticed, all poles infected should be cut out and removed before the blisters are fully developed.

The complete **life-history** of the commonest, most widely spread, and most destructive of the Pine-blister fungi, that temporarily specified as *Peridermium pini* Kleb., is not yet known. Despite innumerable infection-experiments, the alternative host-plant on which the *uredo-* and *teleuto-spores* are produced has not yet been discovered; and nothing further is meanwhile known than that this *Peridermium* is certainly heterœcious, and not autœcious. German experiments have shown, however, that the very similar (and in fact almost indistinguishable) but much rarer form of *P. cornui* has its alternative form as *Cronartium asclepiadeum*, producing its yellow *uredo-* and brown *teleuto-spores* in spots on the leaves of *Cynanchum vincetoxicum*, and as *Cr. flaccidum* on the leaves of peonies (*Pæonia officinalis*, *P. tenuifolia*).

Cronartium ribicolum, which belongs to this same category, is produced on different species of *Ribes*, and alternates with *Peridermium strobi*, a common and destructive fungus on the bark of the Weymouth Pine.

2. *Chrysomyxa.*—This genus has velvety, pustular, red beds or layers of *teleutospores*, while the *uredospores* (not always produced) are also ranged in rows (as in the genus *Coleosporium* above described).

Chrysomyxa abietis, **the Spruce needle-rust or blister,** is the commonest species of this genus; and it has the peculiarity of being *autœcious*, and mostly on Spruce (Fig. 179). Only young needles become infected; 1-year-old or older foliage is immune, and the upper parts of the crown are much less liable to infection than the middle and lower parts. Plantations from 10 to 20 years old, and growing in a damp close situation with a hot southern or south-western exposure, suffer most, though the disease is also found in woods 30 to 40 years old. On the Continent it is much more prevalent on lime than on any other kind of soil. Warm damp spring weather favours spore-production and infection, while a cold dry spring, which retards the flushing of the new foliage, helps to keep the disease in check. Considerable injury is only done to plantations when the disease appears for several years in succession; but it is always likely to increase the danger of attracting bark-beetles.

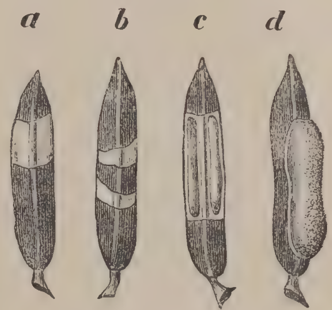
Life-history.—It only produces *teleutospores* in orange-yellow or reddish longitudinal blisters, which ripen in May and at once infect the new young needles of Spruce-trees. The first signs of infection are pale yellow bands breaking out here and there on the needles of 1-year-old shoots about the end of May or in June. These enlarge and become bright yellow, whilst the uninfected part of the needle retains its normal green colour. By autumn longitudinal brown pustules appear along both sides of the midrib on the under-side of the needles, and gradually redden and swell slightly. These are beds of *teleutospores*, which hibernate and then become enlarged in the following spring, when their envelope bursts

Fig. 179.

Natural size.

Spray from a Spruce-tree attacked by Rust (Chrysomyxa abietis).

Fig. 180.



3 to 4 times natural size.

a, b. First appearance of pale yellow marks about the end of May or in June.
c. Formation of long *teleutospore* pustules during the autumn.
d. The bursting of a sporophorous pustule in the following May.

along the middle of the blister in April or May, and the velvety bright-orange, pustular spore-bed scatters its spores about the middle of May over the needles of this year's shoots. The old diseased needles then wither, and are shed in June and July, after the spores have ripened and been scattered.

Prevention and Extermination.—Spruce is most liable to attack when planted pure on wet soil in a close confined situation; hence mixed plantations are least likely to become infected. The removal of infected twigs and regularity in thinning are the only practicable way of eradicating the disease.

Similar diseases are occasioned by the *heterœcious* species, *Chr. rhododendri*, whose *teleutospores* are produced and hibernate on Rhododendrons, while the *basidiospores* infect young Spruce-needles, forming first of all small yellow pycnidia, which usually in August develop into large yellow clusters of *œcidia*, with a long white envelope (*peridium*) that ruptures at the apex. The needles are then shed after the scattering of the spores. On the Continent *Chr. ledi*, also *heterœcious*, grows on *Ledum palustre*, and likewise produces a similar disease on Spruce foliage.

(*d*) The **Pucciniaceæ** are another group belonging to the family of rusts, but are of far more importance to the farmer and the fruit-grower than to the forester. The *teleutospores* are stalked, and germinate with a typical *promycelium*. This group comprises several genera and many species, which almost all infect shrubs and weeds, and which are partly *autœcious* and partly *heterœcious*.

The *Puccinia* genus includes *P. graminis*, which produces its *œcidia* on the leaves of Barberry (*Berberis*), and then appears destructively as the rust on wheat (for which reason the Barberry should not be tolerated in hedges round wheat-fields); *P. coronata* on the Alder Buckthorn (*Rhamnus frangula*) and *P. coronifera* on the Common Buckthorn (*Rh. cathartica*), both of which produce rust on oats; and *P. pruni spinosæ* on the leaves of the Blackthorn or Sloe and other species of *Prunus*, whose alternative host-plant has not yet been discovered.

The *Gymnosporangium* genus perenniates in the foliage and twigs of Juniper, on which the *teleutospores* (no uredospores are formed) break out in small cones in spring, and become large jelly-like pustules during wet weather. The *pycnidia* and the *œcidia*, which are enclosed in a strong thick envelope (*pseudoperidia*), opening either pencillately or like a gate (and thus forming the characteristic form *Roestelia*), ripen in summer and autumn on the leaves of Apple- and Pear-trees. There are five European species, of which the two commonest are *Gym. juniperum* and *Gym. tremelloides*, which both occur on the Common Juniper. The former breaks out as pustules on the foliage and on spindle-shaped swellings all round the twigs, then develops the alternating form of *Roestelia cornuta* on the leaves of the Mountain-Ash; while the latter causes similar swellings on twigs (but only on *one* side of them and not all round), where thick brown spore-pustules break out and then turn yellowish-brown, before rupturing and producing the alternating form of *R. pencillata* on the leaves of the Service-tree (*Sorbus aria*), and often also in large numbers on the foliage of Apple-trees. *Gym. clavariæforme* causes similar one-sided swellings on the twigs of Juniper, and produces yellow cone-like beds of *teleutospores*, which produce the alternating form of *R. lacerata* on Hawthorn foliage; while *Gym. sabinæ* infects the foliage of other species of Juniper, and then becomes *R. cancellata* on the leaves of Pear-trees.

II. **Hymenomycetes.**

This family belong to the higher class (*Autobasidiomycetes*) of the *Basidiomycetes*, and is characterised by having unseptated *basidia*, which usually have four filaments (*sterigma*) at their apex, each of which produces one *basidiospore*. Except in the genus *Exobasidium*—one species of which, *E. vaccinii*, produces red and white blisters on the Cowberry (*Vaccinium vitis-idea*), and another, *E. rhododendra*, similar blisters ("apples") on Rhododendrons — the extended *hymenia* occupy definite, free-lying, characteristic positions, and have mostly sporophores of striking shape, such as the well-known mushrooms and "toad-stools." Conidia and chlamydospores are only produced in comparatively few cases.—This family includes a great many saprophytic fungi to be found in dead wood, but those here described below are wound-parasites which enter and entirely decompose and destroy the woody tissues, making the trees useless as timber. Three of these (*Trametes pini*, *Fomes annosus*, syn. *Trametes radiciperda*, and *Agaricus melleus*) are very destructive in woodlands.

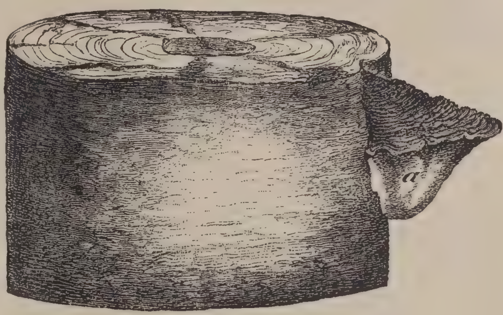
In the genera *Trametes*, *Fomes*, and *Polyporus* the substance of the sporophore, which is usually bracket-shaped, unstalked, and growing out from the side of its host, is firmly connected with the *hymenium* formed of a compactly interwoven mass of narrow tubes.

In the genus *Trametes* the substance between the intervowen spore-tubes of the receptacle is the same as that of which the cap is made; whereas, in the genera *Fomes* and *Polyporus* it is different (see pp. 182, 184). In all these three genera the spore-receptacles are bracket-shaped and sponge-like, whereas the genus *Agaricus* differs from them in its characteristic cap (*pileus*) forming the typical mushroom or "toad-stool."—*Trametes*, *Fomes*, *Polyporus*, and *Agaricus* are the fungi which produce "red-rot" and "white-rot" in trees. When the cell-wall substance (cellulose) is dissolved by a ferment in the fungus mycelium, a residuum of tannin, &c., is left behind, which oxydises and becomes reddish-brown (**"red-rot"**); but when the fungus ferment merely decomposes the lignine deposits on the cell-walls and leaves the cellulose undissolved, the decomposed wood is whitish (**"white-rot"**). The best way of preventing attacks of such wound-parasites is to tar wound-surfaces after pruning, &c.

(*a*) The genus **Trametes**.

1. *Trametes pini*, **the Pine Stem-rot Fungus.**—This disease (Fig. 181) chiefly attacks and causes rot in the stems of Pines about 40 years old or more, though it also infects Spruce, Larch, and Silver Fir. Younger trees are less liable to attack, as wounds on them in the shape of broken branches, &c., are usually closed up by outflow of resin before the fungus can obtain a firm foothold; whereas on older trees, which have already begun to form heartwood, this natural protection is diminished.

Fig. 181.



About ¼ natural size.

Section showing the rot caused in a Pine-stem by Trametes pini.

a. Bracket-shaped sporophore issuing from the side of the stem.

Life-history.—The spores germinate on wound-surfaces or wherever green branches have been recently broken off and are not yet occluded with resin. The *hyphæ* enter, destroy the cell-walls of the woody tissues, and force their way into the heart of the tree. The mycelium extends up and down the stem, and especially in the spring zone of the annual rings, so that *ring-* or *heart-shakes* are formed, extending from the crown downwards. The rapid increase of the mycelium soon produces rot in the heartwood, while the sapwood usually remains uninfected. The diseased wood first becomes reddish-brown, then white patches appear here and there, wherever the ligneous substances consisting of cellulose become dissolved, and sometimes the tree becomes completely hollowed. The mycelium next issues from branch-holes only in Pine and Larch, or else both from branch-holes and direct through the bark in Spruce and Silver Fir, and forms a brown, corky-woody, bracket-shaped receptacle or sporophore. In Pine and Larch the decomposition of the woody tissue proceeds only as far as the sapwood, where it is stopped by the formation of a hard layer of resin. In Spruce and Silver Fir, however, which have no well-defined zones of heart and sapwood, and in which there is no special resinification at this particular part, the wood rots right through to the bark. The brown, corky-woody, bracket-like spore-receptacles which thus appear outside the infected stems show concentric ridges, varying up to about 10 inches in breadth, and sometimes live for about 50 years.

Prevention and Extermination.—Infected trees should be at once thinned out.

This not only helps to prevent the disease from spreading, but allows one to have the use of the timber before the stem becomes rotten and valueless on the disease spreading down from the crown of the tree. Large branches of conifers should not be pruned without at once giving the wounds an antiseptic coating of coal-tar, or of a mixture of 1 gill paraffin to ½ gallon coal-tar.

(*b*) The genus **Fomes.**

The genus *Fomes* differs from *Polyporus* in having its bracket-shaped sporophore corky-woody from the outset, and in forming regular concentric layers of spore-tubes as it grows older; whereas in *Polyporus* the receptacle is at first fleshy and tough, and only hardens later on (though in some cases it becomes brittle), and the spore-tubes are never ranged in layers.

1. *Fomes annosus* Fries (*Trametes radiciperda* R. Hartig), **the Red-rot Root-fungus** (Fig. 182), is one of the most destructive diseases in coniferous woodlands. It chiefly attacks the living roots of Scots and Weymouth Pines from about 5 years old upwards, then Spruce and Silver Fir; but it is also found on those of Douglas Fir and other conifers. It is the most

Fig. 182.

Half natural size.

Sporophore of Fomes annosus (Trametes radiciperda) *on a Scots Pine root.*

destructive form of "red-rot," and when once it obtains a foothold in a conifer timber-crop, it spreads centrifugally from root to root. It is sometimes found on the roots of various broad-leaved trees (especially Beech and Birch), but is not then anything like so destructive or so apt to spread epidemically as in conifer woods and plantations. When attacked, young plants, poles, and trees soon show pale needles and stunted shoots (as also in attacks of *Agaricus melleus*), then they rot near the roots and die suddenly, after which the disease quickly spreads around, and, unless eradicated, makes blanks in plantations and interrupts the canopy in older woods. Wherever a diseased root comes in contact with the roots or rootlets of a healthy tree, infection takes place. The roots then gradually die, and the whole tree rots. The diseased wood first turns violet, then pale brownish-yellow, with black spots here and there which afterwards become surrounded with a white zone. The wood gradually gets lighter and spongier, then hollows become excavated, and the whole rots.

Life-history.—Infection usually takes place in the roots, and, as a rule, comes from the diseased roots of a neighbouring stem, although the spores can easily be conveyed to wound-surfaces on the roots of healthy trees by mice, insects, &c.

The soft mycelium, sometimes transparent, sometimes snow-white, develops beneath the bark and quickly permeates the cambium and the woody tissue of the roots and the butt of the tree. The cell-walls are penetrated and destroyed by masses of mycelial filaments, and the whole root-system often looks rotten and damp. This rottenness soon spreads up into the stem and penetrates the wood by the cambium and the medullary rays—except in the Scots Pine, in which morbid resinification is at once induced to such an extent as to hinder the mycelium from growing further upwards, and thus to confine the rot to the butt of the stem. Destroying the living cells as it spreads, the mycelium quickly penetrates the wood of the infected roots and then extends more slowly into the bark, where it forms between the bark-scales long, thin, tissue-paper-like mycelial strands with small nodes where they protrude between the bark-scales. The small yellowish-white pustules protruding from the bark-fissures are a secondary symptom indicating that the disease has already obtained very complete possession of the tree infected. The mycelium can now spread from the diseased roots and carry infection to all the neighbouring plants or trees. The small, glossy, yellowish-white, grape-like masses of sporophores, appearing mainly on the roots, or at the base of the stem between the bark-scales, afterwards turn chocolate-brown above and snow-white below, and form thin concave woody cushions which unite with similar adjoining groups, and sometimes form large flat incrustations or bracket-shaped excrescences about 12 or 15 inches across. But mould-like masses of conidia can also be produced where the mycelium comes out into free air.

Prevention and Extermination.—Direct infection by spores can hardly be prevented. When the disease has broken out, the best that can be done is to grub up and remove all diseased material before the sporophores are produced, and to plant broad-leaved trees in place of the conifers lifted. Infected patches can be isolated by means of narrow trenches; but this usually leads to prolific development of sporophores on the roots cut through, so that this measure is only to be recommended where the sporophores can be collected and burned before they can ripen and scatter their spores.

2. *Fomes igniarius*, **the White-rot Fungus**, is one of the commonest wound-parasites producing "white-rot" in most kinds of broad-leaved trees, but especially in Oak, Willows, and fruit-trees. At first the infected wood turns brown, then yellowish-white. The sporophores are hard throughout, round, and tubercular, then form a cap or turn bracket-shaped, and measure up to about 10 or 12 inches across. At first they are yellowish-brown and felty, but afterwards turn blackish-brown and smooth with concentric ridges. The openings of the spore-tubes are cinnamon-brown in colour. It owes its specific name to the spongy sporophore having formerly (as well as *F. fomentarius*) been much used as tinder in the old days of flint and steel.

3. *Fomes fomentarius* is a wound-parasite on the Beech chiefly, but also on Oak and Elm, where its broad leathery mycelium, penetrating the wood radially, also produces "white-rot." It forms large, hoof-shaped, russet-brown or greyish sporophores, sometimes over 3 feet long, with a hard upper crust and soft spongy inner tissue (formerly prized as tinder).

4. Other species of parasitic rot-producing *Fomes* (all of them wound-parasites) include *F. connatus* on Maple and Sycamore, with white or grey corky sporophores; *F. fulvus*, producing "white-rot" on Aspen, Hornbeam, and Plum-trees, with large, smooth, yellowish-brown sporophores, turning grey and fissured; *F. marginatus*, mostly on Beech, and also on Oak and Birch, producing large, flat, smooth or grey-downy, concentrically ridged sporophores, with variegated edges and leather-coloured interior; *F. salicinus*, often very destructive to Willows and Osiers, with smooth, hard, cinnamon-brown sporophores, often more or less inverted, which change to grey. *F. pinicola* is another

species found on dead portions of Pines, Spruce, Firs, Birch, and Cherry-trees, and probably also growing parasitically on them. It has large, hoof-shaped, corky-woody sporophores, yellow at first, then blackish, with a vermilion-red edge, and whitish internally.

(*c*) The genus **Polyporus.**

1. *Polyporus sulphureus* is a wound-parasite producing "red-rot" on Oak, Willows, Poplar, and Birch chiefly, but also on other broad-leaved trees, and on Larch and other conifers. It is also a common saprophyte in orchards. The sporophores appear annually, at old branch-holes or on the stem, as large, fleshy or cheese-like, bright sulphur-yellow or reddish-yellow receptacles of different forms, and varying up to over 2 feet long.

2. *Polyporus vaporarius* is another wound-parasite which produces "red-rot" in Spruce, Scots Pine, and Silver Fir. It is also destructive as a saprophyte in decomposing and rotting timber lying in the woods (much in the same way as *Merulius lacrymans*, which is seldom found living parasitically on trees in the woods; but the mycelium of the latter soon changes from white to grey, while that of *P. vaporarius* always keeps white). Its sporophores are not bracket-shaped, but so inverted that the *hymenium* is above; and they form flat, thin, white incrustations on the bark of the trees infected.

Other parasitic *Polypori* which produce red- or white-rot on living trees include—

(*a*) *Producing "red-rot"*—(1) *P. betulinus*, a wound-parasite on Birch, which annually forms fleshy white sporophores mostly of horse-shoe shape, which afterwards turn corky and have a thin brownish skin and short spore-tubes. (2) *P. sistrotrematis* (syn. *P. mollis* R. Hartig; *P. Schweinitzii* Fr.) on Scots and Weymouth Pine. In this case, however, the cellulose is decomposed as well as the lignine (see remark about "red-rot" on p. 181), and the diseased wood, which smells very strongly of turpentine, gradually becomes rotten. It annually forms orange-yellow, soft, spongy sporophores, sometimes bracket-shaped though mostly in the form of a wine-funnel, and with short thick stalks, but afterwards becoming dark-brown and corky. The mouths of the spore-tubes are broad and sulphur-yellow or greenish (turning to brown later), but when touched they change to deep-red.

(*b*) *Producing "white-rot"*—(1) *P. Hartigii* (*P. fulvus*), common on Silver Fir, and especially near canker-spots, and occurring also on Spruce, produces sporophores reddish-brown or ashy-grey above and yellow-brown at the mouths of the spore-tubes. On the stem these sporophores are bracket-shaped, while on the branches they are more or less irregular in form. (2) *P. dryadeus* produces yellowish and white irregular stripes of decomposition in the dark heartwood of Oak-trees, and annually forms large sarcous sporophores up to over 18 inches broad, which afterwards turn corky and rusty-brown, and have deep ridges and furrows on their upper surface. They soon rot after the ripening of the spores. (3) *P. hispidus* is common on Apple-trees, and also occurs on Ash, Elm, and Plane. It annually forms soft, spongy, cushion-like sporophores up to about 10 inches broad, rusty-brown above and yellowish below. (4) *P. borealis* produces a peculiar kind of "white-rot" in the Spruce. Small transverse holes are produced in the spring zone of wood and are filled by the mycelia, and the whole of the wood finally decomposes in small cubes or rectangles. The sporophores are formed annually, and appear as white, sarcous, watery, cushion-like or bracket-shaped excrescences, usually growing in clusters and overlapping like the slates on a roof, and about 2½ to 3 inches broad and 2 inches thick, which have an unpleasant smell. (5) *P. squamosus* often infects various kinds of broad-leaved trees, and annually produces semicircular or kidney-shaped sporophores, at first toughly sarcous and later corky, with stalks placed excentrically or at one side, yellow above and brown-scaled, often clustered in masses ranged like roof-tiles. (6) *P. lævigatus* infects the Birch, and produces inverted, thin, brown, rough leathery sporophores, with a felty light-brown edge at first, but afterwards forming an incrustation which loosens itself from the host-plant.

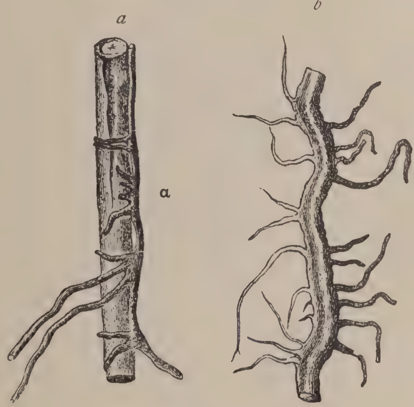
"White-rot" is, however, also caused by two other parasitic fungi belonging to other families of this group, *Hydnum diversidens* (*Hydnaceæ*) and *Stereum hirsutum* (*Thelephoriaceæ*).

Hydnum diversidens is a wound-parasite producing ashy-grey stripes in the wood of Oak- and Beech-trees. It has sarcous yellowish-white sporophores about 2 inches broad and 1 inch thick, and either bracket-shaped or else forming incrustations, which are thickly studded on the upper side with prickles about ½ an inch long and covered by the *hymenium*.—*Stereum hirsutum* is parasitic on various broad-leaved trees, and produces the peculiar kind of decomposition known as "white- or yellow-piping" in Oak stems, or else sometimes turning it all yellow. After the fungus obtains an entrance at a branch-hole, it spreads peripherally in white zones throughout the stem, so that a transverse section appears dotted over with rows of white points, while the longitudinal section shows numerous white stripes. It produces fawn-brown, rough-haired, leathery sporophores, at first appearing as incrustations and then usually turning cup-shaped, with a sharp yellow edge, and generally a *hymenium* with orange-red zones.

(*d*) The genus **Agaricus** (of the *Agaricaceæ* family, the radial *lamellæ* of which are mostly covered with the *hymenium*).

1. *Agaricus melleus*, **the Common Agaric or Honey Fungus**, one of the edible mushrooms very often found growing saprophytically on the dead stools and roots of old trees (especially on Beech), is a common and often very destructive parasite in young coniferous crops (Figs. 183, 184). It especially attacks Scots and Weymouth Pines, but is also found on Spruce, Larch, Douglas Fir, and sometimes also on Austrian and Corsican Pine. It mostly attacks young crops of from 4 to 15 years old, though it may also be found in trees 100 years old. Crowded plantations formed with wisps of three or four seedlings are most liable to bad attacks of the disease. It often breaks out in plantations on deteriorated soil where a coniferous crop has had to succeed a fall of broad-leaved trees, on the roots and stumps of which the mushrooms or "toad-stools" develop saprophytically in large numbers. Such decomposed wood is phosphorescent in the dark, so long as the mycelium is living.

Fig. 183.



Natural size.

a. Part of a Scots Pine root killed by *Agaricus melleus*, and showing an external rhizomorph which penetrates the root at *a*.
b. Flattened internal rhizomorph from between the bark and the dead wood of a Scots Pine.

The first signs of the disease are that the needles of the infected plant, pole, or tree gradually turn yellow, wither, and are shed; then the shoots wither and become stunted, the butt of the stem swells, the bark fissures, resin exudes and flows to the ground, the cambium is killed, and finally the infected poles or trees usually die either in spring (from April till June) or in autumn (October till November). The copious outflow of resin from the diseased roots and base of stem, and the rhizomorphs formed in the rotting wood and pervading the soil round about, show the presence of the disease in an advanced stage, even when no tawny yellow "toad-stools" are noticeable.

This disease is characterised by breaking out here and there in patches, and by rapidly killing young plants in full vigour, after they have made good growth during the season. Such damage is easily distinguishable from death caused by insects, drought, or the like, when the plant first sickens for some time. Young plants attacked usually die during the same year. A microscopic examination will then show that the mycelium pervades the cambial layer and the resin-ducts, which are converted into hollow cavities by disintegration, the starchy cell-matter being transformed into turpentine and causing the morbid resinous outflow. The honey-yellow or dirty yellowish-brown, toughly sarcous receptacles, with darker-coloured brown hairy scales and yellowish-white lamellæ, which turn flesh-coloured, or on which reddish-brown spots form later—the mushrooms or "toad-stools" (*pilei*) — appear

Fig. 184.

Young 8-year-old Scots Pine attacked and killed by the Honey Fungus (Agaricus melleus).

a. Branching subterraneous sterile strands (*Rhizomorpha subterranea*) thrown out from the mycelium formed under the living bark of the Pine.

b. Abortive sporophores produced at the extremity of a rhizomorphous strand.

c. Normal sporophores produced at the extremity of a rhizomorphous strand.

d. Sporophores produced in a cluster from the bark at the base of the stem of the dead Pine.

in October, and are most numerous in damp seasons. The mushrooms vary from about 2 to 6 inches in diameter. The pale flesh-coloured stalk of the mushroom shows a yellowish-white ring of skin at the point of rupture below the cap.

Life-history.—From the white spores produced during the autumn in large numbers by this fungus when living saprophytically, a fine saprophytic mycelium is formed which produces long, branching, purplish- or brownish-black cord-like strands, called *rhizomorpha*, which spread singly like roots throughout the soil, as well as in large number between the bark and the wood of the dead stump infected. These rhizomorphous mycelial strands can grow at their points and thus spread the disease below ground, entering the tissues of healthy neighbouring plants or trees wherever any wound-surface is made by the contact of roots, and perhaps also through the unprotected root-hairs and rootlets.

"They can penetrate the roots of the most different kinds of healthy conifers, although this certainly takes place under conditions still requiring closer investigation, because this fungus is one of the commonest saprophytes on old stumps and roots. According to Hartig, it also infects broad-leaved trees, and especially Maple and Sycamore, as a wound-parasite under certain conditions, and can kill Oak-stools in coppice-woods before they flush their new shoots" (Klein, *op. cit.*, p. 410).

When a subterraneous rhizomorph has obtained entrance to the root of any conifer, numerous mycelial filaments are produced from its apex, and these spread quickly upwards in the woody tissue, especially in the resin-ducts, and kill the wood-parenchym. The mycelium which happens to penetrate under the bark of living roots and stems grows more slowly, and forms thickish, white, ribbon-like strands, producing most of the well-known *pilei* or mushrooms in autumn, while the characteristic outflow of resin takes place at the base of the stem, and often in young trees causes the formation of hard masses of earth round the roots. Afterwards the mycelium penetrates the sap-conducting tissues, and produces a kind of "white-rot." When once the mycelium has spread from the place of infection on the roots upwards to the base of the stem, and has from there been able to extend throughout the other healthy roots (as also does *Fomes annosus*), the poles or trees soon wither and die, and the process of decomposition is arrested before the mycelium has time to reach the harder heartwood.

Prevention and Extermination.—The best way of preventing this fungus from spreading is to pull up infected plants *with all their roots* and burn them. Infected spots may also be isolated by completely encircling them with small trenches about 1-1½ ft. deep, so as to hinder the subterraneous extension of the rhizomorphs. The saprophytic mushrooms on old stumps should also be collected. When broad-leaved crops are replaced by conifer plantations, the stumps should, if possible, be grubbed up. Where blanks have been made in young conifer crops by this disease, it is best to beat them up with broad-leaved species, as conifers are more liable to be again infected.

2. *Agaricus adiposus* is (like *Polyporus Hartigii*) a common wound-parasite on canker-spots of the Silver Fir. It has golden-yellow mushrooms about 2 to 3 inches in diameter, and covered with concentric rows of dark flocky scales, which afterwards disappear. Its mycelial strands penetrate and soon decompose the wood, which turns yellow or honey-coloured and scales off in its annual layers, while they also extend horizontally and radially throughout the wood.

Dry-Rot in Timber used in buildings is occasioned by the "dry-rot" fungus (*Merulius lacrymans*). Despite modern improvements in ventilation, &c., it appears to be gradually increasing, owing chiefly to the use of immature and imperfectly-seasoned wood, and to the rapidity with which modern houses are built.

Infection with the dry-rot fungus sometimes takes place in the forest, when felled timber remains stored there for some time. This is first indicated by the presence of red stripes in the sawn wood; but if such wood be thoroughly seasoned, the mycelium present in the red stripes is killed. If seasoning be imperfect, the latent mycelium recommences active growth when the wood is used in any part of a building where it is exposed to dampness—*e.g.*, as when the ends of joists are built into a wall.

But the fungus is also often found in old beams and boards in woodyards, &c., and it is mainly from such sources that spores, or portions of the spreading mycelium, are introduced into buildings.

Thorough ventilation is of primary importance; to try and exclude dry-rot by hermetically closing all communication with the outer air in the spaces between flooring-boards and joists, and similar places, has proved an utter failure. The best *preventive* is painting with antinonnin (see p. 539), or with a solution of corrosive sublimate in methylated spirit (6 oz. to 1 gallon). In timber infected, the spreading mycelium can be checked by applying carbolic acid; and when once its presence is detected, all wood-work that can be reached should be thoroughly saturated with this. For further details, see Agricultural Leaflet No. 113 (*Dry-Rot*).

CHAPTER VI.

PROTECTION AGAINST INJURIOUS INFLUENCES IN SOIL OR ATMOSPHERE.

I. Protection against Non-Parasitic Diseases of Trees.

Any *abnormal disturbance* of the organism in a plant which may cause any portion of it to die prematurely is a diseased condition. But this term, of course, does not apply to the *normal disturbance* in growth due to want of sufficient nourishment, light, or moisture—*e.g.*, as in the suppression of unnecessary branches, by maintaining close canopy overhead.

Any tree may become *predisposed to disease*, perhaps only temporarily, and not necessarily involving injurious after-effects; but such natural or abnormal periods of predisposition are those when it is most exposed to the danger of diseases due either to parasitic (see chap. v.) or non-parasitic causes. Such *predisposition to disease* may result from unsuitable soil or situation, from old age, from early or late flushing of foliage in spring, from smoothness of the bark (*sunburn*), from atmospheric impurities, &c., or from wounds and injuries (leading also to parasitic rusts, rot, and cankers).

In plantations, where the plants are often not indigenous, are more or less all of one age, and are all at nearly equal distances apart from each other, trees grow under conditions less favourable to normal healthy development than are offered in natural woods, where young crops spring up as the old trees die of senile decay. If the soil and situation be such as to satisfy the natural requirements of the trees forming the crop, disease is infrequent. But if, on the contrary, the plants have not been well chosen for the given locality, then the crop, or any individual species forming part of it, may be more or less *predisposed to disease* in various forms and degrees, according as the soil and situation may vary from the conditions best suited to the kind of tree in question.

Predisposition to disease in woodland trees is more often caused by unsuitability of soil than by anything else. But in Britain, where the woods often consist of many trees from different countries, predisposition to disease also arises from unsuitability of situation and local climate, and becomes more or less pronounced according to the degree of fitness or unfitness of the situation for the given timber-crop. For example, if any tree whose natural habit is to grow in damp sheltered valleys be planted on a dry exposed situation (the soil being similar in both cases), it will soon show symptoms of disturbance more or less pronounced according to the degree of exposure and other conditions; or take any tree that naturally grows at lofty elevations, with pure dry air (*e.g.*, Larch), and plant it in a low-lying, sheltered, and humid situation (the soil being similar in both cases), and it will probably soon begin to show more or less marked symptoms of predisposition to disease. The best means of preventing disturbances of the organism amounting to disease, or to predisposition towards disease, among woodland crops is therefore to select for each species of tree only such conditions of soil and situation as are known to be favourable to its healthy or normal development, and to imitate nature by forming mixed crops in place of pure woods.

1. **Diseases due to unsuitable Soil and Situation** are principally noticeable in the stunted growth of pole-crops, or in the crown becoming dry and "stag-headed," or the roots becoming spongy or "dosed," and the stem "pumped" or hollow.

(1) **Stunted growth in Young Crops.**—When the mistake made in planting has been so great that even the young pole-thickets look stunted and backward, there is no remedy but to wait and clear them whenever a suitable opportunity offers, and then replant with other trees more likely to thrive on the given soil and situation.

(2) **Stag-headedness**, or decay or death of a part or the whole of the crown, may be due to old age or to want of water and nourishment. It is then merely the first stage in the gradual death of the tree. It is the commonest sign of senile decay, and is especially noticeable in park-trees (*e.g.*, the old Oaks in Richmond Park at present). Stag-headedness is also common when Oaks and other trees that have long stood in close canopy are given a larger growing-space and free enjoyment of light, warmth, and air, or when coppice-standards are heavily pruned of lower branches, because, in either case, this stimulates the development of shoots from the adventitious or dormant buds on the stem.

In his *Text-book of the Diseases of Trees*, p. 14, R. Hartig remarks that "Oaks which have grown up in close canopy along with Beech, and have only a slightly-developed crown of foliage, acquire a predisposition towards a drying-up of the top of the crown (*stag-headedness*) when they become fully exposed to light and air ; while, under similar conditions, trees with well-developed crowns do not suffer from this disease."

Sudden lowering of the water-level in the soil through drainage is almost certain to interfere with the health of any timber-crop, and in most cases leads to stag-headedness. Beech-woods often become stag-headed long before the trees are mature if the fallen leaves are removed from the soil (to be used as litter) for several years in succession. This affection is easily distinguished from any other by the top and upper branches of the tree becoming quite bare of leaves and young twigs, and assuming the look of stag's horns. Willows and Poplars, which grow best in a rather damp soil, generally become stag-headed when grown on dry soil. Decay of the top of the crown of conifers is almost always soon followed by the death of the tree ; but stag-headed Oaks and other broad-leaved trees usually remain alive for many years before finally succumbing.

Prevention.—Any drainage required should be done before planting, and not after the crop is formed. In old woods nothing should be done to interfere with the soil-moisture, *e.g.*, draining or removing (for litter) the layer of dead foliage on the ground. In open woods of Oak or other light-demanding trees, the soil should be protected against sun and wind by underplanting or encouraging the growth of shrubs of all sorts (but not weeds), and in making heavy thinnings or partial clearances to stimulate increment. The falls should not be made suddenly, but the trees left should be gradually accustomed to increased supplies of light and air. Standards in coppice should be pruned with care. When ornamental trees in parks or gardens begin to turn stag-headed, they can often be saved by opening a trench all round the roots and pouring in liquid manures. Bullocks' blood is usually particularly efficacious,—and fine old trees will merit such a libation.

(3) **Root-rot** may arise from stagnating water and defective aeration of the soil. Sufficient aeration is usually effected by variations in temperature throughout the upper layers, by infiltration of oxygenated moisture, and by diffusive processes. But when tenacity or wetness of soil hinders the transfusion of gases, the roots of plants get choked and asphyxiated, and rot away. This effect may sometimes be seen in young Scots Pine plantations when the tap-root rots away while the side-roots remain in a healthier state. This condition is unusual in the shallower-rooting Spruce, and seldom occurs among broad-leaved species of trees.

Prevention.—Drainage of wet land, raking and removal of moss hindering soil-aeration, and change of crop to other species better suited for the soil.

2. **Diseases due to External Injuries.**

(1) **Wound-rot**, though chiefly due to parasitic fungi (and especially species of *Fomes* and *Polyporus*, see pp. 182-184), can also be induced by saprophytic fungi on dead parts of the plant or tree exposed to the air after bruises, sun-burn, bark-stripping by deer, gnawing of rabbits, squirrels, mice, &c. The danger is always greatest if the injury is of such a nature that water can lodge in the wound. The wood darkens more or less in colour owing to the formation of a dark humic solution, but when decomposition proceeds further, the rotten wood again becomes lighter in colour. There is always a danger of such diseased spots extending into the stem through the saprophytic fungi becoming parasitic. Injuries to shallow-rooting trees, caused by horses or cattle, often produce rot which gradually extends into the stem (*e.g.*, the brown patches often found on stumps of Spruce); but here the diseased condition occasioned by the injuries gives place to the more acute form of disease caused by parasitic fungi (chiefly species of *Fomes*, *Polyporus*, and *Agaricus*).

Wound-rot, at first non-parasitic and then parasitic, may also be caused by injudicious or badly executed pruning. If large branches be cut or sawn off, rot usually sets in before conifers can protect themselves by outflow of resin or before the wound can cicatrise and become occluded; and then the rot often extends (parasitically) deep into the stem.

Prevention.—Care should be exercised in felling and extracting timber, the removal of large branches over 4 in. diameter in broad-leaved trees or 2 in. in conifers should be avoided, and the wounds made should be tarred at once (see also vol. i., Part III., p. 453).

(2) **Premature seeding** is the sign of an unhealthy condition, which excites an abnormal tendency towards reproduction of the species. Trees in

a healthy normal condition seldom produce much seed till they have nearly completed their main growth in height. Generally speaking, woodland trees bearing much seed under about 40 years of age (or 35 to 40 years in the case of conifers) are hardly likely to grow to any very valuable size. However healthy any tree may be, it can be made to bear seed by creating an unnatural disturbance within the organism—*e.g.*, by mutilating its roots or hacking its stem (as often in orchards, with Walnut-trees), but where a young tree produces seed largely at an abnormally early age, without any outward signs of injuries having been inflicted, it can hardly be in a healthy condition. Premature prolific seeding of Larch, for example, is usually a sign of heart-rot; and even in young Pines the bearing of much seed at once points to a weakly constitution, and indicates that the trees are not thriving, but will probably culminate in increment prematurely. Many of the newer coniferæ are found to seed early, and still appear to grow well; but this early bearing of seed is probably a sign that they are not yet acclimatised.

All kinds of trees, but more especially the broad-leaved species, store up large *reserve supplies of nutrients* annually, which are utilised for developing the buds in the following year, and for all the processes of awakening vegetation until assimilation can be conducted independently of their assistance. But in any abnormal or diseased condition there is what might be called an instinctive tendency or involuntary impulse to utilise an abnormally large proportion of these nutrient reserves in forming flowering-buds for the production of seed and the reproduction of the individual.

Prevention is only possible by growing timber-crops of a kind for which the soil and situation are thoroughly suitable.

(3) **Bark-bound Trees.**—This abnormal condition of the stem is often found in broad-leaved trees growing on a soil or in a situation not naturally suited to them. It is due to want of elasticity as regards the *turgidity* or state of tension in the various tissues of the bark and the wood. When the normal state of tension between the hydrostatic pressure on the one hand and the elasticity of the cell-wall on the other becomes interfered with by loss of expansive power on the part of the cells forming the cambium and the rest of the bark, then a *mechanical pressure* arises which constricts the bark and causes physiological disturbance. The outer bark of a tree thus affected looks hard and compressed, and of a dry leathery texture. If the bark-binding be not of long standing, it can usually be relieved by making a longitudinal incision in the outer bark with a knife during early summer, when the bark will immediately contract upon each side of the incision and leave the cut much wider than in the case of a healthy tree. But if the disease be of long standing, this contraction will not take place, as the bark will have lost its natural elasticity. Another result of this disease is that the top and side branches only make small, weakly, annual shoots; and each year, as the disease is more confirmed, the shoots become more weakly.

(4) **Moss or Lichen on the Bark** is not necessarily an unhealthy sign in damp localities. But the tendency to become much overgrown with lichen is an unhealthy condition often found in a damp humid atmosphere, where the trees have not a free circulation of air about them, because it results in choking the **lenticels** of the bark (see chap. v., p. 140).

II. Protection against Wetness and Aridity of Soil.

1. **Wetness.**—Though a certain amount of soil-moisture, varying for the natural requirements of different kinds of trees, is necessary for the growth of timber-crops, yet too great a quantity is in many ways disadvantageous. Wetness, or excess of soil-moisture in woodlands, may be due to want of any sufficient off-flow channel for water coming from springs or after heavy rainfall, or to any sort of impermeable subsoil hindering the percolation of water, or to temporary inundations, after the subsidence of which part of the water is left in hollows without natural drainage. Stagnant soil-water is also due to moisture percolating horizontally from neighbouring water-channels, or lakes, or ponds close by. To whatever cause the excess of moisture be due, whenever the soil becomes very wet a *marsh*, *bog*, or *swamp* is formed.

The class of weeds growing in any woodland at once indicates roughly to what degree the soil is burdened with superfluous moisture. Rushes (*Juncus*), Bulrushes (*Scirpus*), Wire Bent or Mat-grass (*Nardus*), and Hair-moss (*Polytrichum*) indicate a certain amount of stagnant water; Sedges (*Carex*), Cotton-grass (*Eriophorum*), and Knot-grass (*Polygonum*) show a greater degree of wetness; Great-moss (*Sphagnum*), Cranberry and Bog Bilberry (*Vaccinium oxycoccos* and *V. ulginosum*), are characteristic bog- or swamp-plants.

Even with little or no drainage, however, moist tracts very often become much drier after being planted, as large quantities of moisture are transpired through the foliage. But most of our timber-trees become stunted and badly grown on wet soil, owing to the want of proper aeration in the soil, to its low temperature, and to the incomplete decomposition of humus, whereby free humic acid and other injurious acids are formed.

Danger from frost, causing the death of the tender plants or parts of plants and the lifting of soft soil around seedlings and young transplants, is greatest in wet localities. On very moist soil frost can even lift out of the ground large transplants planted with balls of earth around the roots.

Red-rot and a "dosed" condition of middle-aged and old stems is frequently, on account of excessive moisture, to be found in the roots and butt, and often going far up into the stem, of Larch, Scots Pine, Spruce, and Silver Fir, and this diseased condition is usual wherever a rather thin gravelly soil rests on a clayey or otherwise impervious subsoil.

Windfall is another danger increased by wetness in the soil, especially when the stiff layer causing the wetness prevents the roots of the trees from penetrating into the subsoil.

The Felling and Removal of Timber are also frequently interrupted when the soil is wet, and work in Alder-crops growing in swamps liable to inundation can often only be carried out during hard frost in winter.

All kinds of trees do not suffer alike from the disadvantages of wet soil. Alder and most tree-Willows actually require a good deal of moisture, while some kinds of Poplar, as well as Ash, Hazel, and Spruce in a less degree, grow well on a decidedly moist soil; but in none of these cases is *stagnating* moisture other than injurious.

Prevention of Damage from Wetness.—The first thing to do is to ascertain the cause of the wetness. If due to *subterraneous springs* without any proper off-flow channel, small catchment basins should be dug round them, and the water led off by ditches. But if due to *impermeable subsoil* drainage is then necessary. With any sufficient though small gradient, the land can easily be drained by ditches carrying off the water to a lower level. If, however, the sheet of water lodges like a shallow lake or pond, then its disappearance can only be effected by boring down through the impervious stratum, or by digging ditches to lower the water-level. When the impervious stratum (plastic clay, moorpan, &c.) is thin and the swampy tract only of moderate extent, the water can sometimes be conveyed (though not often in actual practice) to the subsoil by boring through at the lowest point. The bore-hole should be made of ample size and covered over with large stones to prevent choking with silt. In other cases (*e.g.*, throughout many of the Scots Pine tracts on the great North German plain) the water-level is reduced by digging trenches over the whole area of sufficient depth and number to allow the water to collect in them, while the spoil-earth from the trenches is put over the intervening spaces to raise the surface of the soil previous to planting (see vol. i. p. 427).

Inundations can be hindered by facing and banking-up the sides of streams, by clearing or cutting through accumulations of silt, and by correcting the water-course to increase the gradient. But these are engineering works which the forester will seldom be called on to perform.

The main Principle of Drainage (see also vol. i., Part III., chap. i., pp. 315-320) is that only the actual excess of moisture should be carried off, because any thorough drainage of the soil operated on, and going so far as to lower the water-level all round about (*e.g.*, as is sometimes the practical effect of deep railway-cuttings), can prove injurious both to the actual area drained and to all the land surrounding it. Unfortunate experiences have often in this way been made owing to the consequent drying-up of springs, the too rapid off-flow of rain-water, the sinking of the water-level necessary for working saw-mills, &c.

To allow the soil to set, drainage should always be carried out a year or two before new land is planted. Drainage of areas already under wood should only be done very cautiously and very slightly, otherwise the crops are certain to suffer. When drains carrying off surplus moisture from other areas pass through middle-aged or old crops, these generally suffer more or less, and have often to be prematurely cleared in consequence.

In planting drained tracts that are still rather moist and prone to rank growth of weeds, strong transplants of species hardy against frost should be planted during dry autumn weather. Transplants with balls of earth attached to the roots may often be necessary, or mound-planting for moist localities.

Drainage is usually effected by digging open ditches. Drains covered with stones or brushwood, or led through pipes, are dearer. There must be sufficient fall towards some neighbouring water-channel whose normal level is below that of the water in the area to be drained. If the water-level in the out-spill channel is *always* lower, the drainage can easily be carried out at any time; but if it be *occasionally* higher, then sluices are needed at the mouth of the ditch to hinder at such times the in-flow of water towards the area being drained.

Careful levelling is necessary whenever the difference in level is very slight, or before any extensive drainage is undertaken; but otherwise the run of the ditches may easily be fixed by the naked eye or with simple levelling instruments.

From any large area the water is generally led off by small *feeders* conducting the water into *side-drains*, which lead it into the *main-drain*.

The **main-drain** should usually follow the line of strongest gradient towards the place where it is to debouch. But if the gradient is so great that the ditch is likely to scour and have its walls damaged by the quick flow of the water, the bottom of the ditch should either be terraced or paved, or the course of the drain should be lengthened, making it wind in curves. Its depth and width depend on the amount of water to be led off. None of the drains should be deeper than is absolutely necessary, because, apart from the greater expense, deep and exhaustive soil-drainage is often disadvantageous for timber-growing. The *width* of the drains depends on their depth and slope, the sides being steeper in tenacious soil, and more sloping in light soil to prevent their falling in or getting scoured and washed away.

The **side-ditches** may enter the main-drain either at a right angle on nearly level land, or at an acute angle if the gradient is steep and large quantities of water are likely to be conducted into the main-drain. In the latter case, if the side-drains entered the main-drain at right angles, the opposite side of the main-drain would soon be scoured and undermined by the water flowing into it. The width and depth of, and the distance between, the side-drains, as also the width, depth, and distance of the narrower and shallower **feeders** leading into the side-drains, depend on the nature and wetness of the soil.

Drainage should be done in late summer or autumn, the driest time of the year. Work should begin at the lowest level of the main-drain and proceed gradually upwards to the higher levels. If begun above, work would soon be interfered with by water filling the drains. The spoil-earth from the drains should be thrown well back from either side and not merely laid near the edges, as it might easily be washed in again by heavy rain.

The ditches should be kept open, clean, and in good repair as long as necessary. All weeds should be cleared away, earth that has fallen in should be removed, and any damage to the sides of the drains repaired. But when any excess of moisture is in course of time got rid of by the growing crops imbibing larger quantities of water for transpiration through the foliage, there is no longer any object in spending money on the maintenance of the ditches. If the ditches are found to be draining the land to a further extent than seems desirable, they of course have to be partially refilled.

Open drains are certainly cheapest for temporary requirements, but they are easily damaged by rain, frost, cattle, men, &c. At places where they are likely to interfere with the extraction of timber, or where their maintenance is likely to cost much above the average, it is sometimes preferable to make covered drains with brushwood or stones. The ditches dug are filled with bundles of brushwood (fascines) and covered with a layer of moss or turf, over which earth is piled. The brushwood remains serviceable for several years, and its interstices form the channels through which the water trickles in sufficient quantity for a moderate drainage. Filling drains with stones costs a good deal more than brushwood, unless the land is stony ; but of course they remain much longer effective.

Drainage with subterraneous drain-pipes, as in agriculture, is too expensive for woodlands. But in making roads through woods the use of wide circular drain-pipes here and there, wherever required, is much cheaper than making masonry culverts.

2. **Aridity,** or Deficiency of Moisture, has to be contended with in planting *Sand-drifts.*

Sand-drifts consist of small particles of quartz without sufficient clayey admixture to bind them together. Small and light, they are easily carried away by wind, and are thus continually blown about from one place to another.

Shifting sands are usually found, and often in large quantity, on the seashore, and often also along the banks of large rivers. The cementing particles are washed out and deposited at the bottom, while the fine quartzy particles are thrown on the shore by the waves, and in course of time form large banks of sand, called **Dunes.**

Even when more or less bound by surface-vegetation, a dry, arid, sandy soil is naturally poor and unable to yield high returns in timber. But if the sand be denuded and allowed to drift, it soon covers adjoining fertile land, and often converts it also into sand-drifts. We have nothing of this sort in Britain, but large extents of country have thus been rendered sterile on the Continent of Europe, and elsewhere.

Prevention of Sand-drifts is best effected by carefully retaining whatever soil-covering there may be, whether consisting of tree-growth, or merely of weeds of any sort. If wooded with Scots or Corsican Pines, as is usually the case where there are woods at all, no extensive clearance should ever be made. On poor sandy soil of this class, natural regeneration is usually quite out of the question; and the falls for planting should be mainly confined to clearing very narrow strips, while no fresh clearances should be made until the fall last cleared has been successfully replanted. The falls should form a series running in the opposite direction to that of the prevailing winds, and each annual fall should (in spite of risk from weevils) be at once planted without delay. Pasturage, here of small value at best, and the grubbing of stumps tend to loosen the soil and destroy the soil-covering, and should therefore be prohibited.

Besides the drifting of sand through clearing mature timber-crops without sufficient caution, any sudden laying bare of the soil, such as may occur after storms, fires, or destructive insect attacks, may result in sand-drifts which can only be fixed by replantation.

When replanting, care should be taken not to break up or loosen the soil more than is absolutely necessary, and to preserve all dead foliage or other soil-covering, as even heather, often troublesome as a weed, is here very useful.

Planting is the best and often the only way to fix shifting sand; and the manner in which this has been done, on a small scale in Norfolk, and on a large scale in the S.W. of France, is described in vol. i., Part III., chap. iv., pp. 429-433.

The preliminary steps in reclaiming and binding of dunes are generally carried out with the Sea-marram (*Psamma arenaria*), the Lyme-grass (*Elymus arenarius*), and the Sand-sedge (*Carex arenaria*). All of these are grassy plants with halms ramifying underground when covered with sand. When once the sand is thus fixed, it is planted with Pines (*Pinus montana*, *P. austriaca*, *P. corsica*, *P. Banksiana*, &c.)

The Fixation of Shifting Sand.—Wherever extensive areas are to be fixed, the first steps taken must be to bring the sand in motion to a standstill, otherwise young plants set in the sand would be smothered in some places and laid quite bare in others.

The area to be fixed is therefore first of all covered with sods of turf (**inland sand**), or fences are formed with parallel lines of hurdles woven with twigs of brushwood (on **Dunes**), or else both of these methods are combined.

Inland Sand.—The sod-laying is usually only partial, owing to the expense, and the material used may be either turf, peat of little value, or brushwood. Turf-sods are either laid down in strips more or less like a chess-board pattern, or in hallow squares with a sod in the middle. Hillocks and bunkers are covered carefully and closely, while Scots Pine branches (the only brushwood usually available) are stuck well into the ground with the thick end downwards and the foliaged ends pointing in the direction in which the wind blows, and overlapping each other like the tiles on a roof.

Dunes.—Fences or hurdles woven of twigs or brushwood are used wherever operations are being conducted over extensive and very wind-swept areas, where brushwood or turf-sods alone would prove ineffective. They are erected at right angles to the prevailing wind, and are bent crescently at the ends to afford protection even when the winds veer round in either direction. The whole area is thus subdivided by parallel lines of hurdles into a series of strips, the distance between which varies from 100 ft. on sloping, broken, or very exposed ground, to 200 ft. on fairly level ground. The object of these hurdles is not so much to intercept the sand, as to prevent its drifting after once it settles.

In erecting the fences, Scots Pine poles about 5 ft. long and 4 to 6 in. diameter are driven into the ground for about 20 in., so as to leave about 40 in. above ground. Between these uprights, placed from 2½ to 3½ ft. apart, according to the material available for weaving the hurdles, green Pine brushwood, broom, reeds, or sedges are woven horizontally, but not too closely, so that drifting sand blown against them may partly sift through to the other side and support the hurdles against the weight of subsequent drifts of sand. If there be any subsoil-moisture, White or Black Poplar and Willow poles used as uprights have a fair chance of taking root. Where poles are scarce, the uprights are put in up to 10 ft. apart, and are lashed together by horizontal bars, between which the Pine brushwood, &c., are woven perpendicularly; and in many places on the Continent this kind of fencing is in general use for fixing sand-drifts.

These parallel lines of fencing break the force of the wind and bring the sand to rest. This object is further attained by simultaneously covering with brushwood or sods of turf those parts of the parallel strips that are least sheltered by the hurdles in front. This at the same time permits of the parallel lines of hurdles being put somewhat further apart, and reduces the cost of the work.

Operations are of course always begun from the windward side, and continued line by line in the direction of the wind, each line helping to form a shelter for the subsequent lines of fencing.

A method adopted successfully on the island of Seeland was to cover the sand with a thin layer of loam. This method is, however, expensive, but useful for fixing sand in bunkers and other small spots where the sand is specially likely to drift. The loam is in autumn piled in little heaps as required and left there throughout the winter. Through the action of frost it can be easily pulverised in the following spring and spread in a thin layer over the sand, which in the course of a year or two thus becomes bound sufficiently to give the sowing or planting of Pine a fair chance of success.

As a preliminary step towards raising timber-crops, the planting of Jerusalem artichoke (*Helianthus tuberosus*), a tuberculous plant of the same genus as the common sunflower, is often found very useful in warm localities (much used in Austria). It grows even on poor inland sand-drifts, is easily produced by its tubers, which in spring throw out long flexible stalks 7 to 10 ft. high, that are not broken by the wind, but remain erect during the winter. It therefore both forms a protection against the wind all the year round, and also protects the planted young Pine seedlings against insolation, drought, and frost.

Planting with the future timber-crop should be taken in hand along with the fixing of the drifting sand. Scots Pine mixed with Corsican and Maritime Pine, and fringed to the windward with *P. montana* and *P. Banksia*, is the kind of crop generally grown. Birch and Acacia also thrive on poor soil, where the latter throws out numerous suckers, helping to bind the soil more firmly. Stout layers or strong sets (poles) of Canadian and Black Poplars and Willows do well wherever the subsoil is moist, while some of the smaller Willows (*S. acutifolia*, *S. cinerea*, *S. arenaria*, and *S. repens*) are particularly useful in binding and improving the soil. For forming protective belts along the Baltic coast, the bushy branching Mountain Pine (*P. montana*) has been found especially suitable, while Banks' Pine (*P. Banksia*) is now grown largely as a first crop, paving the way for the Scots Pine in future years, as it can thrive on poor sandy soil too dry for the latter.

Planting of Scots Pine has been found more successful than sowing on shifting sand in the north of Germany, but sowing is preferred in the S.W. of France. Strong plants twice transplanted are preferable to small seedlings or 1-year transplants; and plants with balls of earth around their roots are preferable to 1- or 2-year-old naked seedlings or transplants, although these latter have often to be used owing to the difficulty of raising plants with a ball of earth round their roots in nurseries on such sandy soil. Owing to the poverty of the soil, planting has to be exceptionally close (2½ to 3 ft. apart at most).

Blanks in young plantations should be beaten up at once, because it is far more important to replace the plants, which often die from drought in large numbers during dry years, than to extend reclamation work without being sure that what is already accomplished has been thoroughly done and given a fair chance of proving in every way successful.

III. Protection against Injurious Atmospheric Influences.

Damage may be caused in nurseries, young plantations, and older woods by **Wind, Frost, Heat and Drought, Aqueous Precipitations** (Rain, Snow, Hail, Ice, and Hoar-frost), **Lightning**, and **Atmospheric Impurities.**

1. **Storm-winds**, very rapid and destructive, cause far more damage in British woodlands than all the other dangers combined, and there can be no doubt that danger of serious damage from gales is considerably greater here than throughout the interior of Continental Europe. This is due partly to our insular position, and partly to the relatively small size of our blocks of

woodland, thus involving an unduly high percentage of specially exposed outer fringe.

Aerial currents shown by the anemometer to have a velocity up to 72 feet (24 yards) per second are classified as **Winds**; those with a velocity from 72 to 117 (24 to 39 yards) are called **Storms** or **Gales**; and those whose velocity is beyond 117 feet (39 yards) per second are called **Hurricanes**;—or approximately up to 50, from 50 to 80, and over 80 miles an hour respectively. Sometimes such disturbances are merely local, but often they extend over large areas, either as continuous *storms*, moving in some definite direction, or following a less regular course as whirlwinds or *cyclones*. Most of our storms are due to S.W., W., or N.W. winds, and the great destruction they sometimes cause is due to the fact that they often come after heavy rainfall, which loosens the soil, increases the leverage obtainable on the tree-tops (especially of evergreen conifers), and greatly weakens the power of the roots to resist the wind-pressure. East winds, being generally drier than west winds, are less frequently destructive, though their violence is equally damaging if they happen to come after heavy rainfall. Gales are usual about the end of March and September (the spring and autumn equinoxes), but the most destructive storms are generally in winter.

Storm-winds either snap the branches and stems of trees (*wind-breakage*), or throw down trees singly or in clumps or in whole woods (*windfall*) by tearing the roots out of the ground. Whether breakage or windfall is the more likely, in any particular case, depends on the soundness of the stem, the kind of tree, the soil, &c. Broad-leaved trees, generally leafless when the most violent storms occur, are not so liable to be thrown as evergreen conifers; while deep-rooting species like Oak are not so easily thrown as Beech. When the storms are cyclonic in character, they often cut a narrow track through the woods and throw down everything opposing their onward progress, while close to this comparatively little damage may be done.

The great storm of the night of 17th November 1893, which followed continuous and heavy rainfall, threw, in Perthshire and Forfarshire alone, over 1,500,000 trees, valued at nearly £300,000. The storm in the south of Ireland on 26th February 1903 threw many hundreds of thousands of trees of all kinds, principally conifers.

The root-system of ornamental trees naturally accommodates itself to their special requirements by forming stronger roots on the southern and south-western sides, enabling it the better to resist wind-pressure of S.W., W., and N.W. storms. This natural endeavour to throw out a much larger proportion of roots in that direction is also assisted by the greater amount of warmth given to the soil on the warmer southern and south-western side, causing the root-system to become more active, and therefore better developed, than on the colder northern side overshadowed by the foliage of the crown. The north and south sides of valleys running east and west suffer more from windfall than woods facing west, where the outer roots are generally firmer.

The *north wind* is occasionally very destructive; but it is not usually so violent as west winds, and it more frequently blows at a time when the soil is not soddened with rain. Its action is more generally confined to the base of the valleys, and to the lower sides of hills, than to the higher tracts. The *south wind*, on the contrary, is generally more violent at hill-tops, and not usually so destructive to woods skirting the valleys. Although the most exhausting and injurious from an agricultural point of view, the *east wind* on the whole causes least windfall in timber-crops, because it is usually dry, and blows at a time when there is little chance of the soil being soddened with recent rainfall.

But it is a drying and exhausting wind for young plantations, tending to evaporate the soil-moisture and to interrupt the normal humification of dead foliage.

All winds are more violent when the local configuration enables them to take a downward direction than when they are forced to ascend; hence, when storms rush down valleys, they are apt to be more destructive than when blowing up the valley. And when valleys grow gradually more confined, the fury of the storm becomes increased, owing to the growing pressure from behind. Thus at Comrie, Perthshire (17th November 1893), the west wind sweeping in from Loch Earn simply blew down *en masse* the whole of the woods on the Comrie side.

Continental Note.—In Germany it is calculated that, at a low estimate, windfalls average about 1,225,000 cubic feet annually. The most destructive storms recorded took place in December 1868 (when over 245,000,000 cubic feet were thrown), in October 1870 (over 390,000,000 cubic feet), in March 1876 (over 154,000,000 cubic feet), in February 1894 (over 105,000,000 cubic feet), and on 31st January and 1st February 1902 (over 58,000,000 cubic feet).

Even when not producing widespread windfall, storms interrupt the leaf-canopy and form blanks in timber-crops. The injury done sometimes necessitates the damaged woods being prematurely felled, while the breakage and splintering of many stems render them useless as timber, and only fit for fuel, the splintered parts being usually absolutely useless. In Beech-woods being naturally regenerated, the seed-trees are specially liable to windfall, while the young seedling crops may be much damaged by the thrown and broken stems. Where any extensive windfall has occurred, the local market is often glutted with timber, and timber-merchants only offer very reduced prices for good-sized trees, while the smaller material is sometimes almost unsaleable. And to extract, handle, and prepare windfall wood, the price of labour also rises owing to the increased demand and the greater difficulty and danger of working among a tangled mass of fallen trees.

The protective covering of dead foliage is blown away and piled in hollows; fungus-spores and other seeds are borne much farther than usual by the wind, and the soil laid bare soon gets overrun with a rank growth of weeds, making replantation more difficult and more expensive; bark-beetles soon infest the stems, unless these can be peeled at once; the normal course of clearing, thinning, planting, &c., as forecast in the Working-Plan, may be interrupted for the next few years: and all these effects operating together must cause the forecast of the revenue and expenditure to be entirely vitiated.

The extent of the Damage done by wind depends on the kind of tree, the age and density of the crop, its general condition of growth, and the nature of the soil and situation.

(1) **The kind of Tree.**—Evergreen conifers are, of course, far more liable to be thrown or broken by winter storms than the deciduous Larch and broad-leaved trees. Spruce is, owing to its dense foliage and its shallow root-system, more liable to be thrown than any other tree. The equally thickly-foliaged Silver Fir has a deeper root-system, which protects it, while it is usually grown on drier and more binding soil than best suits Spruce. Scots Pine, though lightly foliaged and deeper rooted, is by no means secure against windfall on light sandy soil. Among broad-leaved trees the comparatively shallow-rooting Aspen, Birch, and Hornbeam, and, during violent gales, the Beech, are far more likely to be thrown than Ash, Maple, Sycamore, or Elm (though the last often loses its branches), while the deep-rooting Oak offers the greatest resistance. Douglas Fir is specially liable to have its leader broken by wind. (See also *Note on Spruce*, p. 218.)

(2) **Age and Density of Crop.**—Storms seldom damage young crops to any considerable extent, but the danger increases with age, and is greatest in old woods. Coppice-woods run no risk whatever, copse-woods but little, especially

when the standards are Oak and Ash, and only in highwoods is extensive damage done. Highwoods in which only casual falls, or so-called "selection fellings," are made in place of regular annual falls or clearances, suffer less than equal-aged woods, as the trees have a freer individual space, and therefore greater power of resisting wind-pressure, than trees grown in regular annual or periodic falls of equal age. In the latter, too, the smaller areas that would otherwise form several annual falls are comprised within one periodic fall to facilitate natural regeneration; and in consequence of this the leaf-canopy has to be interrupted considerably in making the preparatory and seed fellings, and in the gradual clearance of the old crop, so that until their final clearance the comparatively isolated trees become more and more exposed to danger of windfall.

(3) **General condition of Growth.**—The danger of trees being thrown of course increases with the length of their stem, and the greater leverage thus given the crown. Trees that have grown with a comparatively large individual space are far less liable to become windfall than those drawn up rapidly in close canopy, and then suddenly given a considerably larger growing-space. Stems damaged in any way (canker, red or white rot, wound-holes, stripped by deer, or gnawed by squirrels, &c.) are of course much more liable to wind-breakage than sound healthy trees.

(4) **Soil and Situation.**—Trees growing in exposed situations are naturally exposed to far greater danger than those protected by hill ridges, or by other timber-crops lying to windward; and crops on shallow light sand or damp marshy soil are more likely to be thrown than those growing on deep stiff clay or stony and rocky soil. Windfall is, of course, more frequent on the former, and wind-breakage on the latter. Rainfall, by soddening and softening the soil, increases the danger of windfall, while frost decreases it, and makes wind-breakage more probable.

Prevention of Damage.—Absolute immunity against violent storms is never obtainable. Even in sheltered localities, crops which form good canopy, and are otherwise well able to resist wind-pressure, are liable to be thrown during exceptionally violent storms after heavy rainfall. But danger from wind can be reduced to its minimum by practical measures such as the following:—

(1) **Forming mixed woods** in preference to pure woods. Trees liable to be thrown are least exposed to danger when mixed with others less liable to windfall. Thus evergreen conifers should be grown along with Beech or other deciduous trees, while Spruce is protected greatly by being grown along with Larch, Scots Pine, or even Silver Fir.

(2) **Planting** is preferable to natural regeneration, as the partial clearances before and after the seed-year expose the standards to unavoidable danger. In Spruce-woods it is best to clear the annual falls in long narrow strips, and then replant.

(3) **A wind-break or protective belt** of hardy trees should be maintained all along the outer edge, and especially on the windward side. Along the sea-coast such belts will naturally consist of Pines (Mountain, Banks, Maritime, and Corsican) on sandy soil, and Beech, Maple, Sycamore, Elm, and Horse-Chestnut on other classes of soil near the sea-coast. It would be impossible to plant many of our extensive waste lands (with any reasonable chance of profit) until wind-breaks of Pines or White Spruce be formed at convenient distances to afford shelter to the young plantations (see also vol. i., Part III., p. 424).

(4) **Care in selecting Standards.**—Only well-grown trees of species able to resist strong wind-pressure, and likely to have well-developed root-systems, should be retained as standards in copses or natural regenerations. In exposed situations, or where the soil is light or moist, the danger of standards becoming windfall and damaging the young seedling crop is considerably greater than in sheltered localities with loamy or clayey soil.

(5) **Moderate thinnings**, begun early, and repeated whenever necessary, promote sturdy growth and a well-developed root-system. The leaf-canopy should be kept fairly close, and all heavy thinning likely to form blanks in it here and there should be carefully avoided, especially in crops of evergreen conifers, which are most liable to breakage and windfall.

(6) **Judicious location of the annual falls** should be carefully considered when framing the Working-Plan, because it is only thus that a favourable succession of annual crops can be secured giving the maximum of protection against storms.

(7) **The fall of mature crops** should always begin on the lee side, and should proceed in subsequent years in the direction opposite to that of the prevailing dangerous winds. Thus, where the storm-winds most to be feared come from N.W., W., and S.W., the annual falls should begin on the east side and proceed in the teeth of the W. wind by means of a succession of narrow annual falls running north and south, so that the young crops planted may be under the lee and protection of the old maturing woods to windward. For coniferous forests (and Spruce especially) this rule is of great importance (see also Part V., pp. 257-265).

(8) **Avoid sudden exposure** of middle-aged crops when making falls in mature crops lying to windward. In order to locate the successive annual falls of timber judiciously (when a Working-Plan is being framed), the felling of older crops has sometimes to be delayed, while younger crops are cut before they are quite mature. The best way of avoiding sudden exposure to wind of 40- to 60-year-old crops is the system of **Protective Falls or Severances**, long practised throughout Saxony and the Saxon states, for the purpose of strengthening the windward edge of a young wood (especially in Spruce-woods) against the time when the older wood to the windward of it will be felled and its shelter lost (see Part V., p. 265).

Such **Severances** or **Protective Falls** consist in clear-felling a strip from 33 to 50 ft. broad in the older sheltering wood, and at right angles to the direction of the most dangerous wind. This enables the younger crop to throw out strong roots and to assume a more branching habit among the trees along the edge, and this naturally protects the wood against storm-winds when the older crop is felled. For such an operation to prove successful it is of course necessary that the severance be made while the younger crop is still a thicket or pole-wood of 15 to 30 years old, and therefore still able to develop strong side-roots and numerous branches forming a thick wind-mantle. The strip cleared in the older wood should be replanted at once, to form an additional protection.

(9) **The period of rotation** should not be high in stormy districts, as the danger from storms increases owing to the trees having larger crowns and to the larger blanks made when sickly or damaged stems become windfall. As experience in Britain has often shown, conifer woods of 30 to 40 years old are liable to be entirely destroyed during exceptionally violent gales. Now, if the rotation be 60 or 80 years, this simply means that a very much larger proportion of the wooded area is unduly exposed to serious danger.

(10) **Lopping the crowns of trees** at the edge of the wood, dry-stone dykes, and heaping stones above the roots of trees on the windward edge, all help to protect against wind. As storms catch hold of trees lying behind blanks formerly made in the crop, it is important to try and make the trees wind-fast at the exposed edge of blanks and interruptions of the leaf-canopy; and this is often achieved in Spruce-woods in Germany by piling heavy masses of stone along the windward side to weigh down the shallow roots. A couple of strong poles being first laid over the roots, and then cross pieces of about 3½ ft. long, another couple of long poles is placed above the first pair, and used as a framework on which to pile up large stones and bits of rock to a height of 2 to 3 feet. If the windward trees and

those immediately behind them are at the same time lopped at about one-third of their height, this shortens the leverage obtainable by the wind and increases the protection afforded to leeward.

Remedy of Damage.—As windfall and broken timber requires to be extracted as soon as possible, to avoid danger from insects, and to shorten the time of the land lying unproductive, the roads and rides should be at once prepared or opened out for extracting the damaged timber; and in natural regenerations broken trees and ends should be immediately removed, otherwise the young crop may get badly damaged. Windfall standards, often blown down in large numbers on areas undergrowing natural regeneration, kill the young seedling crop if left lying for any length of time. If the quantity of timber thrown be too large to clear immediately, the stems should at any rate be topped at once, and the branches and brushwood removed to the edges of the compartments and piled along the roads and rides. Where the roots of the thrown trees have torn great masses of earth out of the ground, the stems should in natural regenerations be sawn through at the butt and the stumps tilted back into their former position, especially when seedlings are numerous in the soil lifted.

Attacks of injurious insects can only be obviated by barking coniferous windfall timber at once. Unless the stumps can be grubbed up weevils will breed in them and hinder replanting for the next three or four years.

Preventing minor Damage.—Ordinary stiff winds, less violent than destructive gales, blowing continuously from any direction soon stunt the growth of crops exposed, and especially along the outer edge, where the trees form only stunted malformed wind-bent crowns. They may also do a good deal of damage by *blowing away dead foliage* near the edge of the wood and from exposed knolls and ridges. The formation of humus is thus hindered, and the soil is dried up, hardened, and exhausted in some places, while the dead leaves are piled up in hollows to injurious depths. Oak, Beech, and other broad-leaved highwoods and coppice soon become backward in growth under such circumstances.

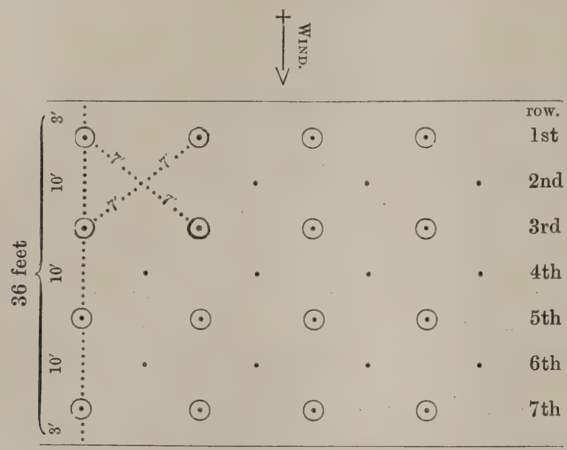
Dry east winds in spring exhaust the soil, partly by evaporation of moisture and partly by stimulating the plants to increased transpiration resulting in their withering and drying up. During planting operations at all times, but especially in spring, the plants should be carried in deep baskets packed with damp moss, and the tender rootlets carefully protected against the drying effect of the wind, because when the root-hairs get withered the plant finds greater difficulty in establishing itself.

Here, again, the best measures are—

(1) **Forming shelter-belts** along the edge of exposed woods. This is often attained in Germany by planting several rows of Spruce, which, though a shallow-rooting species, develops specially strong roots to windward when grown in exposed situations. The White Spruce has in Denmark and Jutland been found still better adapted for forming shelter-belts round plantations. Douglas Fir should also be specially suitable, as the loss of its top is of no matter in such a case, the chief thing being the maintenance of a thick mantle of foliage to break the wind and prevent its sweeping in through the wood. Where likely to succeed, parts specially exposed to danger may be underplanted with shade-bearing trees (Beech, Hornbeam, Spruce, Silver Fir).

(2) Avoid unnecessary **thinning** along the exposed edge of the wood, and encourage any natural undergrowth there, as also in the interior of wind-swept woods. Hedges skirting woodlands should be kept well clipped, so as to make their foliage thick. It helps to preserve the dead foliage and the soil-moisture if coarse clods be hoed along the windward edge of the woods.

Shelter-belts to protect agricultural land should vary from 36 to 60 ft. in breadth, according to the given circumstances. It is not likely that a belt less than 36 ft. across can prove really effective in an exposed situation. Taking 36 ft. as the minimum width, the belt may best be planted in four rows at 10×10 ft., with intermediate plants also at 10×10 ft., so as to form a double-square or quincunx plantation, in which the plants would stand in triangles about 7 ft. apart ($x^2 = 5^2 \times 5^2 \therefore x = \sqrt{50} = 7$ ft. apart), and the total number of plants required per acre would (in the case of planting close to the fence on both sides of the shelter-belt) be 847 per acre, or about 840 for every 400 yards in the length of the enclosure (1210 × 36 = 43,560 sq. ft.) To form a good wind-screen the plants should have plenty of growing-space to permit of rapid and thick branch development. This double-square (quincunx) method of planting, while easy to carry out, offers about the largest possible surface to the wind, and it is very considerably cheaper than planting in squares at 6 × 6 ft. (1210 plants per acre). Where the soil is poor sand, of course the choice of trees to form a shelter-belt is mainly limited to evergreen Pines (Scots, Austrian, Corsican, Cluster, Mountain, and Banks'); but otherwise a good shelter-belt for agriculture may be formed on loamy or limy soil near the sea-coast as follows:—



row.		per acre.
1st	Cluster Pine (on loam or sand), or Mountain Pine (on sand or lime)	$\frac{1}{7}$=121
2nd	Norway Maple or White Spruce	$\frac{1}{7}$=121
3rd	Sycamore .	$\frac{1}{7}$=121
4th, 5th	Ash or Black Poplar	$\frac{2}{7}$=242
6th	Elm . .	$\frac{1}{7}$=121
7th	Beech . .	$\frac{1}{7}$=121
		Total about 847

In the course of from 5 to 8 years after planting (according as the young trees establish themselves and thrive) a good many may have to be removed. This can best be done by coppicing these flush with the ground, and with a clean smooth cut to encourage the growth of stool-shoots to grow up as underwood below the other young trees. For forming shelter-belts of this description, good, stout, healthy plants should be obtained, and they have perhaps the best chance of establishing themselves if grown in a home-nursery or got from some locality with a similar coast-climate. Bushy well-rooted transplants not above 2 to 2½ ft. high are most likely to establish themselves successfully.

The best time for planting is usually in autumn for deciduous plants, and in spring for evergreen conifers. The main portions of the shelter-belts should therefore be made in autumn, and the outer single (or double) row of Cluster Pine, &c., in spring.

2. **Frost** may either do damage as **late frost** in spring, **early frost** in autumn, or **winter frost.** When portions of plants in active vegetation are frost-bitten, water is withdrawn from the cells and passes into the intercellular spaces; and the effect of this is that the tissue loses its *turgor* or power of tension, and the affected parts wither and die when a thaw comes. It is not yet definitely known whether the tissue is actually killed at the time the cell-sap is withdrawn by the frost, or only dies after thawing, and in consequence of the inability of the cell-wall to reabsorb the sap before the chlorophyll is decomposed; but the latter is the generally accepted view.

(1) **Late Frosts** in spring are by far the most destructive. They occur when the temperature falls below the freezing-point, after young portions of plants have begun their active vegetation. Young shoots, leaves, and flowers nipped by the frost first droop and wither, then turn brown or black as the chlorophyll decomposes, and at last die and fall off. Seedlings are usually killed outright, while stronger plants lose their young shoots, and are often stunted by being frost-bitten year after year in damp, low-lying, sheltered localities (*frost-holes*). When the

young shoots have been destroyed by spring frosts, the increment for the year is necessarily less than it otherwise would be; and when the flower-buds of standard trees in natural regenerations have been nipped, seed-production is impossible. Late frosts are specially to be feared on the nights of 12th, 13th, and 14th May, though they also frequently occur in Britain after then.

(2) **Early Frosts** in autumn nip and kill the young shoots before they have had time to harden and become woody; but they seldom kill the whole plant outright, the damage being mostly confined to the summer shoots. Autumn frosts are one of the causes of the widespread disease known as *leaf-shedding*, which attacks young Scots Pine chiefly, but also most other species of Pine (except perhaps the Weymouth Pine).

Leaf-shedding may often be caused by the drying up of the needles through drought or the action of frost, although in most cases it is undoubtedly due to the fungus *Lophodermium* (*Hysterium*) *pinastri* (see p. 160). The liability of young 1- to 5-year-old Scots Pine to suffer from this affection has increased to such proportions in some localities as to have caused considerable loss in nurseries and young crops.

This peculiar disease often in a few days causes the needles of young 1- to 5-year-old Pine to wither and die, while in older plants only the needles on the lower branches are affected. Weakly plants, and those growing in thick masses as 1- and 2-year-old seedlings in nurseries, often thus die off suddenly in large numbers; and though the stronger of them may perhaps recover to a certain extent, they are not fit for planting during that year, and are often rendered altogether useless.

This disease, which occurs mostly in spring (March to May), and especially during dry, cold, windy weather, but is not widespread in Britain, was at first supposed by Ebermayer to be due to drying up of the needles, owing to bright sunshine in winter and early spring stimulating transpiration and depleting the plants of water which the roots could not replace by imbibition from the frost-bound soil. Here much the same process of exhaustion of the available water-supply takes place as during continuous summer drought. When dessication of this sort causes the leaf-shedding, the needles turn brown or reddish-brown all over, and show no traces of fungous spots; and the only way of protecting seed-beds in nurseries during winter and spring is to cover them with a light framework. Temporary nurseries formed where they have the side protection of older crops suffer less than those fully exposed to the sunshine.

(3) **Winter Frosts** do damage chiefly by lifting the plants and soil in nurseries and very young plantations, and in making frost-shakes in trees (see pp. 206 and 207). Most of our indigenous trees and acclimatised exotics are hardy, although summer shoots are often nipped and roots of young Oaks killed during continuous hard frost when the ground is not covered with snow. Here again damage is due to the withdrawal of cell-sap from the tissue, while the foliage of evergreen conifers may also wither after rapid transpiration of water on sunny days, during which the evaporated water cannot possibly be replaced, the water-conducting tissue of the stem being frozen. This particular kind of damage may often be seen on trees at the sunny edge of woods, and on any that stand freely exposed to the south.

Extent of Damage by Frost.—Different kinds of trees vary greatly in their hardiness, or power of resisting the effect of frost; but the age of the crop, the nature of the soil, situation, and soil-covering, the time of the year, and the kind of weather accompanying the frost, are all of more or less influence as regards the damage done.

(1) **Hardy and Sensitive Trees.**—Some kinds of trees can bear exposure to 10° or 12° (Fahr.) of frost without suffering any damage, and the leaves and

flowers of most of them can endure a few degrees. But the state of the weather then becomes of importance, because any wind or light breeze decreases the risk of damage, while a continuation of the frost, or simultaneous hoar-frost occasioned by rapid evaporation from ponds or meadows, increases it. The leaves of many plants droop and look yellow after a frosty night, but gradually recover again. The flowers are always more sensitive to frost than leaves, but flowers on hardy trees are also less sensitive to late frost than those of other species.

Our woodland trees may thus be classified as to late and early frosts :—

	Broad-leaved Trees.	Conifers.
Hardy . .	Alder, Birch, Hornbeam, Poplars, Willows, Mountain-Ash ; Hazel (in coppice).	All Pines (except the Maritime or Cluster Pine), Douglas Fir (Colorado variety).
Somewhat Sensitive .	Maple and Sycamore, Horse-Chestnut, Lime, Pedunculate Oak.	Larch, Spruce, Douglas Fir (Pacific variety), Maritime Pine.
Sensitive .	Ash, Sweet-Chestnut, Beech, Sessile Oak, Robinia.	Silver Fir.

Most of the hardy trees (*e.g.*, Alder, Birch, and Hornbeam) break into leaf early in spring, while the more sensitive species (Oak, Sweet-Chestnut, and Acacia) only flush their leaves later, even as late as the middle or end of May, when late frosts are usually nearly over. Beech breaks into leaf earlier, and therefore, although a less sensitive species, suffers more from late frost than the Oak. The side-shoots of the Silver Fir are often killed by frost, while the leading-shoot escapes by being enclosed in the terminal bud, which only develops later than the side-buds forming the whorl. The Larch is very sensitive to frost just when its buds are opening ; but as soon as the needles expand somewhat it becomes decidedly hardy. In the Alps the flushing of the foliage takes place even more rapidly than in Britain, in consequence of the climate ; and this again subjects the Larch with us to greater danger of wounds (frost, hail, &c.), permitting the entrance of canker-fungus spores.

(2) **Soil and Situation.**—Wind-still dells and sheltered hillside coombs, or even shallow depressions in the leaf-canopy of timber-crops, increase the danger of frost wherever the soil is moist. The evaporation of the soil-moisture produces heavy cold layers of air which there is no air-current to waft away, so that **frost-holes** are formed; and these patches, exposed year after year to late and early frosts, very often show inferior growth in sharp contrast with the rest of the crop. Woods fringed by damp meadows, the strong evaporation from which makes the nights cold, only escape danger from frost for a short time during the height of summer ; while E. slopes, exposed to the cold dry winds, and S.E. exposures, where active vegetation is awakened early, suffer more from frost than N. aspects. On E. exposures there is the additional danger of the morning sun causing the frozen parts to thaw quickly and destroy the tissue of shoots.

(3) **Soil-covering.**—A dense growth of grass and other low-growing weeds increases the radiation of heat, especially during clear cloudless nights, and therefore increases the danger from frost above that on cleaner soil; while thorns, juniper, broom, and other shrub-like weeds act as a protective covering to the soil by decreasing radiation of warmth.

Young seedlings of any kind, and 1- and 2-year-old seedlings of sensitive kinds of trees, are usually killed outright by late frosts; but the liability to injury ceases when the plants grow above the *frost-height* or normal level of the cold layers of air laden with the moisture evaporated from the soil—a level often distinctly marked by damage in thickets. Quick-growing kinds of trees (*e.g.*, Douglas Fir (Pacific), Larch, Birch, Aspen), therefore, outgrow danger from frost sooner than those which come up more slowly (*e.g.*, Birch and Silver Fir in particular).

The later a frost occurs in spring, the more damage it is likely to cause; and those coming about the middle or end of May are often exceedingly injurious both in nurseries and in young plantations. Late frosts accompanied by hoar-frost are usually more destructive than simple dry frost; but the damage is always greatest when the parts frozen at night thaw rapidly under the direct action of the morning sun. On good soil and during damp warm weather, damaged plants have more chance of recovering than on poor soil and during cold dry weather.

When deciduous trees lose their foliage by late frosts, it is replaced to a certain extent by the development of adventitious buds, while evergreen conifers are unable to replace lost shoots during the same year. But the different deciduous trees vary greatly in such reproductive power. For example, it is greater in Oak than in Beech.

Early or autumn frosts are always less destructive than spring frosts, because only those parts of the young shoots not yet thoroughly hardened are lost, and neither flowers nor germinating seedlings can be damaged. The damage done depends on much the same factors as for late frosts; but in Oak-coppice, if the fall be delayed till spring (in place of late autumn or winter), the shoots flush late from the stools, and early autumn frosts often find them still partially unhardened. A cool summer, followed by a damp warm autumn, prolongs the period of active vegetation and increases danger from early frosts. *Leaf-shedding* of Scots Pine (see p. 161) is often caused by early frost, as also frost-shakes in trees, which are, however, more often due to hard winter frost (p. 206).

Prevention.—In nurseries with light sandy soil, clay should be added to stiffen it. Nurseries should, wherever practicable, only be formed in places little exposed to late frosts, such as gentle slopes with a N. or N.W. aspect where active vegetation is later in awakening, spots protected on E. and S. by older crops, and large open spaces in old woods.

Seeds sown in autumn germinate early in spring, unless covered with leaves and brushwood; whereas autumn-sown seed thus protected and spring-sown seed can often be made to germinate only after the main danger from early frosts is over. Sowing deep is not good, as the seedlings then come up very irregularly, and many not till the following year.

Very young seedlings and older seedlings of sensitive species can best be protected by a horizontal framework of small pieces of wood about 1 in. broad set 1 in. apart. This is much better and less troublesome than sticking twigs and brushwood into the beds, and there is no danger of conveying fungous disease (*Botrytis cinerea*, *Hysterium pinastri*, &c.) to the seed-beds.

Young plantations and thickets of trees sensitive to frost (Beech and Silver Fir especially) should be regenerated naturally under the shelter of parent standards kept in fairly close canopy, and these seed-trees should be gradually cleared, avoiding any sudden exposure of the young seedling crop. Where practicable, it is best to maintain a protective belt on the E. and N.E. sides till the young crop has outgrown danger. Birch, Aspen, and Goat Willow often spring up self-sown in large numbers throughout the young crop, and are useful in protecting more sensitive species; but when once the latter outgrow the danger from frost, the softwoods should be gradually weeded out.

In making new plantations on land exposed to frost, hardy and quick-growing trees like Pine and Birch, or Alder on moist land, should be planted as **nurses** in rows wide apart. They should be put out a year or two in advance of the general planting, and whenever they are high enough to afford protection, the trees to form the subsequent crop should be planted between the rows of nurses; but as soon as the main crop gets above the frost-height, the nurses should be gradually cut out. Whenever practicable, only hardy trees should be planted in frost-holes.

In forming crops of sensitive kinds of trees, or in planting in frosty localities, only large healthy transplants with strong root-systems, not likely to be killed by cold, should be used, while wet patches of soil should be well drained and rank growth of weeds cleared. If sensitive kinds of plants be removed early in spring from the nursery and bedded in some cool place for a few weeks before planting, the flushing of their foliage is retarded ; while late planting also protects them against late frosts during the first spring. Seedlings taken from the shelter of old woods are not good for planting in the open, as they are sensitive both to cold and heat.

Remedy of Damage.—Plants damaged to only a slight extent by frost or hoar-frost can sometimes be saved by watering them with cold water early in the morning. This retards the thawing process, and thus gives the cellular tissue a chance of recovering its turgidity. But this measure is only practicable in nurseries, and even then it cannot be relied on to prove successful. Broad-leaved saplings badly frost-bitten should be cut back to give them a chance of shooting from the stool, while blanks in young conifer plantations should be beaten up with hardy species (Pine, Birch, Aspen, &c.)

Frost-shakes or Frost-cracks are longitudinal fissures chiefly produced on the lower part of the stem of trees, and especially of 50- to 70-year-old Oak-trees. They are caused by excessive and rapid shrinkage of the bark and sapwood during intense frost, especially during winter. Whenever the extent and the rate of shrinkage exceed a certain limit, varying according to the species of tree, a sudden rupture of the woody-fibrous tissue takes place along the line of least resistance, and is usually accompanied by a loud noise. The clefts or frost-shakes thus formed are often only about a yard long, but sometimes extend all along the bole, and even penetrate right into the core of the tree. When the thaw occurs the woody-fibrous tissue again expands so as almost to close up the wound, which cicatrises by the formation of a ridge of callus tissue. This operation may be repeated almost every winter, or the cleft may remain closed during a succession of mild winters ; but the frost-shake remains visible as a long swollen ridge standing out from the ordinary contour of the stem. Although not interfering with the vitality or increment of the tree, frost-shakes spoil the timber for technical purposes, and also enable fungus-spores to enter the stem. Rot is therefore frequent near frost-shaken parts.

Frost-cracks are chiefly formed during the maximum cold of early morning in winter. According to R. Hartig, the damage is caused by the freezing water being withdrawn from the cell-walls and drawn into the interior of the cells, while the cell-wall substance contracts at a greater rate tangentially than radially, and more rapidly and to a greater degree in the sappier outside zones than in the drier heartwood. On this shrinkage exceeding a certain limit, the woody-fibrous tissue suddenly divides with a loud crack in the direction of the medullary rays and at the end of the long diameter in stems of eccentric shape (thus in either case splitting along the line of least resistance), and a frost-shake is formed. When the crack remains closed during several mild winters, the fissures may become permanently occluded. Each layer of wood deposited along the edges of the cleft is somewhat thicker than the rest of the annual ring, so that the two cicatrised edges gradually form frost-scar ridges standing well out on the side of the stem.

Trees with large medullary rays (Oak, Elm, Sweet Chestnut) are those on which frost-cracks are most to be found ; but they also occur on Beech, Ash, Maple, and Sycamore, as well as a few softwoods (Lime, Poplar, Willow). Conifers are seldom split by frost, though cracks are sometimes to be seen on Spruce and

Silver Fir. They occur most frequently on isolated park or avenue trees, or standards in copse (especially when grown from stool-shoots) or highwoods, and are usually found on the N. and N.E. sides of the stems, as the hardest frosts usually occur during N. and N.E. winds. Frost-shakes are most prevalent in low-lying tracts with damp soil.

Prevention is hardly possible on any large scale, though the stems of valuable individual trees may be protected by being wrapped in straw or covered with brushwood. In copses and highwoods, trees badly frost-cracked should be cut and utilised at the first convenient opportunity, to prevent their getting fungous disease and depreciating still further in value.

Frost-canker is sometimes found on young Oak, Ash, Beech, and other broad-leaved trees before they outgrow the frost-level in damp hollows. When a shoot is frozen through and killed near the ground, the bark fissures and scales off, the dead wood of the stem is exposed, and callus excrescences form which often also fissure and become scaly from hard frosts in each successive year. It is distinguishable from fungous canker by its only increasing in size after hard frost.

Lifting of Soil and Seedlings by Frost.—When the ground freezes in winter, the loose soil is lifted when the water it contains expands in crystallising. As the loose earth is thus lifted, the young plants in nurseries or young sowings or plantations are also lifted with it; but when a thaw comes only the soil sets, while the young plants remain with their roots more or less exposed. This is repeated each time a frost and a thaw take place, till at length the young plants are killed. Damage of this special kind only occurs in light or loosened moist soil (especially if humose), and is most frequent in February and March, when night-frosts are frequently followed by thaw during clear days. As the earth below the surface-soil is still frozen, the water thawed cannot percolate to any lower layer, so that each night's frost still finds the same amount of water in the upper layer. Thus whole rows of plants in seed-beds are sometimes lifted several times till they fall over from their own weight. The seedlings and young plants most exposed to this particular danger are the shallow-rooting Spruce, and 1- and 2-year-old Silver Fir, while Oak, Sweet Chestnut, Scots and other Pine seedlings, whose roots from the very first strike deeper into the soil, are very seldom lifted.

Prevention in Nurseries.—The soil should not be broken up nor grass or weeds uprooted from the seed-beds after September, rank weeds being only removed after that by cutting or clipping close to the ground. The spaces between the rows of seedlings can be filled during autumn with sawdust, moss, loose earth, or leaves, or the plants themselves may be banked up. If deep paths are formed between the beds, this helps to drain the upper layer of soil, and reduces the danger. Broad, thickly-sown seed-drills suffer least by lifting through frost, but they only produce badly developed plants, and that is worse than the danger to be obviated.

In the woods damp patches should be well drained and then planted with stout transplants, with balls of mother-earth around the roots, if necessary. In very damp places mound-planting is advisable.

Remedy of Damage.—In nurseries, seedlings lifted should be pressed down again after the thaw, and any exposed roots covered with loose soil. In young plantations the balls of earth round transplants should be pressed down either with the hands or feet, to connect them intimately again with the soil.

3. **Heat and Drought.**—The only direct damage occasioned by the sun's warmth is *bark-scorching* or *sun-burn* (see p. 210); but damage is often done by *drought*, when the warmth and dryness exhaust the soil-moisture.

Warmth is, like intensity of light, beneficial to active vegetation so long as there is a sufficiency of soil-moisture obtainable either by percolation, capillarity, rainfall, or artificial watering. But if the soil gets dried up, so that plants are unable to obtain sufficient moisture enabling them to maintain equilibrium between transpiration (which is increased by warmth and wind) and imbibition, then physiological disturbance is inevitable; leaves and flowers droop, wither, die, and fall off; seeds fail to germinate; seedlings and young plants, and even older plants during continuous drought, wither and die; and fruits set on trees are either shed immaturely or are only formed sterile, as often in Oak and Beech. Old trees with deep roots naturally suffer least, but in the year following any abnormally dry summer there is always a larger fall than usual of dead wood from the crowns.

Last, and not least, a serious increase of danger from fire during the month of August is one secondary effect of continuous heat and drought; and another is that danger from noxious insects also increases owing to dry weather being favourable to them, while severe drought is at the same time apt to predispose young plantations and pole-woods to insect attacks.

Extent of Damage.—Both the direct and the indirect injurious effects of heat and drought are greatest during the months of July and August, and are increased by dry E. winds. Shallow-rooting species (Spruce, Silver Fir, and Beech) suffer most; while those that at once begin to form deep roots (Oak, Larch, Pines, and Robinia) suffer comparatively little.

Drought is, of course, most destructive to tender seedlings and young plants recently planted and not yet having had time to fully establish themselves. Corsican Pine is extremely sensitive to drought, and finds difficulty in establishing itself even in ordinary years. Young plantations already beginning to form canopy are seldom injured by heat or drought. The effects are most plainly seen on any shallow, loose, and naturally dry soil, such as sand, sandy peat, or lime, and S. and W. exposures suffer more than E. slopes, while cool fresh N. aspects suffer least of all. As the heat is generally greater on flat stretches and in low uplands, the injurious effects of heat and drought are there more often noticeable than in humid mountainous tracts. A dense rank growth of grass and other weeds on land to be planted is of course a sign that there is a fair amount of soil-moisture; but it also means great transpiration, and it prevents light rainfall reaching the ground. Refraction of heat from the stems of standards in coppice or from stems standing at the edge of the next year's fall often causes damage to young seedlings by awakening active vegetation early in spring, and also by killing weakly plants upon which the heat is refracted. Such refraction is greatest from smooth-barked stems like Beech.

Abnormal heat is especially injurious during May, as it hinders the germination of seed sown, and dries up slender shallow-rooting seedlings and young transplants whose root-systems have not yet accommodated themselves to their new position.

Protection against Damage by Heat and Drought.—Whatever measures help to retain the natural soil-moisture and enable light rainfall to reach the soil, tend also to prevent damage from heat and drought. Whatever reduces direct insolation of plant or soil, or direct exposure to wind, tends to check both excessive transpiration and evaporation from the surface-soil, and therefore helps doubly to retain the soil-moisture. Supplying of soil-moisture by watering or irrigation can only be applied on a limited scale, as in nurseries.

The most important practical measure serving these ends is to avoid laying bare the soil. Thus, wherever practicable, natural regeneration under parent trees (Beech, Silver Fir, Scots Pine)—or under protective standards (Oak, Larch, &c.) of kinds of trees other than the young crop—is preferable to sowing in the open or planting. Such parent or protective trees should belong rather to the smaller girth-classes than to the largest class of big stems with large crowns overshadowing a large area and intercepting light rainfall and dew. Under great old Beech-trees the self-sown seedlings are few and comparatively weakly, and they often die off during hot dry summers. On dry, stony, or limy soil, and on hot southern slopes, annual falls consisting of casual or sporadic extraction of mature stems here and there are preferable to any more regular method, while natural regeneration is far more suitable than clear-felling and replantation. In natural regeneration on a dry soil, the parent standards have to be cleared as soon as a fair number of seedlings appear, because the young crop requires all the rain and dew which fall, and the standards intercept such precipitations. Any advance-growth of self-sown seedlings should be retained for soil-protection, even though they be softwoods or kinds of trees not very suitable for the new crop. When the latter has been fairly established, these undesirable species can then be cut out.

If clear-felled, the annual falls should be made in narrow strips running from N.W. to S.E., and year after year gradually advancing in a S.W. direction, so that the youngest crop may have the side-protection of the following year's crop of mature timber against the hot mid-day sun. This is sometimes found preferable to the direct over-shadowing of parent standards.

Woods and plantations on hillsides with hot S. or W. aspect should be very carefully and lightly thinned, and the operation repeated as often as necessary. Heavy thinnings are there out of place. The layer of dead foliage, &c., should be carefully retained, especially on hillsides, because a layer of leaves or moss not only diminishes evaporation from the ground, but also prevents the rapid off-flow of soil-moisture received as rain or snow, and enables it to percolate down to the subsoil after the surface-soil is saturated and can retain no more. Shelter-belts of thickly-foliaged trees along the edges of woods break the passage of winds and help to prevent the exhaustion of soil-moisture and the blowing away of dead foliage, and thus contribute greatly towards obviating drought. Horizontal ditches dug in broken parallel lines to catch rain-water (see p. 211) also help to retain and increase the amount of soil-moisture.

In selecting a site for a nursery, some place should, if possible, be chosen which is neither exposed to the full blaze of the sun nor likely to be swept by drying winds. The shady side of old crops and N. and N.E. hillsides are preferable to hot S. or W. slopes.

In nurseries, loosening the soil between the seed-drills and the transplant lines helps to retain the moisture, as light rain and dew can penetrate more easily and to a greater depth; while, at the same time, the wider spaces between the individual soil-particles prevent rapid capillary attraction of water to the surface, and thus keep the soil-moisture near the roots. Loose porous soil is always better aerated than heavy tenacious soil, and therefore enables the atmospheric moisture to penetrate more freely.

Where young crops are to be formed by sowing, the soil on the prepared strips should be loosened to a good depth, and the weeds and top-covering should be made to form a ridge on the S. side, while the seed-beds should, if practicable, be covered with dead leaves, moss, or brushwood. Young plants and sensitive young seedlings are best protected by branches stuck in the ground, or by layers of moss spread between the rows. The use of protective frames or very loosely woven hurdles during the hottest time of the day (eleven to four o'clock) is, like watering or irrigation, seldom practicable on any large scale, and is limited almost entirely to nursery-beds.

Watering is expensive, and is only resorted to in nurseries. Seed-beds are watered both before and after the seed germinates, and as the seedlings or transplants grow older, the watering becomes less frequent. Elm or Alder are very sensitive, and require occasional watering during long-continued drought. Unless urgently needed, it is best not to water, as small suction-rootlets are formed which die soon unless they have sufficient moisture. Thus watering, once it is begun, must be continued till rain falls. Where the soil cakes after watering, it should be occasionally loosened with the hoe.

Irrigation of dry hillsides is also expensive, unless under exceptionally favourable circumstances, wherever surplus moisture can be obtained by draining damp plateaux, or where water collected in the ditches along roadsides can be carried sidewards along the slopes into horizontal ditches, and there allowed to percolate into the soil. In Germany, small brooklets are sometimes dammed-up and the water led off sidewards to irrigate dry hillsides.

Planting is preferable to sowing for obviating the bad effects of drought on any soil that is naturally dry. For example, on dry sandy soil it is better to notch 1-year-old Pine seedlings with long roots than to try and raise a crop by sowing Pine seed. Large seedlings, or sturdy transplants with good roots, and plants with balls of earth attached, suffer less than smaller and naked plants.

Sowing or planting quick-growing hardy species (Pine and Birch) in advance as nurses, or sowing such along with slower-growing sensitive species in dry situations, helps to protect the main part of the young crop. For deteriorated limy soil Austrian Pine is the best species to plant, and especially on dry warm exposures.

Sun-burn or Bark-scorching is the effect produced by the direct action of the sun (*insolation*), which causes strips or patches of bark to dry, fissure, and fall off. When the sun's rays fall direct on smooth stems during the height of summer, so high a temperature may be generated between the bark and the wood as to kill the cambium. The wood then dies down, and sometimes rots deep into the stem, so that its normal growth is interfered with, and the death of the tree may even result.

In close-canopied woods sun-burn is almost entirely confined to hot S., S.W., and W. edges of woodlands, previously protected by an adjoining crop, and then suddenly exposed to full sunshine. Trees which have been exposed to insolation from their earliest age are not scorched ; but when large branches are lopped from trees in avenues or hedgerows, the stem sometimes gets sun-burnt.

Trees with smooth bark always suffer more from sun-burn than those protected by rough corky bark. Beech suffers most, then Hornbeam, Ash, Maple, Sycamore, and young Spruce and Silver Fir. Oak, Elm, and other rough-barked trees are never scorched after the bark begins to fissure. Sun-burn may affect young pole-crops, but older trees are more sensitive and more exposed to damage. Beech is very sensitive to insolation, as even large transplants often get scorched and killed.

Prevention.—So far as practicable, sudden exposure of S. and W. edges of maturing crops should be avoided, and no branch should there be pruned. If it can be foreseen that such edges must later on be exposed, a row of some quick-growing evergreen tree like Douglas Fir, Spruce, or Pine can be planted to give side-shade. Beech-trees grown in close canopy and kept as standards to grow into large timber are very likely to get scorched, so that this measure is not so applicable to Beech as to most other trees. Sun-burnt stems along the edge of woods should not be cut on that account. They continue to grow for a long time, and if they are cut, the stems immediately behind them are just as likely to get scorched.

4. **Damage caused by Aqueous Precipitations.** — The atmospheric aqueous vapour may be deposited in a watery form either as **dew**, or else as **rain** condensed in the upper atmosphere and falling to the ground more

or less violently. When radiation of warmth reduces the temperature of the plants below the freezing-point, **hoar-frost** or **rime** is formed in place of dew, owing to the aqueous vapour being deposited as ice-crystals; and when the upper atmosphere is cooled below the freezing-point, **snow** falls in place of rain, the snow-flakes being small and dry if produced by great cold, but large and moist if produced by a temperature only slightly below freezing-point. When snow hanging to the trees melts and freezes, or when moist snow falls during a hard frost, or when rain-drops become so greatly cooled in falling through very cold layers of air that they crystallise into ice on coming into contact with cold branches, twigs, or dry foliage, a layer of **ice** is formed. Finally, when sudden depressions, combined with electrical disturbances, occur in the atmospheric temperature, **hail** is formed.

(1) **Dew** is always beneficial to vegetation. It prevents excessive transpiration, and helps to supply the surface-soil with moisture.

(2) **Rain** is generally beneficial in providing the necessary supplies of soil-moisture. A large amount of rainfall is only injurious on soil already moist, and where it forms marshes or causes temporary inundations. A rainy year favours the growth of trees, as young crops establish themselves easily, and damage by late frosts or insects is sooner and more fully repaired by a good flush of new foliage; but it also favours the spread of fungous diseases. Want of rain in spring and summer, and especially in May, often hinders young sowings and plantations from establishing themselves; and at the same time a dry warm year favours the increase of many noxious insects.

Heavy rainfall is, however, injurious, whether occurring as violent downpours or as long continuous rainstorms. In either case it to a greater or less extent erodes the soft surface-soil from unprotected hillsides, and the dead foliage and humus from other places, washes out the seed from seed-beds and from sowings on slopes, and damages roads and drains.

Prevention mainly consists in keeping steep hillsides well wooded, and in interfering as little as possible with the soil-covering of undergrowth, brushwood, dead foliage, or moss in making falls and in natural regeneration. The great importance of woodlands on all steep slopes, and especially those forming the catchment areas in mountain tracts for municipal water-supplies, and their effect in regulating the water-supply and preventing erosion or inundations, is now being practically recognised in Britain by the planting of extensive water-catchment areas. Woods and plantations break the force of heavy rainfall; the layer of dead foliage and moss acts like a sponge in retaining the water and preventing it from running off before it has had time to percolate into the soil (see vol. i. p. 77). Falls of timber should be made carefully.

Continental Notes.—In Germany, horizontal ditches have often in recent years been dug for water-catchment. They are made to run in broken lines horizontally along hillsides, trenches from 10 to 15 ft. long being dug about 10 to 12 in. deep, so as to alternate in parallel lines from 15 to 30 ft. apart, according to the slope (the steeper, the closer together). They catch the water coming from the space below the next ditch above, and allow it to percolate gradually into the soil below, so as thus also to irrigate dry hillsides.

Sowings are always made in horizontal drills or bands on slopes to prevent the seed being washed away by rainfall. Nurseries in mountainous tracts have sometimes unavoidably to be formed on steep gradients, in which case the ground is terraced, and narrow seed-beds with paths between them are made to run horizontally, while between the beds strips of unbroken soil are left with their original covering of weeds, &c., in order to prevent scouring of the soil. The beds are covered with a framework of branches, moss, or leaves to prevent the seed being washed away.

(3) **Snow**, when dry, does not injure woodlands, unless it falls in very large quantity. A thin covering of snow protects young seedling growth when the standards are being felled and the timber extracted from natural regenerations; it facilitates extraction, and prevents the roads being cut up. But when moist snow falls in large flakes, and settles in great quantities on the branches, twigs, and leaves of evergreen conifers, and on dead leaves adhering to deciduous trees, it presses heavily on the crowns of the trees; damage may then be caused, and when a fall in temperature brings frost, followed by further snowfall, serious damage may arise through the continuous pressure either snapping off the tops or breaking the branches in the crown of the trees, or else simply laying prone part or all of the crop. When stems, poles, and trees or top-ends and branches are snapped by snow, the damage is called **snow-break**; but when individual stems or whole patches in young plantations or older woods are levelled with the ground (often tearing out the roots from the ground as in windfall), the damage is called **snow-pressure**. Poles bent for some time under a load of snow are unable to recover an upright position, but remain bent and sickly till they gradually die.

Snow generally breaks individual trees near the edges of compartments or destroys small patches here and there in the interior of the woods, though sometimes it does a great deal of damage all over Scots Pine woods.

Nature of Damage.—The damage done may be either direct or indirect in its nature. *Direct damage* consists chiefly in blanks being made in the leaf-canopy and throughout the crop, which means diminished increment. The more the canopy is interrupted and broken, the greater of course is the loss in increment; and the younger the crop, the greater is the loss owing to the immaturity of the material realisable. The damage can sometimes be so great that the whole crop has to be prematurely harvested. Where there has been much snow-break the soil soon gets overrun with weeds and brushwood, and deteriorates through the effects of insolation and exhausting winds, and then great difficulty is found in regenerating or replanting the timber-crop. As in wind-breakage, many stems otherwise suitable for timber are only partly, if at all, saleable as fuel; and even then a lot of wood is lost by the splitting and breaking.

The market is also soon glutted with timber of small dimensions (poles and top-ends), and prices obtainable are often so small that sometimes they hardly cover the cost of extraction, while labour is often dear and difficult to obtain when extensive damage requires to be repaired.

Further direct consequences include the beating-up of blanks formed in young crops, the underplanting of older crops whose leaf-canopy has been much interrupted, and the replantation of areas so badly damaged that their immature crops have to be cleared.

Indirect consequences include increased danger from insects, owing to the broken wood and injured stems, poles, stumps, and roots offering the most favourable conditions as breeding-places. At all ordinary times such material can be duly removed; but when windfall or snow-break has been extensive this is often impracticable, and then bark-beetles, weevils, and cambial-beetles increase rapidly, and cause further destruction.

Extensive damage from snow must always, like that from wind, interfere to a greater or less extent with the operations prescribed in the Working-Plan as to the sequence of the annual falls of timber ; and if the damage be very great, it may even necessitate a re-survey of the existing stock of timber of all age-classes, and considerable amendments in the Working-Plan.

The Extent of Damage done by snow, and the frequency of its recurrence, depend on various circumstances. Of these, *situation* is one of the first importance, because damage is most frequent in mountainous tracts of no great elevation, that are not high enough to have snow mostly in dry small flakes (as in Alpine districts). But *soil*, too, can affect the matter, because timber-crops that grow quickly on good soil and form clean stems suffer more from snow-break than the shorter-boled crops produced on poorer soil. *Species of tree, age of crop, and density of canopy* are likewise important factors. When the snow-pressure on the crowns exceeds the resisting power of the stem, the latter breaks. But the pressure depends mainly on the branch formation and the kind of foliage, because these determine the quantity of snow that can accumulate on each individual tree, whilst the density of canopy determines the total quantity that can accumulate over the whole crop. Evergreen conifers (Douglas and Silver Firs, Spruces and Pines) must therefore be far more exposed to damage from snow than deciduous trees that are bare in winter, and offer a very much smaller resting-place for snow. Of our common woodland trees, the brittle Scots Pine is more easily broken than any other conifer ; while the thickly-foliaged but tough Spruce suffers most from snow-pressure during the pole-wood stage of growth. Among deciduous trees, Beech, Alder, Robinia, and the Crack Willow (*S. fragilis*), on account of their brittle branches, are most often broken, whilst young Oak- and Beech-woods, which retain their dead foliage right into winter, are often damaged by snow-pressure.

Snow-break usually occurs near the top of the tree, and thus frequently (particularly in the case of Spruce) destroys the terminal shoot and causes formation of double leaders or the bayonet-like growth of the side-shoot replacing the leader. But stems that are cankered, bark-stripped, or otherwise injured, may also be broken much lower down, wherever the weak point happens to be. Any unequal pressure, due to irregular development of the branches, as on hillsides and along the edges of compartments, or to the unequal distribution of weight in snow-fall during windy weather, increases the danger.

Young crops in the thicket-stage of growth suffer only from snow-pressure ; and the denser they are, the more they are pressed down. Natural regenerations and thick sowings therefore run more danger than plantations, and unthinned crops more than those properly thinned. Pole-woods and older crops only suffer from snow-break ; and the danger decreases with the age of the crop, owing to the greater power of resistance attained, as the diameter thickens after the most active period of growth in height is completed.

Snow does little damage in coppices. In copsewoods only the youngest class of standards (*stores* or *tellers*) gets bent down badly under long-continued pressure, while branches of older standards get broken off here and there. It is only in highwoods that either breakage or pressure ever does extensive damage.

Prevention.—In parks, avenues, and small ornamental plantations, any unduly heavy accumulation of snow can be dislodged by shaking the poles or tapping the stem with a padded mallet. But this is out of the question on any very extensive scale ; and consequently preventive measures are limited to a judicious selection of the trees to form the crop, to adopting the method of formation best suited to the soil and situation, and to careful tending of the woods.

Continental Notes.—In high mountain tracts where snow-breakage is greatest, in place of growing the brittle Scots Pine largely in pure woods, mixed forests are generally formed, and wherever possible Beech is introduced into coniferous woods. The admixture of any deciduous trees not only facilitates the passage of part of the snow to the ground, but also diminishes the total pressure through varying the nature and the level of the leaf-canopy. Planting at moderate distances has proved preferable to sowing, or to planting seedlings in wisps. But the chief preventive measure lies in the proper tending of the timber-crops. When the golden rule of thinning is carefully attended to—*Begin early; conduct moderately (especially at first); repeat as often as required*—the canopy is not too dense to permit of a fair proportion of snow reaching the ground, while the branch-development is more equally balanced and the dominating poles increase sooner in girth, and therefore in power of resistance. But when crops are allowed to grow crowded, thinnings should be very cautiously made and frequently repeated, because the rapidly drawn-up stems have little power of resisting pressure.

Remedy of Damage.—The first thing to be done is to extract and dispose of the damaged timber. For this purpose the roads and rides must be put in proper condition, and broken trees and tops immediately removed from crops undergoing natural regeneration, else the young crop is very likely to be damaged. The broken timber should be prepared for sale as soon as possible, before it can deteriorate in quality or become attacked by insects. Where the quantity of wood to be prepared is very large, it is best to begin with the timber completely thrown, and the stems and poles entirely broken, leaving any stems with green branches till all the dead trees have been removed. Coniferous stems which cannot be immediately disposed of should be stripped of all bark, as this prevents bark-beetles attacking them and is also the best way of seasoning the timber. The logs should then be removed to broad roadways or other airy places, and stored there on rests well raised above the ground.

Continental Notes.—When patches of young Beech-crops between the thicket and the pole-wood stage of growth have been bent down, they can sometimes be raised and supported by props and poles. But this is not usually practicable, and the bent poles have then to be pollarded at the bend and allowed to shoot from the bole; or the damaged patches are coppiced to make them spring from the stool.

In conifer thickets the patches pressed down must either be cleared and the blanks planted with quick-growing species, or else, when the damaged areas are only small and the crop is already of fair age and size, underplanted with shade-bearing species (Beech, Spruce, Silver Fir) to protect the soil. Broken pole-woods of Scots Pine are also often underplanted with shade-enduring species in Germany; and all blanks in older crops not intended to be cleared till some much later date, but already exposed to the danger of rank weeds overrunning the soil and deteriorating it, should also be beaten up with some protective species suited to the soil and situation.

After extensive damage from snow, particular attention should be paid to see if injurious insects are increasing; and if so, the earliest possible steps should be taken to try and annihilate them, as they soon become enormously prolific in the stumps and in damaged sickly trees.

In Alpine tracts avalanches may do great damage, particularly if formed when the snow is melting. When a thaw sets in, they glide down the steep slopes slowly at first, but soon increase greatly in size and sweep away everything, including woodlands, lying in their course and opposing their downward progress. So long as avalanches glide year after year down old and well-defined courses, no damage is done; but it is different when they open out new courses. In the high mountainous regions of Switzerland and Austria woodlands are therefore maintained chiefly as **ban-forests**, for preventing the formation of avalanches (which never begin inside the woods) and for arresting their downward progress when they have begun on a small scale above the wooded areas.

Such *ban-forests* are under the direct management of the State Forest Department, and can only be worked to a limited extent (see vol. i. p. 213).

What is considered a sufficient number of trees must always be kept on the area. No clear-felling of timber is permitted, but only prudent selection of mature and damaged timber. The crop is carefully regenerated, natural regeneration being assisted by sowing and planting; and everything is done to protect the forest itself, and through it the pasture and other land below the woodlands. The replantation of woods destroyed is extremely difficult, as the avalanches usually form in the same places year after year.

(4) **Hail.**—Hail-storms beat down, injure, and often kill outright young plants in nurseries and plantations, and sometimes do such serious damage to older crops (on the Continent) by wounding the bark and stripping the foliage, twigs, and fruits, as to require their clearance. But in Britain the chief damage is done to the Osier-crops in the fen districts. Scots Pine and Larch are more easily damaged than Spruce and Silver Fir, which are protected by their thicker foliage and closer branches. When Oak-coppice is damaged the bark will not strip at the cicatrisation, while Osier-withes do not peel freely, and break off at the injured parts when being used for basket-making, &c.

Prevention is impossible; but the better wooded the country is, the more do the woodlands tend to prevent the formation of hail, by helping to modify extremes and to equalise the distribution of atmospheric electricity during storms.

Remedy consists in coppicing the saplings or poles, &c., injured in young crops, and in filling blanks in older woods with whatever kinds of stout plants seem suitable.

(5) **Ice.**—In mountain tracts, and especially on N. and E. slopes, ice often weighs down branches and twigs during cold N. and E. winds in winter and early spring. Evergreen conifers are naturally most liable to such damage, and especially the long-foliaged Scots Pine, on which ice easily accumulates and snaps off its brittle branches, unable to resist the heavy weight. The Alder, the most brittle of broad-leaved trees, is also very liable to injury; and next to it young Oak standards in copse suffer most when their crowns are still more or less covered with dead foliage. Damage is usually greater in 30- to 50-year-old crops than in younger or older woods; while isolated park or avenue trees, standards in copse, and trees at the edges of compartments, are of course more exposed to danger than those growing in close canopy inside the woods.

Prevention is impossible. Mixed conifer woods are, however, less subject to damage than pure Scots Pine.

Remedy of Damage is as for that caused by wind and snow.

(6) **Rime or Hoar-frost**, which also forms an ice-coating on twigs and branches, does all the more harm when immediately preceding snowfall. A coating of rime then enables the snow to settle in larger quantities on the foliage and twigs, and when this thaws slightly and freezes again a thick coat of ice is formed. While therefore in itself injurious, the greatest danger from hoar-frost is the more extensive damage from snow and ice that may arise indirectly through it.

Prevention.—The only practicable measures consist in forming mixed woods rather than pure crops of the brittle Scots Pine in misty tracts, in maintaining a good shelter-belt or fringe along all exposed edges, and sometimes also in heavy thinnings.

Remedy of Damage is the same as for snow and ice.

5. **Lightning** very often strikes trees, and frequently kills them outright; but the total amount of damage thus done to woodlands is fortunately trivial, as the forester can do nothing to prevent its occurrence. From their isolated position, all park, field, hedgerow, and avenue trees are more apt to be struck than those growing in close-canopied woods.

When lightning strikes a tree it in many cases merely destroys a strip of bark about an inch broad, and follows the run of the fibres. In trees of tortuous growth (like many Horse-Chestnuts) it therefore makes a spiral mark. Conifers struck by lightning soon die; but Oak and most other broad-leaved trees heal the wound by cicatrisation, and continue growing. In other cases, however, the lightning-struck trees shed their bark almost entirely, and are often completely split or even splintered. Lightning has sometimes been seen to spring from one tree to another; and it is a remarkable fact that in Pine-woods, when a tree has been struck and killed by lightning, many outwardly uninjured stems gradually die off round about it.

Dry, inwardly unsound, and rotten trees are sometimes set fire to and burned down by flashes of lightning; but it can hardly be said that there is any practical danger of lightning causing fires in woodlands.

From their usually standing either isolated or towering above other trees, Italian Poplar and Oak are more frequently struck than any other trees. In the close canopy of woods Spruce and Pine are more often struck than most other trees, but Beech very seldom, owing no doubt to its rounded crown not offering any prominent point upon which the electricity can discharge itself.

In Alpine districts the tops of young Spruce sometimes die off extensively. It has been maintained (v. Tubeuf) that this is due to slight electric discharges between the tree-tops and clouds enveloping them during the winter period of rest from active vegetation; but the damage has also been asserted (Möller) to be due to the attacks of a small moth, *Grapholitha pinicolana*, destructive to Spruce and Silver Fir foliage in Central Europe (v. Tubeuf and Möller controversy, 1904).

6. **Atmospheric Impurities.**[1]—Smoke from houses and lamps in cities, from factories and smelting-works, and even from railway-engines when frequently passing through wooded valleys, is always more or less injurious to the growth of trees and of woodlands subjected to their influence. The injury is mainly due to the sulphurous acid[2] contained in the smoke, which changes the natural colour in the foliage, and causes the death of many poles and trees. Similar injury is also, though not on so large a scale, caused by hydrochloric acid gas evolved in making soda, and by arsenious or nitrous acids.

The action of smoke is both mechanical and chemical. Its *mechanical action* excludes sunlight from the green cells of the leaf, and hinders assimilation; and in proportion as the light is excluded, the plant suffers. The smoke in the air reduces the intensity of the sunlight, and the superficial coating of soot over the leaf-surface clogs the pores. Dust acts similarly, but affects less the intensity of the light, and is therefore less injurious. Rough-leaved trees suffer most, as the soot and dust are less easily removed by wind and rain. The *chemical action* of smoke is mainly or entirely due to poisonous gases. The carbon monoxide liberated during the incomplete combustion of coal is not of itself directly injurious to plants. Arsenious acid, sometimes present in coal-smoke, is also not

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[1] See also remarks on *Trees in Towns*, in vol. i. p. 503.

[2] Sulphuric anhydride (SO_2, often called sulphurous acid) on combining with water forms sulphurous acid (H_2SO_3), and this oxydises into sulphuric acid (H_2SO_4).

specially injurious. Fluoric acid may seriously injure trees near manufactories producing fertilisers containing soluble phosphoric acid. But by far the most injurious gas found in smoke is sulphurous acid. Even one part in 50,000 of the air is decidedly injurious to plants. The injurious gases penetrate the leaves by osmosis over the entire surface, and not through the stomata. They directly poison the leaves, and indirectly destroy the balance between imbibition and transpiration, the sulphurous acid desiccating and destroying the leaf-tissues.

Sulphuric anhydride gas is imbibed by osmosis through both leaf-surfaces, and becomes converted into *sulphuric acid* by moisture and oxidation. But when rain washes sulphurous acid into the soil, the roots of plants are not injuriously affected, as the water soon converts the sulphurous into sulphuric acid,

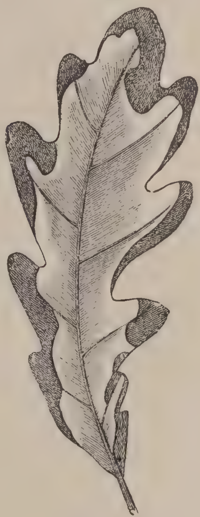
Fig. 185.

Spray of Scots Pine injured by Sulphurous Acid. The upper needles are all dead, and most of the lower ones are dead for about half-way down from the tip.

Fig. 186.

Young Oak-leaf injured by Sulphurous Acid. The dark spots are dead tissue.

Fig. 187.



Old Oak-leaf injured by Nitric Acid. The dark edging of the leaf is dead tissue.

which combines harmlessly with alkalies contained in the soil. Dew and rain do not affect the absorption of the sulphurous gas, but only hasten the injurious action of the acid on the foliage, because they quickly transform the sulphurous acid on the leaf-surface into sulphuric acid. The needles of conifers first turn yellow or red at the tip, and sometimes show a sharply-defined line between the damaged and the still healthy parts, until the whole needle is poisoned, changes colour, and dies (Fig. 185). In broad-leaved trees the action of the sulphuric acid on young foliage that is just developing gives the leaves a mottled appearance, and covers them with light and dark reddish-brown spots (Fig. 186), which may gradually increase until the whole of the green tissue is poisoned and the leaf is killed. When the injury is due to nitric or hydrochloric acid, the leaves have always discoloured edges (Fig. 187).

Evergreen coniferous trees, owing to the long persistence of their needles, are far more sensitive than broad-leaved trees to the injurious action of all kinds of atmospheric impurities. And the longer their foliage persists, the less power have they to resist the poisonous action. The trees that are most injured are Silver Fir (and probably also Douglas Fir), then Spruce, then Scots and other Pines, while the deciduous Larch is far more susceptible than any of the broad-leaved trees, which, owing to their annual change of foliage, are altogether less sensitive. Among broad-leaved trees in woodlands, Elm, Maple, Sycamore, Oak, Ash, Poplar, Lime, and Mountain Ash, are less damaged than Birch, Alder, and Hornbeam, while Beech is usually the most sensitive of all. Agricultural crops and vegetables suffer far less than shrubs and trees from atmospheric impurities.

In woodlands the damage is always greatest in the vicinity of factories, and especially where narrow valleys make the air-currents set in particular directions; and most damage is done when the atmosphere is damp and foggy, and wherever the smoke is blown on the woods mainly in one direction. The injurious influence of smoke from chemical works and similar factories may be plainly felt to a distance of 2½ to 3 miles. The first signs of injury consist in a general sickly look, then in discoloration of foliage, death of twigs and branches, stag-headedness, and the dying off of trees here and there. The leaf-canopy next gets partially interrupted, and as the nuisance continues the crown of foliage gradually becomes thinner and more broken, until large blanks are made by the trees being killed. Young pole-woods from 15 to 30 years old suffer most in this way; and the beating-up of blanks or replantation of woods destroyed is an extremely difficult operation. Pine pole-woods are very liable to attacks of the fungus *Lophodermium pinastri* in smoky localities (see p. 161).

Prevention and Remedy.—In Germany, the owners of factories are liable to pay compensation for injury done by smoke from their works, so that they use every endeavour (without much success as yet) to mitigate the nuisance.[1] Endeavours to catch the sulphurous acid contained in the smoke and to convert it into sulphuric acid for commercial purposes have been found impracticable, as only about one-quarter to one-third of it can be withdrawn from the air; while tall chimneys conducting the impurities into higher layers of air merely widen the area affected. Somewhat similar protection is in Britain afforded by the Alkali Acts, under which steps may be taken to enforce prevention of the escape of hydrochloric acid from gas in injurious quantities from works.

The only practical measures of any real use are to try and grow broad-leaved crops instead of conifers in smoky localities, to maintain thick shelter-belts of hardy species in the direction from which factory-smoke comes, and to make casual falls of mature wood here and there annually or periodically, combined with natural regeneration, rather than clear falls and replantation. But where woods or plantations have been destroyed by the atmospheric impurities, sowing or planting of smoke-poisoned blanks is next to useless. Coppice-woods are least liable to injury. But unfortunately the market for small wood is now so poor that such crops are seldom profitable in Britain.

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[1] The latest invention of this sort is a fuel-saving and smokeless-combustion process patented by Messrs Ganz & Co., Vienna. It has been favourably reported on to the Austrian Government by a specially appointed Commission (in May 1905), but details concerning it have not yet been published.

Note on Spruce (see p. 198).—When growing on glacier boulder-drift and in very stony, rocky alpine tracts (*e.g.*, Chamonix, 3000-5000 feet), Spruce resists storm-winds quite as well as Larch or Scots Pine, and is as little liable to windfall as either of these, despite the fact of the Larch having no foliage in winter. But Spruce is there shorter and more conical and tapering in the stem, relatively thicker and more strongly buttressed near the roots, more sparsely branched, and distinctly less thickly foliaged and less shade-bearing than throughout the hill-tracts of Central and Southern Germany.

PART V.

THE MANAGEMENT AND VALUATION OF WOODLANDS

BRITISH LITERATURE.

Brown and Nisbet, *The Forester*, 6th edit., 1894, chapters xiii.-xv.; J. Laird Macgregor, *Organisation and Valuation of Forests*, 1883; J. Nisbet, *The Theoretical Principles of Woodland Management, and the Measurement of Timber*, published as a series of articles in the *Land Agents' Record*, 1901, and of which chaps. i. and ii. of the present work (pp. 221-336) form a 2nd, revised edit.; W. Schlich, *Forest Management* (vol. iii. *Manual of Forestry*), 2nd (issued as 3rd) edit., 1905. Part of the subject is treated of by T. Bright, *The Principles and Practice of Timber Measuring and Valuing*, 1899.

CHAPTER I.

THE THEORETICAL PRINCIPLES OF WOODLAND MANAGEMENT.

1. Matters to be considered in framing any Scheme of Management.
2. Essential requisites for the "normal condition" of the Growing-Stock or Capital in Wood.
3. Choice of the Sylvicultural Treatment.
4. Selection of the kind of Crop to be grown.
5. Fixing the Rotation with which the Timber-Crops should be worked.
6. Sylvicultural and Actuarial Considerations affecting the management of Woodlands.
7. Subdivision of the Woodlands into Working-Circles and Compartments.
8. Allocation of the Annual (or Periodic) Falls.
9. Different methods of fixing the Annual Fall.
10. The method of Management recommended for British Woodlands.

1. Matters to be considered in framing any Scheme of Management.— Like every other commercial enterprise, forestry requires a certain amount of capital. This consists partly of the land, and partly of the growing crops of wood.[1] In highwoods worked with a long rotation, the capital required in the growing-stock of woods far exceeds the value of the soil. But even when such may not be the case, as in copses and coppices worked with a low rotation, forestry has the peculiarity, in comparison with most other commercial undertakings, that the commodity it produces (timber, fuel, bark, &c.) is exactly of the same description as part, and usually by far the greater part, of the capital which produces it. And this is apt to lead to confusion. Unless the annual falls of timber, &c., are carefully regulated, they may very easily be made so that, on the one hand, they are either actually eating into the capital in wood, or else, on the other hand, they fail to harvest all the annual increment. For we shall see that any given area of woodland requires a certain amount of capital in wood, proportionate to the area and the kind of crop, for its proper working on commercial principles; and no system of management can be economical which either diminishes this normal capital in

[1] In addition to this invested capital, regular annual expenses are incurred in supervision, protection, rates and taxes; and for making actuarial calculations these may most conveniently be capitalised and regarded as representing an annual return from a capital sum equal to these yearly expenses divided by $0{\cdot}0p$, where p is the interest or rate per cent, which the business of forestry is supposed to yield locally. But this need not here be taken into account (see chap. v. p. 394.)

wood or increases it unnecessarily by failing to utilise the amount of wood, &c., it annually produces. The amount of this produce can be expressed either in cubic contents or else in its monetary equivalent. The latter is the standard with regard to actuarial calculations for fixing the rotation of woods, and for comparing one method with another as to probable profit, while the former is the standard actually employed in carrying out practical operations based mainly on business principles.

Woodland products consist of **major produce** (timber, fuel, bark) and **minor produce** (grazing, fruits, &c.), but, for all practical purposes in Britain, only the former need here be considered. It, however, may consist either of the **mature fall** or **final yield** of timber, &c., or of **intermediate returns** in the shape of **thinnings**—often very remunerative in themselves—rendered necessary for the proper tending of the still immature woods, so that the trees which will form the ultimate mature crop may be assisted in their development by the removal of all undesirable or badly-grown trees, or of dominated and suppressed stems interfering with their growth and expansion.

The products of forestry differ essentially from those of agriculture by usually only maturing at a great age, in place of becoming marketable within the course of a few months or of a year, like most agricultural crops. Now, as wood is a bulky, heavy material, whose transport for long distances by land soon becomes unduly expensive, local markets can only be supplied, and the advantages of a constant demand secured, if the woodlands are managed so as to yield annual supplies of the given kinds and dimensions of wood in about equal quantity. If sales of wood are held only intermittently, at intervals of more than a year, it is improbable that the same advantages can be derived by the producer as if he could place more or less constant quantities of timber, &c., on the local market. To obtain the full advantages of a regularly sustained annual yield, however, it is of course necessary that the total area of the woods should be sufficiently large to admit of the annual falls being of a workable size ; because the full advantages of systematic management become most apparent where large areas have to be dealt with, just as, in other commercial enterprises, wholesale production with a large amount of capital is usually more economical and more remunerative than business conducted on a smaller scale. Woods that are worked intermittently, as is most frequently the case throughout Britain, can be very simply managed. Any complex working-plan is unnecessary; all that is required is to ascertain (by means of average yield tables) from the present age and condition of the crops what their yield is likely to be when they are mature, and to determine when it may be most profitable to fell and regenerate or reproduce them, thinnings being meanwhile made only to the extent required by the trees intended to form the ultimate crop. Where there are only small woodland areas, this simple method is often best and most convenient for the landowner, while the small quantities of timber thus thrown intermittently on the local market are not likely to interfere with the normal conditions of supply, demand, and prices.

In the management of extensive woodlands, however, it is desirable that the timber-crops should be so arranged and worked as to yield regular supplies of mature produce of about equal amount year by year. To attain this object it is therefore necessary that the woods should consist of a regular series of crops varying from each other either by one year only (as in annual falls of Pine, Larch, &c.) or else merely by such number of years as may be included in periodic falls for natural regeneration (Oak, Beech). It is not necessary—indeed, as we shall see later on, it is not desirable—that the series of falls should succeed each other consecutively like one long arithmetical progression; but they must be all represented within the area under management (**working-circle**), otherwise a regularly sustained annual fall or yield is impossible.

2. **Essential requisites for the "normal condition" of the Growing-Stock or Capital in Wood.**—The main object of management on business principles is to bring the woodland area into a condition enabling it to yield the largest profit consistent with due security for its future maintenance—although any other scheme of management may of course be arranged so as best to attain any particular end desired by the proprietor. Where woodlands are primarily intended to be either ornamental or else game-coverts, as is frequently the case in Britain, they can of course not be worked on business principles. Otherwise, a **working-plan** aims at bringing the woods into a sort of ideal state or **normal condition**, so that they should exhibit (1) a **normal succession of crops** or regular series of woods of all ages, from the seedling up to the mature marketable tree, each age-class occupying an equal area, or at any rate an equally productive area; (2) a full stock or **normal density of crop** throughout the whole of each area;[1] (3) a normal rate of

[1] The **normal density** of crop varies, of course, with the species of tree and the nature of the soil and situation. Thus, on the classes of land most favourable to the development of each species, the normal density of pure crops throughout Germany is on the average (*British Forest Trees*, 1893, p. 43):—

Age in years.	Scots Pine.	Spruce.	Silver Fir.
	Number of stems per acre.		
40	727	1053	1375
60	377	509	529
80	244	317	316
100	171	240	223
120	141	224	175
See also, however, the data given in Appendix III. (pp. 407-415) as to number of stems per acre.			

And again, it has been shown that (*Studies in Forestry*, 1893, p. 188)—As regards the influence which the species of tree has on the extent to which thinnings are necessary, Schuberg (see Gayer's *Waldbau*, 1889, p. 550) found in the Black Forest that in 40- to 80-year-old crops, which had been regularly thinned, the following were the results on soil of average quality:—

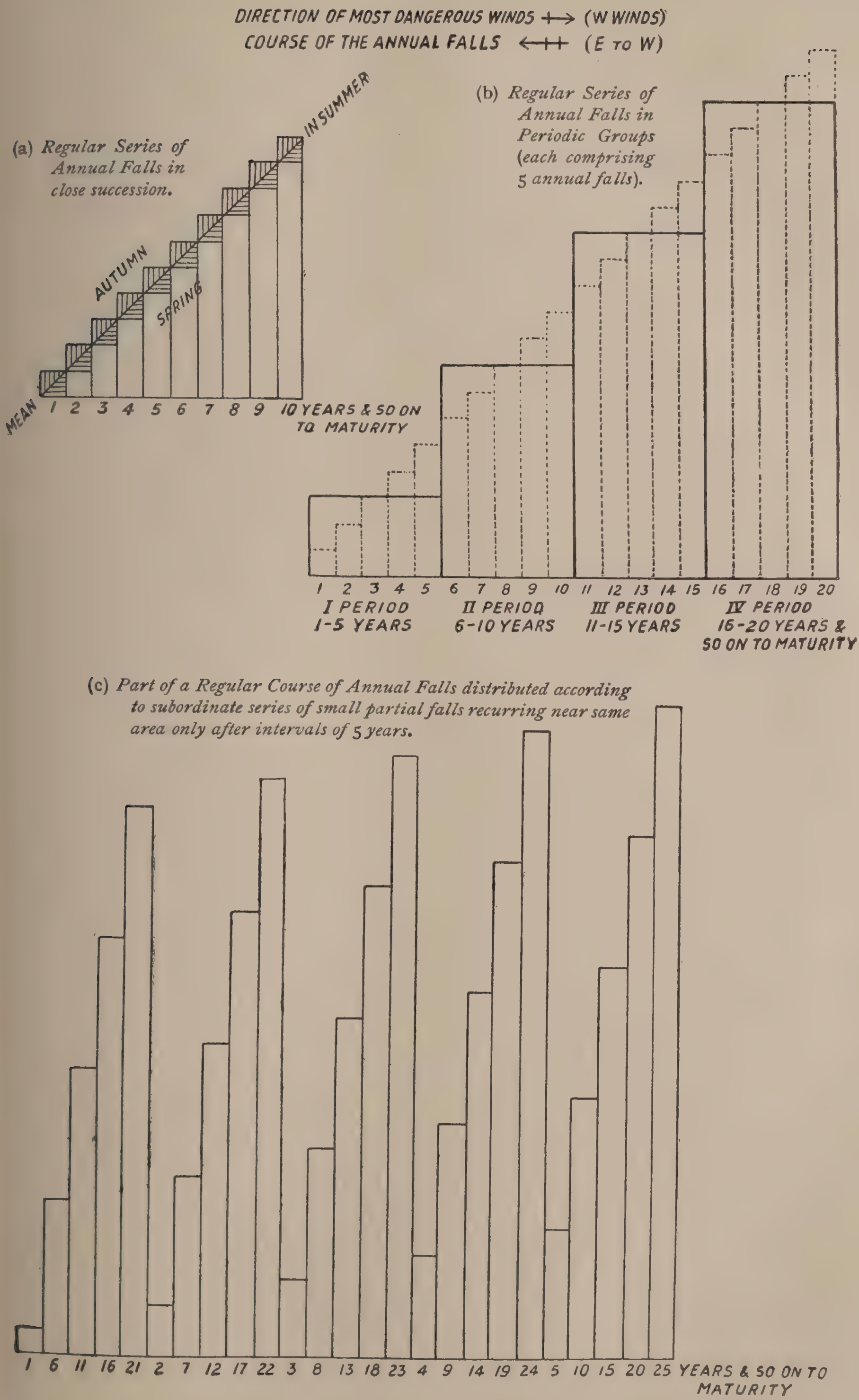
	Scots Pine.	Spruce.	Beech.	Silver Fir.
Average number of stems per acre .	545	619	686	864
Absolute individual growing-space in square feet	80	70	63	50
Relative individual growing-space .	**100**	**87**	**79**	**63**

growth or **normal increment** on all the various crops, so that the growth annually made is fully proportionate to the quality of the soil; and (4) a **normal distribution** of the annual falls—that is to say, such a location of the various crops of different ages that the falls of mature timber may take place regularly within suitable sections of the forest, although not necessarily in close succession year by year. If these four conditions be provided, then one must have what can be more simply expressed as (1) a **normal growing-stock** or capital in wood with a regular series of annual (or periodic) falls properly distributed over the working-circle, and (2) a **normal increment** or rate of growth fully proportionate to the quality of the soil, and producing equal returns in timber, &c., year by year. And these are naturally each dependent on the other for their possible attainment. This is, of course, merely an ideal standard which could only be achieved and maintained if the woods grew without being affected by mismanagement, fire, disease, insects, wind, &c.

In comparison with intermittent utilisation, a system of managing extensive woods so that they shall yield a regularly sustained annual yield has certain obvious *advantages* and *drawbacks.* By offering regular annual supplies for sale it affords the best opportunity for securing, utilising, and maintaining the local market; the constant employment afforded to woodmen in felling, thinning, and planting makes labour cheaper and more efficient than is otherwise possible; and the woods are made to yield a regular income not subject to inconvenient variation from year to year. No available market can be utilised to the best advantage if the quantity of wood offered for sale is large one year, small the next, altogether wanting a third year, and so on irregularly. Its drawbacks are that, in order to try to attain the normal series and distribution of annual falls, the crops now on the ground have sometimes either to be felled before they have reached their full maturity, or else must be allowed to stand after the most profitable time for felling has been passed; while at the same time the striving after regularity precludes advantage being taken of specially favourable prices in any one year to make heavier falls of timber than usual. But on the whole, and certainly where large areas of woodlands are in question, the best system of management will usually be that which aims at providing a regularly sustained annual yield.

The **normal Growing-Stock**, or **Capital in Wood** required for the proper management of any given working-circle or compact block of woodlands, consists in the total sum of the crops growing on all the various annual falls of **normal** size, age, and distribution. It is annually diminished by the **normal yield** forming each year's fall, which is, at the same time, the embodiment of the normal increment throughout the whole term of the rotation of the crop, and also equals in amount the growth for one year on all the annual falls forming the working-circle. But this loss is each year made good by the normal increment accruing throughout all the crops of different ages, from the seedling to the mature tree; hence the current capital required in the production of timber is a constant quantity if the average of each year be taken. Apart from the temporary variation from the average of capital in wood shown in autumn and in spring, the normal growing-stock required for any given working-circle is dependent (1) *on the length of the rotation in which the woods are worked, and with which it rises and falls more or less proportionately, and* (2) *on the normal increment or rate of growth proportionate to the quality of the soil.* And of course any circumstances affecting the increment, such as the kind of crop grown, the system of management, the quality of the soil and situation, &c., must also exercise direct influence on the amount of capital which should be provided and can best be utilised in timber-production.

Fig. 188.


DIRECTION OF MOST DANGEROUS WINDS ⟶ (W WINDS)
COURSE OF THE ANNUAL FALLS ⟵ (E TO W)
(a) Regular Series of Annual Falls in close succession.
IN SUMMER
AUTUMN
SPRING
MEAN 1 2 3 4 5 6 7 8 9 10 YEARS & SO ON TO MATURITY
(b) Regular Series of Annual Falls in Periodic Groups (each comprising 5 annual falls).
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
I PERIOD 1-5 YEARS
II PERIOD 6-10 YEARS
III PERIOD 11-15 YEARS
IV PERIOD 16-20 YEARS & SO ON TO MATURITY
(c) Part of a Regular Course of Annual Falls distributed according to subordinate series of small partial falls recurring near same area only after intervals of 5 years.
1 6 11 16 21 2 7 12 17 22 3 8 13 18 23 4 9 14 19 24 5 10 15 20 25 YEARS & SO ON TO MATURITY

As a regular series of properly distributed and equally productive annual falls (though several of the latter may be grouped to form periodic falls, if desired) is essential to the normal growing-stock, it therefore follows that the properly adjusted capital in wood must consist of a regular series of falls forming a simple arithmetical progression, although such series need not necessarily be distributed consecutively. Their consecutive distribution is, in fact, not desirable in practice, on account of danger from fire, wind, insects, fungous diseases, &c. In the simplest circumstances, where the soil is homogeneous in quality, the size of each such annual fall will of course be found by dividing the total wooded area by the number of years forming the rotation of the crops of timber. Whether the woods be managed as coppice with a rotation of, say, 10 years, or as copse with a rotation of 20 years, or as highwoods with a rotation of 100 years, is quite immaterial. In each case there will be regular arithmetical progression—namely, from 1 to 10, 1 to 20, and 1 to 100 equally productive falls or annual sections in the cases of these given rotations.

It may perhaps be desirable to remark here that the meaning of the term **rotation** in forestry has no connection with its meaning in an agricultural sense. A rotation or change of crops is necessary on arable land to avoid exhausting the soil of particular kinds of food-supplies required by the crop grown, while manuring from time to time is also required to maintain the fertility of the land. Nothing of this sort is necessary in forestry. If any kinds of woodland crops that can be advantageously grown are properly managed they can be regenerated naturally, or reproduced by sowing and planting, time after time, *in perpetuo*, without requiring any change in the kind of crop. In agriculture, the larger the cereal or root crops taken from the fields, the greater is the necessity for manuring; while in forestry, the larger the crops of timber taken from the woods, the more completely are the fertility of the soil (especially its moisture) and its power of production safeguarded against deteriorating influences. As the dead foliage gives to the soil, in the form of *humus* or leaf-mould, larger supplies of carbon, drawn from the air, than the trees withdraw from the soil, as the larger portion of the mineral salts are then also returned again, and as the leaf-mould assists in preparing larger supplies of mineral salts in a soluble form available for plant-food, the production of large crops of timber does not exhaust the soil to anything like the same extent as agricultural crops. Sun and wind, and an incomplete stock of the timber-crop permitting the rank growth of weeds, are the only agencies causing deterioration and exhaustion in woodland soil. Hence "rotation" in forestry means merely the change from an older to a younger crop of the same sort, so as to form one generation or cycle. Far from requiring manuring, woodland soil improves greatly in productivity so long as the timber-crops can be kept in close cover, so that an unbroken crown of foliage protects the soil against the deteriorating effects of sun and wind; and this quality of improving the soil is most marked in the case of Beech and of coniferous crops, so long as their leaf-canopy does not become broken. Sometimes, indeed, a change in the kind of crop, from hardwoods to conifers, becomes necessary; but this is then consequent on deterioration of the soil, either through mismanagement or misfortune. So greatly, however, does the soil improve under conifer crops kept in close canopy, that land may thus frequently be rendered again suitable for a subsequent change back to more exacting crops of trees, if the cultivation of these latter seem more profitable.

In the above cases the series of annual falls would range in autumn, before the fall, from 1 to 10, 1 to 20, and 1 to 100 years in age, and in spring, after the fall, from 0 to 9, 0 to 19, and 0 to 99 years. This gives on the average—or at midsummer, half-way between two falls—a series of $\frac{1}{2}$ to $9\frac{1}{2}$, $\frac{1}{2}$ to $19\frac{1}{2}$, and $\frac{1}{2}$ to $99\frac{1}{2}$ years. Now, these form simple arithmetical progressions, whose addition gives the respective totals of 5, 10, and 50 times the amount yielded by the fully-stocked mature fall for the rotations of 10, 20, and 100 years. It thus becomes apparent that the normal growing-stock or capital in wood required in any working-circle may be ascertained by multiplying the normal yield of the mature fall into the total number of years forming the rotation of the crop, and dividing this sum by two. The spring stock will be less than this amount, and the autumn stock will exceed the same, the difference in each case being equal to one-half of the quantity yielded by the annual fall.

Examples.—(1) A working-circle of 800 acres of Scots Pine is managed with a rotation of 80 years, and the mature fall yields 7000 cb. ft. per acre. What is the normal growing-stock required to work this woodland properly?

$$10 \text{ (acres)} \times \frac{7000 \text{ (cb. ft.)} \times 80 \text{ (years)}}{2} = 2{,}800{,}000 \text{ cb. ft.}$$

(2) If the same area were to be worked for a similar crop with a rotation of 100 years, and yielding then 8500 cb. ft. per acre, what normal growing-stock would there be required?

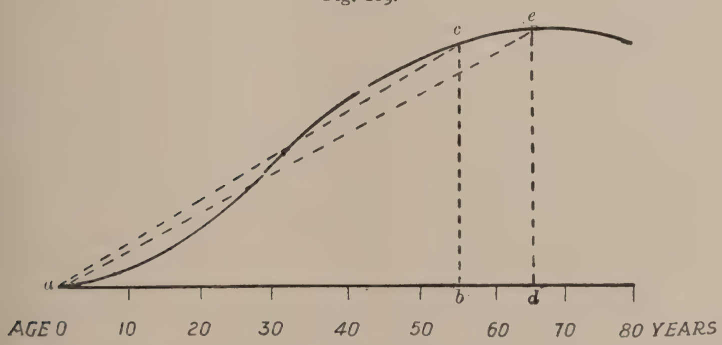
$$8 \text{ (acres)} \times \frac{8500 \text{ (cb. ft.)} \times 100 \text{ (years)}}{2} = 3{,}400{,}000 \text{ cb. ft.}$$

From these two examples it is clear that a long rotation not only reduces the area that can be felled annually, but also adds considerably to the capital required in wood. These results might perhaps *primâ facie* convey the suggestion that an 80-years' rotation, involving a considerably diminished capital in wood, would probably be the more profitable system of management. But it must be borne in mind that, in the woods worked with a rotation of 100 years, the timber would be of larger dimensions and would command a higher market price per cubic foot; and there would probably be profitable thinnings between the age of 80 and 100 years. Hasty conclusions are therefore not justified.

The above formula is based on the supposition that each item in the series of annual falls is stocked with a crop equal in amount to its age (number of years) multiplied into the average annual rate of growth of the mature fall of timber. This is not in reality the case, because the rate of growth varies at different stages in the development of the crops, being most vigorous during the pole-wood stage of development; but this variation does not affect the total volume embodied in the mature crop when it attains the most advantageous age and is harvested.

These results can easily be represented graphically. Assuming that the total sum of the annual growths incorporated in the mature fall consists of equal annual

Fig. 189.



increments (which is not really the case, though this fact does not in any way affect the total volume actually harvested), then if a series be formed of annual falls of equal breadth this will result (see Fig. 188) in presenting an indented inclined plane. By drawing a straight line from the commencement of the first fall to the end of the last fall (so as to indicate the actual stock at midsummer) the result will be a right-angled triangle, because the indentations can be eliminated as above shown in summarising the arithmetical progression. And the area of this triangle will be found by multiplying the height of the triangle (representing the mature fall of timber for each year) into the base (representing the number of years in the rotation of the crop), and dividing the result by two.

The actual course described by growing crops of wood, however, is not that of a straight line, as represented in Fig. 188. At first it rises slowly, forming a concave curve, then increases more rapidly, forming a convex curve, till it culminates and then gradually sinks. Exaggerating slightly the actual course of the curve in order to exhibit the point at issue in a graphic manner (as in Fig. 189)—say, with regard to Pine-woods on medium soil—half the product of the mature fall into the number of years in the rotation can prove an unnecessarily large capital for a short rotation (as in *a b c*), while for long rotations it is not large enough (as in *a d e*). Investigations have proved, however, that, as a matter of fact, the amount of capital in wood thus indicated as requisite for the usual rotations in highwoods is somewhat too large for broad-leaved crops, but is, on the whole, about right for conifers. And such being the case, the simplicity of the formula recommends its adoption for framing a rough general estimate of the amount of growing-stock usually required in a working-circle.

Otherwise, the capital in wood might also be calculated from average yield tables by taking the average yield of the crop in successive periods of 10, 20, or 30 years, and summarising these.

Examples.—Assuming that Scots Pine crops on very good soil would measure 1180 cb. ft. at 20 years, 3410 at 40, 5700 at 60, 7700 at 80, and 9290 at 100 years of age, then the normal growing-stock or capital in wood required for working 400 acres with a rotation of 100 years would therefore be :—

(1) By simplest method of calculation from above formula—

$$4 \text{ (acres)} \times \frac{9290 \text{ (cb. ft.)} \times 100 \text{ (years)}}{2} = 1{,}858{,}000 \text{ cb. ft.}$$

(2) By calculating from the results of yield tables in periods of 1-20, 21-60, and 61-100 years of age.

The woods of 1-20 years will have a total stock of—

$$4 \text{ (acres)} \times 20 \text{ (years)} \times \frac{0+1180 \text{ (cb. ft.)}}{2} = 47{,}200 \text{ cb. ft.;}$$

those of 21-60 years will have a total stock of—

$$4 \text{ (acres)} \times 40 \text{ (years)} \times 3410 \text{ (cb. ft.)} = 545{,}600 \text{ cb. ft.;}$$

those of 61-100 years will have a total stock of—

$$4 \text{ (acres)} \times 40 \text{ (years)} \times 7700 \text{ (cb. ft.)} = 1{,}232{,}000 \text{ cb. ft.}$$

Thus showing the requisite capital to be 1,824,800 cb. ft.

The two methods here exhibit a variation of 33,200 cb. ft., or an average difference of only 83 cb. ft. per acre throughout the whole of the 400 acres of woodland.

(3) But if the same intervals of time be taken, and the calculations made in periods of 1-40, 41-80, and 81-100 years of age, then a slightly different result is again obtained.

The woods of 1-40 years will have a total stock of—

$$4 \text{ (acres)} \times 40 \text{ (years)} \times \frac{0+3410 \text{ (cb. ft.)}}{2} = 272{,}800 \text{ cb. ft.;}$$

those of 41-80 years a total stock of—

$$4 \text{ (acres)} \times 40 \text{ (years)} \times \frac{3410+7700 \text{ (cb. ft.)}}{2} = 888{,}800 \text{ cb. ft.;}$$

those of 81-100 years a total stock of—

$$4 \text{ (acres)} \times 20 \text{ (years)} \times \frac{7700+9290 \text{ (cb. ft.)}}{2} = 679{,}600 \text{ cb. ft.;}$$

or a requisite capital of . . . . 1,841,200 cb. ft.

This last result is, in so far, obviously somewhat too low (for this particular method of reckoning), through having to use the yield at 0, 40, and 80 years in place of knowing that at 1, 41, and 81 years (which could, of course, be averaged and interpolated) ; but it is decidedly too high because of reasons already stated in connection with Fig. 189. If the average stock for 0-40 years were taken to be twice that at 20 years a smaller total would be shown, though this would also again be distinctly erroneous, because of the rate of growth being always far greater from 20-40 than from 0-20 years of age.

So far as an approximate estimate of the necessary capital in timber is concerned, therefore, the simplest of the above methods of calculation is the best for practical purposes.

These examples may, however, show that in forestry, after once data have been fixed, the deductions capable of being drawn from them are liable to exhibit differences even though the methods of calculation are each in themselves theoretically correct. *And this is a very important point to be remembered in trying to regulate the management of woodland crops by means of arithmetical or algebraic formulæ* (see vol. i. p. 97). While such matters as the growth of timber-trees, the rate of growth of woodlands, &c., undoubtedly follow fixed laws of nature, these laws are never rigid, but are always liable to modification by local circumstances. And this fact has too often been lost sight of in the teaching of modern German forestry, seeing that the results of minute and intricate formulæ and calculations (based only, in many cases, on data liable to constant variation) are often substituted for simple measures based merely on broad principles. *Hence the forestry that would be too scientific must often fail to be practical.*

A complete separation of the various annual falls can only be made when the woodlands are worked with annual total clearances followed by artificial regeneration, as usually obtains in the case of coniferous crops. When natural regeneration is adopted, as in Beech-woods, the areas which would otherwise be separately allotted to **several annual falls** are grouped together to form a **periodic fall,** which then forms the unit of treatment for gradual clearance and regeneration. Assuming that the latter measures are to extend over twenty years, then twenty annual falls are united into one periodic fall ; and for all practical purposes the average age and the volume of cubic contents of each such periodic group of falls may be regarded as if the old crop were cleared and the new crop formed exactly at the middle of the period, or at the tenth year in this case. Hence, so far as the normal growing-stock is concerned, this method of treatment does not affect the capital in wood required for working the area with any given rotation and kind of tree. So far as the mere amount of this necessary capital is concerned, it is practically immaterial whether the woods be worked by clear-felling of regular annual falls or by gradual clearance and natural regeneration within proportionate periodic groups each comprising several annual falls.

Example.—Suppose a Beech-wood of 720 acres is worked with a rotation of 120 years, and natural regeneration of different parts of the wood can best be accomplished in about twenty years. In place of making 120 separate annual falls of 6 acres each, six periodic falls would be made by grouping together the falls for the years 1-20, 21-40, 41-60, 61-80, 81-100, and 101-120. Each of these periodic falls would have an area of 120 acres, and in estimating their average age and their cubic contents they would be regarded as being stocked with crops of 10, 30, 50, 70, 90, and 110 years old ; and this arithmetical mean gives precisely the same result, as to capital in wood, as if the method of treatment had been by annual falls and artificial regeneration following immediately after clearance of the mature crops.

While it is easy enough to calculate thus the normal growing-stock for high-woods and coppices by means of average yield tables, it is much more difficult to do this with anything like accuracy as regards standards in copse or for woods treated by the method of casual or sporadic fellings, on account of their irregularity and of the great variations dependent on species of tree, soil, and situation. In copse, for example, the quality of the soil and situation determine not only the rotation and the number of age-classes formed by the standards, but also the number of standards of each age-class retained as overwood. Hence any approximately correct estimate of the capital in wood in copse can only be made by local measurements or estimates of the growing-stock. As trees of all ages are grown together under the casual or so-called "selection" system, it has been suggested that the normal capital might be estimated at one-half of the full amount of a mature crop. Considering the actual conditions of growth of the younger classes under the heavy shade of the older trees, however, this method can be of but little practical value.

The **normal increment** or **rate of growth** fully proportionate to the fertility of the given soil and situation is the sum of the increment accruing throughout all the crops of different ages during the course of each year, and it is equal to the yield of the oldest annual fall in which is incorporated all the annual increments on such unit of area. Expressed as a percentage of the capital, it varies proportionately to the capital in wood. Thus, in the examples previously given on p. 228, it is 2½ per cent in the 80 years' rotation and 2 per cent in that of 100 years.

The **normal condition** can never be fully attained in practice. Even if it could in some cases be almost achieved, it would be impossible to maintain it for any length of time owing to the disturbances to which it is always liable from organic and inorganic causes. But constant and close consideration of the normal condition has more than a mere theoretical value, because it is of really great practical use as a basis—a general standard—for all the estimates and calculations required in order to arrange for woodland management with regularity and economy. It is the only practical means by which full attention can be given to the fundamental fact that each series of timber-crops requires a specific capital in wood for the proper utilisation of the soil in the production of timber. Whether the woods be worked as highwoods, copse, or coppice is immaterial. Each of these sylvicultural systems requires, in addition to the soil, a definite capital in wood in order that the productive power of the land be utilised to its full capacity. If the timber-crops be too thin, whether through wide planting or excessive thinning, then the productivity of the soil cannot be fully utilised, while at the same time it is exposed to deterioration through sun and wind. But if judicious thinning be neglected, so that the crops stand too thick, then they are apt to be weakly in growth through overcrowding; and here again the land is not utilised economically, judging by the practical standard of its capacity for producing wood of the best marketable quality and in the largest possible quantity.

3. **Choice of the Sylvicultural Treatment** (*Highwoods, Coppice and Copse*).—**Highwoods** produce the largest returns and the most valuable wood, while they are also best able to protect the soil against the deteriorating influences of sun and wind. If formed with a suitable number of plants per acre and kept in close cover, without being over-thinned, the trees grow up in such a way as to attain the greatest height and produce the largest basal area for the stems forming the crop; while the harvesting of the mature timber only, as a rule, takes place after the average increment has culminated and the trees are of large dimensions. Where grazing is combined with wood production, that can be carried on continuously with much less damage than would be possible in coppice or copse. But highwoods require a large area and a large capital in timber for their proper management, and the returns are not always what one might desire from so large an investment, especially if the woods are worked with a high rotation. No absolute comparison can,

however, be made between highwoods, copse, and coppice with regard to the profit they yield, because so much depends in each case on the available local market, the kind of wood grown, and the rotation with which the woods are worked. All that can be safely said is that though they lock up a far larger capital in the woods than copse or coppice, yet, in the great majority of cases, and especially where the poorer classes of land are in question, highwoods (and conifers in particular) are, on the whole, the most profitable woodland crops where a large capital is available for investment. Moreover, they are the only form in which Pine, Larch, and Firs can be grown; and these are, for many parts of Britain, the crops whose cultivation on a large scale will prove most profitable.

The simplest form of highwood is that in which the whole area is regularly divided into annual falls, of which the oldest is clear-felled every year, and reproduced artificially by sowing or planting. This is the method usually obtaining with regard to crops of Larch, Pine, and Firs. Another system, generally employed with regard to Beech-woods (also Silver Fir on the Continent), is to group several annual falls together, so as to form a periodic fall, as already described, and to clear the mature timber gradually from the area, whilst a young crop is being regenerated naturally from seed. Modifications of this system of natural regeneration under parent standards are to be found in recent developments of forestry, in which selected stems among the old trees are retained for a further series of years, or even for the whole of the next period of rotation, in order to attain specially large and valuable dimensions. The same object can also be attained by making rather heavy thinnings or partial clearances, when natural regeneration is about to begin, so that the individual trees acquire the free, almost isolated, position most favourable to rapid growth in girth. This of course causes well-grown trees to increase rapidly in value, but the operation usually increases the cost of regeneration, and often leads to the soil becoming overrun with weeds, so that it is not in all cases certain to be a profitable measure. Retention of selected trees for a second rotation is usually a questionable matter, as the trees are seldom likely to hold out the full rotation with advantage, and for a long time they meanwhile retard the younger crop by overshadowing it more or less heavily.

In the case of woods treated by casual or sporadic (selection) fellings, the various age-classes are scattered singly or in groups all over the area in place of being contained within annual or periodic falls, and this system can only be adopted when one has to deal with a shade-bearing kind of tree (such as Beech) in Southern England, or Douglas Fir or Spruce in the North of Scotland. Even then it is generally employed either for æsthetic reasons or for protective purposes (as on high hills), so that the consideration of this system hardly falls within the scope of commercial forestry. It need only, perhaps, be remarked that although in some cases the total increment in woods worked by this casual method is more than that in highwoods with regular annual or periodic falls, yet the mature trees are more branching, and have therefore less technical or monetary value than stems grown in close canopy.

Coppice, consisting of stool-shoots and suckers thrown out when the crop is cleared every few years, yields, on the whole, a smaller return in wood than highwoods; but it requires a very much smaller capital in growing-stock, and, worked with a low rotation, gives a comparatively large area for each year's fall. Hence it offers considerable attractions for the working of small woodland areas. This system can, however, only be carried on to any considerable extent with profit where there happens to be a good market for small produce. So long as Oak-bark was well paid, coppices worked with a rotation of about 14 to 16 years yielded higher returns than highwoods or copse, while some of the Osier-holts in the fen country bring in a larger profit than ever the Oak-coppices did. But the cultivation of basket-willows is much more like gardening than ordinary woodland operations. Wherever there is any steady market for charcoal for gunpowder, Alder-coppice may also prove very profitable on marshy land when worked with a rotation of 20 to 30 years. It then closely resembles highwoods in habit of growth and other respects, save only in being reproduced by coppicing in place of by natural regeneration, sowing, or planting.

The permanent maintenance of coppice is dependent on good reproductive capacity in the kinds of wood grown, and on a fairly good soil and situation. The bulk of the crops usually consists of species like Oak, Chestnut, Hazel, Ash, Maple, Sycamore, and such like, with Alder, Willows, Poplars, and Birch on the moister parts. Particular care should be given to see that stools are replaced whenever they begin to flag in reproductive vigour, else the returns soon diminish considerably and unproductive blanks are formed. Where several kinds of trees are grown together it is often difficult to fix on the best rotation. Thus, for example, Hazel is often most profitable at 7 or 8 years old, but Ash only at about 14 or 15 years of age. To try a compromise by a rotation of 10 or 11 years suits neither part of the crop, while at the same time this cannot be worked simultaneously at 7 years for Hazel and 14 for Ash. Here the main portion of the crop obviously demands the chief consideration, unless the area can be broken up into two separate working-circles—one for Hazel with 7 years' rotation, and the other for Ash with 14 years.

Copse, also called **Stored Coppice** or **Coppice with Standards**, is a sort of mixture of highwood and coppice, in such a manner that while the coppice, forming the underwood, determines the rotation over the area, yet the fall will at the same time harvest a portion of the overwood consisting of standards of various age-classes, differing from each other in age by the number of years in the rotation.

For the continuous thriving of copse a good fresh soil is necessary, else the underwood cannot grow well under the shade cast by the overwood. Softwoods then find their way in, displacing the more valuable hardwoods, blanks are apt to form, weeds spring up, and then, unless constant attention is given to the cutting out of these and the replacement of worn-out stools, the soil becomes deteriorated on the surface. When deterioration has really been allowed to go on for several years, as is very frequently indeed the case in many British copses, it would often be more profitable to change the system of treatment entirely and plant a conifer crop, which will both be more profitable in itself and will improve the soil considerably.

The returns yielded by copse are usually below those obtained from highwoods grown on a similar class of soil. But this form of management certainly has often the attraction of still yielding a very fair return, while requiring only a comparatively small capital in wood to be locked up as the growing-stock; for, of course, its low rotation enables large annual falls to be made. It is therefore essentially the system of management for landowners having only 200 or 300 acres of woods, because it can yield small annual supplies of timber of various sizes at each time of felling the underwood—small value though this now has.

For Britain, and especially for England, copse has other special attractions. The English law of entail makes an important difference between highwood (*saltus*) or timber, and copse or coppice (*sylva cædua*).[1] The former is considered part of the estate, and money arising from the sale of it is treated as capital on which the owner in possession can only receive the interest, while the latter can be cut in the ordinary course of estate management for the benefit of the life-tenant. Under Scots law, however, an heir in possession can cut timber so long as his possession lasts (see vol. i. p. 58).

Copses have also the additional advantage of being better suited for covert-shooting and sport generally than any other kind of woodland. This great point in their favour, as well as their beauty in the landscape, will always deserve and receive the favourable consideration of most English landowners. Further, this system is also one of the best ways of growing as overwood the most valuable kinds of timber on a small scale. It is true that standards over coppice have always a larger proportion of branchwood than the clean stems of well-grown highwoods, yet copse is (with a little judicious pruning) not at all a bad way of growing large and valuable Oak, Ash, and Larch, while it enables the forester to select his young standards (stores or tellers) to suit the probable future market.

If the timber on an estate is to be looked to, as will sometimes be the case, as the source whence the present heavy succession duties are to be partially defrayed, then copse is perhaps that system of management which can most easily be made to yield—within moderate limits, of course—an abnormally heavy fall of timber without producing great disturbance in the general working and ornamental appearance of the woodlands on an estate. But such a measure will necessarily, as also in the case of highwoods, cause short returns for many years, till the capital thus utilised is replaced in course of time.

4. **Selection of Kind of Trees to be grown as Timber-Crops.**—Although actuarial calculations with proper data can alone determine exactly in what degree one method of sylvicultural treatment and one special kind of crop may be more advantageous than any other given method or crop, or what rotation may prove most remunerative in each particular case, yet such intricate details are really quite unnecessary in order to arrive at an opinion as to what is likely to prove the best sort of crop for any given soil and situation. Subject to such modifications and mixtures as local market considerations will of course suggest, poor sandy soil is naturally best suited for crops of Pines as the chief species, with Larch, Firs, Birch, &c., in admixture; on lime and chalk Beech will preferably be selected (except when deterioration of the soil renders Austrian Pine advisable for one rotation), with Ash, Maple, and Sycamore, &c., scattered throughout it; on loam and clay, Oak and other hardwoods can best be grown in such mixed crops as are likely to be most remunerative locally; while on marshy tracts and swamp lands, Alder, Willows, and Poplars will at once suggest themselves, unless the land can be drained and made to yield higher returns either agriculturally or under other woodland crops.

[1] The ancient term used in the law of England for all manner of woodlands was *Boscus*; but highwood was properly called *Saltus*, while coppices or copsewoods under 20 years' growth were termed *Sylva cædua* (see articles *Boscus* and *Sylva cædua* in Cowell's *Law Dictionary*, 1708).

On many of the chalk-hills forming the backbone of Southern England—the Chilterns and Cotswolds, and the spurs branching off from them—Beech-woods, the scattered remnants of ancient forests, form the bulk of the woodland crops. They often prove very profitable, yielding a steady annual income of 30s. an acre, although growing on land situated on the tops of hills unsuited for agriculture, and certainly not worth more than 5s. an acre if brought under pasturage. Regenerated naturally without much assistance (often, indeed, without any at all) in the way of artificial sowing and planting, these Beech-woods are grown pure, and are often far from being as fully stocked as they might be. No doubt they would prove much more profitable if natural regeneration were judiciously assisted by soil-preparation to a greater extent than is at present the case, and completed by sowing and planting; while it is certain that the remunerativeness of woods of this class could be raised by sprinkling Ash in particular, also Larch, Maple, Sycamore, Oak, Pine, Elm, &c.—whatever has the highest local value—here and there throughout the crop on spots favourable to their growth. In admixture with Beech, the hardwoods and the best classes of conifers not only grow more quickly and attain larger dimensions than otherwise, but they also then form wood of superior quality, fetching the highest market rate. Beech being a shade-enduring kind of tree, the best returns will of course be obtained when the crops are grown in fairly close cover, as it is only by such means that the soil can be kept in the fresh moist condition which yields the largest increment; otherwise the moisture is soon evaporated from limy soil unduly exposed to the action of sun and wind. Hence it will be evident that, *cæteris paribus*, Beech-woods should give much better returns when forming large compact tracts of woodland than when they are merely scattered over small areas on exposed hill-tops.

On good, deep, loamy, and clayey soil Oak has hitherto frequently been the principal crop; but the upward tendency of market rates for timber seems to indicate that it might be more advantageous to grow Ash, Maple, Sycamore, and Larch to a much larger extent, either in place of Oak or else in admixture with it. If Oak sells locally for 2s. 6d. a cubic foot and Ash for 2s., it will obviously be preferable to favour the latter—(1) as it grows more quickly than will make up for the 20 per cent of difference here indicated in price as making it equal in value to Oak, (2) as its wood is saleable in smaller dimensions than Oak, and (3) as it reaches its full marketable maturity at an earlier age than Oak. Another advantage of having Ash, Maple, and Sycamore in admixture with Oak is that on being cut out, so that the Oak is left as a standard, their stool-shoots or seedlings often form profitable underwood, or, at any rate, can form the basis for this, with the assistance of sowing. Otherwise, underwood ought to be formed by sowing or planting Beech, Hazel, &c., to protect the soil against deterioration through sun and wind. Although, both in admixture with Oak and as underwood in the older crops of Oak, Beech effects this object in view, yet there can be no doubt that in Britain the financial advantage will lie far more with the other hardwoods than with Beech for use in this way. And this applies also to copse and coppice, as well as to highwoods.

Although there are often distinct local advantages obtainable from pure crops of only one kind of tree, yet, on the whole, the formation of mixed crops usually deserves the preference. They have the largest rate of growth per stem and per acre; they protect the fertility of the soil better than pure woods of light-demanding species (Oak, Larch, &c.); they are easier to reproduce, naturally and artificially; and they also—most important point of all with regard to conifers—diminish the danger of damage from wind, snow, ice, insects, fungous diseases, and fire. These advantages, however, can only be fully attained when the different trees forming the mixture are intended to be felled and utilised at various ages; otherwise, in the case of a mixture of light-demanding trees, one would have much the same drawbacks (only in a different form) as in pure woods of these. Hence, when mixed woods are being formed, the intention with regard to the time of utilising the different kinds of trees should be distinctly recorded, so as to assist in regulating the subsequent thinnings. Of course, such intention need not be subsequently adopted as being of the nature of instructions, because the future can be left to decide for itself whether it be advantageous to thin out one kind or the other, or to regard as the ultimate marketable crop a different tree from that originally intended, seeing that the market prices for different sorts of timber may easily undergo relative changes in the course of the years which must elapse before the trees become mature. But it is only by means of the judicious formation of mixed crops that the financial advantages of the future can be provided for in the present. The main drawback to mixed woods is that they require more careful treatment with regard to thinning than pure crops. On this account it is perhaps preferable to make the mixture in the form of small patches of the different kinds of trees on soil favourable to their growth. This is, in fact, merely following the procedure of nature. When an old tree dies, it is only to be expected that its offspring grows up close round about it; and thus "family groups" are formed, as one can see everywhere in the older forests of every description—whether Beech or Oak in Europe, or Deodar on the Himalayas, or Teak in the forests of Burma. But one can also see another law of nature simultaneously at work, and tending to bring large tracts of woodland mainly under one kind of tree. It was thus that the ancient large pure forests of Beech and Scots Pine were formed in Britain, and of Beech, Hornbeam, Silver Fir, Spruce, Pine, Birch, and Aspen on the Continent of Europe, and similar results in other continents. Hence, here again, if anything beyond mere financial advantage comes into consideration, ample justification can be found for the formation of pure crops of trees of one kind or another. On the whole, however, the growth of mixed crops is the safest and the best method with regard to the treatment of woodlands of large area.

So far as the present demand goes and the future condition of the timber market can be forecast, there seems little doubt that the greatest profit is to be found in coniferous crops. First of all, valuable crops of these can be raised on soil which is not sufficiently productive to yield a good growth of Oak, Ash, Beech, &c., and, secondly, they give the largest returns in timber per acre. Even though the price per cubic foot is nothing like so high as for Oak or Ash, yet they can often give quite as good returns as these, and often even better, on land of moderate quality, besides producing a fair yield on inferior soil and poor land where crops of hardwoods could not be grown at all with profit.

On the Continent of Europe the most profitable crops of timber are, beyond all doubt, Spruce and Silver Fir grown on fresh soil not deficient in moisture; while for inferior land, and on poor, dry, sandy stretches, the Scots Pine is the only remunerative crop. No less than 42 per cent of the total wooded area throughout Germany is under coniferous crops. In Britain, Larch has often shown itself one of the most profitable of crops, even despite the canker disease; but the experiences so often made with this fine tree in large pure plantations in different parts of the country, from the Highlands of Scotland to the south of England, should convince any one that Larch should be grown in admixture with other trees, and preferably with broad-leaved kinds, rather than in pure plantations of large extent.

As woodland crops Spruce and Silver Fir do not, for climatic reasons, thrive anything like so well in England as they do in France and Germany; but somewhat better results are obtainable, with regard to Spruce at least, in the Highlands of Scotland, with their harder winter and their mists more resembling the climate where Spruce is indigenous. The much lower rates given locally in Scotland for the "Baltic deals" of Spruce and the "white pine" of Silver Fir in comparison with "red" or Scots Pine and Larch will, however, naturally and very reasonably lead to the two latter species receiving the preference in plantations and natural regenerations. And in many cases, particularly on sandy soil in the south of England, Corsican Pine will yield a fairly good wood and a larger crop per acre than Scots Pine, while creosoting must tend to reduce future differences in price.

Where there is a good market for young stems from the size of hop-poles upwards, there is always a strong temptation to plant Larch pure. A crop of 70 years of age, consisting of about 220 trees per acre, in the south of England recently (1900) realised 20s. a-tree for the whole lot, while the plantation, originally formed at about 4 ft. by 4 ft., had always yielded a fair return in the way of thinnings since the time the poles were large enough to be cut through the centre for rails.

Fast as the growth of Larch often is, yet that of the Douglas Fir is even more rapid, while the quality of the timber produced in Britain is now known to be at any rate far superior to that of Spruce or Silver Fir (see vol. i. p. 250). But it is not merely the question of profit that has to be carefully considered before forming pure crops of any one kind of conifer, because experience has shown in the most convincing manner possible that Scots Pine, Spruce, Silver Fir, and Larch, grown *in large masses* as pure woods, are each exposed to particular dangers, and have each their own special enemies among injurious insects and fungous diseases. And there are unfortunately already signs that it is not likely to be different with Douglas Fir. The greatest ultimate advantages will therefore, in conifer crops as in broad-leaved trees, be found in judicious mixtures. On good soil Douglas Fir, pure or mixed with Larch and with perhaps a sprinkling of Menzies Spruce, in which Larch is distinctly favoured in height at time of planting and specially favoured during thinning, would probably prove one of the largest crops that can be grown, and might also (given cheap plants) prove one of the most profitable. For poorer soil a sprinkling of Larch throughout a matrix of Pines can hardly fail to be profitable, even though the Larch cannot be expected to attain good dimensions on inferior land. Whenever Spruce may form the main portion of the crop an admixture of Larch is preferable to Pine, both as being more valuable in itself and as better suited to the Spruce in its particular habit of growth. A sprinkling of Spruce among Pine affords, by reason of its conical top, convenient opportunity for assisting the latter by the removal of the former during thinnings, without breaking up the canopy to any injurious extent, while it also helps to diminish the risk of heavy damage from breakage by snow during severe winters.

When young plantations of Scots Pine or Spruce are being formed, a mixture of Birch is often useful as a nurse in exposed localities. But it should be mostly cut out when once it has served this purpose, otherwise it is apt to cause trouble by seeding on adjoining areas. A few Birch here and there, however, not only form a pleasant contrast to the sombre conifers, but also add to returns obtained. And it is the best kind of tree that can be grown on poor sandy soil to protect Pine-woods from fires arising through sparks from railway engines. A few rows of Birch planted along both sides of a railway line will prove about the most effective measure that is practicable to try and catch the live sparks, and prevent them from causing forest fires. In coppice, Birch, Aspen, and other softwoods should usually be cut out in favour of more valuable hardwoods, while as highwoods their canopy soon becomes so thin as to be unable to protect the soil against deterioration.

As has already been remarked, a change of crop sometimes becomes necessary in woodlands on account of the soil being deteriorated, usually through bad management in the past. But it also sometimes happens that a change of crop promises better returns from the land, and may therefore appear desirable. It is best, however, to study first of all the details of the past management, to see if improvement cannot be made therein before adopting so drastic a measure as a total change in the kind of crop grown. Any given kind of crop can, of course, only be grown *in perpetuo* on the same area if it is able to protect the fertility of the land; and when woodlands show signs that the soil is becoming, or has become, deteriorated, one must first carefully consider not only whether the kind of crop or the past system of management is the cause of such deterioration, but also how this can best be repaired. A good deal can often be done to remedy matters by layering, sowing and planting, and by improving the system of management in various ways; but when copse and coppice tracts have once become much deteriorated, then there can often be very little doubt that their conversion into conifer highwoods by means of planting is the best step to take. Such changes of crop, however, will necessarily be a new investment of capital, as but few of the crops on deteriorated land of this description will, on being cleared, yield, in addition to the usual returns of the regular fellings, anything like a sufficient surplus to pay for the planting of the land. Before making any such change of crop it is therefore necessary to consider the advantages and disadvantages carefully; because once the change is made, it is an investment of capital from which one cannot withdraw except at great loss.

5. **Fixing the Rotation with which the Timber-Crops should be worked.**—As already mentioned, the term **rotation** used with regard to woodland crops simply means the number of years forming one complete generation of the trees, or one full cycle of the crop—from the seedling growth to the ultimate fall of the mature timber.

As will be explained subsequently in dealing with the practical work of forest management, the first steps to be taken are to subdivide the whole woodland area into convenient working-circles and compartments, to classify and estimate the contents of the crops found growing throughout the whole of each working-circle, and to collect the various other data upon which the scheme of management must be based. The direction in which the several annual (or periodic) falls should take place being once fixed (in the direction opposite to the prevailing dangerous winds—*i.e.*, *generally* running from E., N.E., or S.E., to W., S.W., or N.W. in most parts of Britain), and the choice of the sylvicultural method of treatment and the particular kind of crop having been made, the next most important step is to fix the rotation with which the crops forming each working-circle shall be worked. As a matter of fact, the whole of the management is essentially influenced by this. If Larch- or Pine-woods are worked with a rotation of 80 or 90 years, then each annual fall will (*cœteris paribus*) be equal to the total area divided by 80 or 90 respectively; while Beech-woods worked with a rotation of 100 or 120 years, grouped into periods of 20 years for natural regeneration, will respectively have five or six periodic falls, each equal to what would be the area of twenty annual falls. Hence it is very clear that fixing the rotation of a crop forming any particular working-circle means nothing short of simultaneously determining (1) *the size of each annual* (*or periodic*) *fall*; (2) *the normal growing-stock or total amount of capital in wood required*; (3) *the normal increment or annual rate of growth*, and consequently also (4) *the normal yield annually obtained as the mature fall of timber.*

It is therefore impossible to overrate the importance of careful consideration in fixing the rotation of timber-crops, because, once this is fixed, one is committed, more or less definitely, to a general scheme of management in many respects. But, from the very nature of forestry, it is obviously impossible to fix a rotation for 70 or 100 years, or more, ahead. If large new plantations are to be made, who can say, at present, whether the working-plan had best be framed for 70, 80, 100 years, or any other definite term? All that can safely be said is that—so far as local conditions, existing prices, and the probable tendency of the timber market are concerned—a rotation of x, y, or z years now seems what is likely to prove most profitable. It is, of course, a much easier matter to calculate, as regards a crop of 40 or 50 to 60 or 70 years now on the ground, whether it will pay best to clear it at once or to let it grow for 10 or 20 years more. While recognising the absolute necessity for having some standard to go by, it therefore seems advisable, in the case of forming large new plantations, to adopt, under guidance of existing and probable future market rates, some such rotation as 60 to 80 years for conifer crops, and 100 or 120 years for Beech-woods, which (as also the annual or periodic falls, of course) can easily be raised or lowered later on, by 10, 15, or 20 years, in the light of the better knowledge that will come before the crops are mature.

The rotation with which different kinds of woodland crops can be worked depends to a very great extent on the quality of the soil. It is a matter of common experience, proved also by the Continental Tables of Average Yield, that highwoods growing on good soil and in a favourable situation can be worked with profit in a longer rotation than on poor land and in hot exposed positions. For copse and coppice-woods, on the other hand, the rotation can be shorter on good soil than on inferior land, because there is then less chance of its productivity becoming deteriorated through more frequent exposure.

In fixing the rotation of timber-crops it is not sufficient merely to be guided by what may appear to be the most profitable age for cutting the crop. It is important that the rotation adopted should amply protect the productivity of the soil. If the rotation be either so short (in coppice or copse) or so long (in highwoods) that it leads to deterioration of the soil, then any temporary advantage gained with regard to the crop now growing would be dearly bought at the expense of the next crop, and of the consequent decreased *capital* value of the land for growing timber.

So far as any general statement can safely be ventured on, the rotation which will best suit hardwoods like Ash, Maple, Sycamore, and Elm will in most places lie between 60 to 90 years, Beech from 100 to 120 years, and Oak from 100 to 150, and that for conifer crops 50 to 80 years, so as to yield timber for building, will probably be about the most profitable future rotation. In hardwood coppices and copses it will usually vary from 10 to 15 or 20 years according to the market for the underwood, although Alder-coppices often pay better with a rotation of 25 or 30 years and Hazel with a rotation of only 7 or 8 years, while Osier-holts are cut over annually for their harvest of small rods used in basket-making.

If it were merely desired to obtain the largest crops of wood per acre from the forests, it would be easy to fix the rotation, with a fair degree of accuracy for general purposes, by means of Average Yield Tables. It would then coincide with the time at which the average increment culminates on land of the given quality, and this is when the current annual increment is equal to the average increment (see p. 321). If the total yield of the mature fall be added to all the previous thinnings, and this sum be divided by the number of years in the rotation, the quotient will show the average yield; and a comparison of the results worked out for different ages will at once give the rotation desired. Investigations have shown, however, that this point is reached at a comparatively early age (Scots Pine 30 to 40, Beech 50 to 75, Spruce 60 to 70 years), while the crops are still in vigorous growth on good classes of land, when their clearance would be less profitable than allowing them to grow on for several years. Hence this method of trying to fix a *normal rotation* is of little practical value, since it gives no indication as to whether such a rotation would be more profitable or less profitable than one fixed either somewhat higher or somewhat lower.

The Rotation which promises to obtain the largest annual income from woods takes into consideration not only the total quantity of wood produced per acre, but also the dimensions attained by the timber, because its technical value, and consequently the market-rate per cubic foot obtainable for it, increase with the diameter and the greater rotundity of the stem. This rotation is found by adding together the *net* money-value (*i.e.*, free from the cost of harvesting them) of all thinnings and of the mature fall of wood, subtracting from this total the cost of regenerating the crop (or replanting the area) and the sum of the annual outlay for protection, rates, and taxes for as many years as there are in the rotation, and dividing the difference by the number of years in the rotation. As the cost of regeneration or replanting is practically the same whatever be the rotation, and as the amount annually payable for protection, rates, and taxes is subject to but little variation, it therefore follows that the most favourable rotation can be directly found by adding together the value of all thinnings and of the mature fall, and dividing their sum by the number of years in the rotation. Several such calculations being made, that rotation which gives the largest result will be the one desired. As a matter of fact, the rotation thus indicated is somewhat higher than that which yields the largest percentage on the capital employed in producing the crops of wood. This method of fixing the rotation is certainly a great improvement on that which merely considers the largest out-turn in wood per acre; but its weak point is that the calculation of the largest annual income does not take into consideration, as forestry on purely business principles should, the exact relation this amount bears to the productive capital locked up in the soil and the total growing-stock of wood. Hence it is not the method which can be recommended for Britain.

The most profitable Rotation—that is to say, the rotation which promises to yield the highest percentage on the capital value of the woodland as estimated by the *net* monetary value of its produce—is what should, both in theory and in practice, receive most consideration in the management of woods intended to be worked on commercial lines.[1] It is found (see p. 241) by making various calculations, each as if for a single crop, in accordance with **Faustmann's formula** (the same rate of interest being used in each case, of course), and ascertaining that particular rotation which shows the greatest profit by indicating the maximum productivity or largest capital value for land and growing-stock. Faustmann's formula is as follows:—

The productivity of the woodlands (as estimated by the net value of the timber crop, &c.) is $=\dfrac{F_n+(T_a\times 1{\cdot}0\,p^{n-a})+(T_b\times 1{\cdot}0\,p^{n-b})+\ldots+(T_q\times 1{\cdot}0\,p^{n-q})-(c\times 1{\cdot}0\,p^n)}{1{\cdot}0\,p^n-1}-\dfrac{g}{0{\cdot}0p}$

Where—

F_n = the net income, free from cost of harvesting, yielded by the mature fall at the year n.

T_a, $T_b \ldots T_q$ = the net income, free from cost of harvesting, yielded by the thinnings at the years a, $b \ldots\ldots q$.

p = the percentage or rate of interest which the woodlands are supposed to yield annually on the investment represented by their capital value.

c = the cost of forming the crop originally, or of regenerating or replanting the area on the fall of the mature crop.

g = the annual outlay for general charges (supervision, protection, rates and taxes).

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[1] The same principle of course also applied to British Arboriculture in olden times. What Loudon said (*Arboretum et Fruticetum Britannicum*, 1838, vol. iii. p. 1809) of the Oak, applies to all trees grown for selling:—

"*The age at which Oak timber ought to be felled, with a view to profit,* must depend on the soil and climate in which the tree is grown, as well as on other circumstances. When-

Faustmann's formula is mathematically correct, for it brings into account in a logical and proper manner the various factors that have to be taken into consideration. It is nothing more or less than an algebraic form of expressing the plain and obvious fact that the income and the expenditure occurring at different times have all to be treated as if they were sums of money paid into a bank account and allowed to accumulate at compound interest—that is to say, they must be capitalised at compound interest and summarised with respect to a given point of time; whereas, in the previous method of fixing the rotation merely for the largest annual income, the revenue and expenditure at different times were all dealt with as if the precise time at which they occurred were of no consequence.

There can be no doubt that, *as a guiding principle*, Faustmann's formula is as safe as anything of the sort can be; but, in practice, it cannot reasonably be taken as anything like a hard-and-fast rule for determining the best rotation of any given crop. There is not a single factor in the formula which one can be sure of estimating quite correctly for any given case; and one of the chief of all the factors, p, the percentage or rate of interest at which the business of forestry is supposed to be carried on, is almost an arbitrary quantity, selected more or less at will, except in the very few cases where it might be specifically determined from the returns yielded by woodlands which have been purchased as an investment for the production of timber. Even a difference of $\frac{1}{4}$ per cent in reckoning with p will perceptibly affect the results showing the most profitable rotation.

The important effect of p, the rate per cent in such calculations, may be shown very simply. Suppose, for example, a woodland estate which produces a clear revenue of £1000 a-year is in the market. Any intending purchaser who desires to obtain 4 per cent from such an investment will fix its value at $\frac{1000}{0{\cdot}04}=$ £25,000. Another, content to get only 3 per cent, would reckon its capital value at $\frac{1000}{0{\cdot}03}=$ £33,333; while a third, satisfied with a return of only 2 per cent from such an investment in landed property, would assess its value at $\frac{1000}{0{\cdot}02}=$ £50,000. For other examples, see also vol. i. pp. 98, 99.

Again, with the gradual changes affecting the timber market from time to time, it is impossible to determine future values of wood with anything like accuracy, while at the same time some sort of practical standard *must* be adopted for determining the kind of crop and the rotation likely to prove most advantageous. And in both of these respects, even although absolute accuracy is not thus attainable, the results which Faustmann's formula gives are of great practical use as good general indications of the most advantageous crops and rotations for given situations. More especially will this be the case if the rate of interest be fixed not higher than $2\frac{1}{2}$, $2\frac{3}{4}$, or 3 per cent, according to local circumstances.

Example.—A landowner has land suitable for planting with mixed conifer crops, which he thinks would probably pay best if worked with a rotation of 80 or 100 years. So far as he can ascertain from consideration of average yield tables and existing local market-

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ever the tree has arrived at that period of its growth that the annual increase does not amount in value to the marketable interest of the money which, at the time, the tree would produce if cut down, then it would appear more profitable to cut it down than to let it stand. . . . A writer in the *Gardener's Magazine* states that Mr Larkin, an eminent purveyor of timber for shipbuilding, stated, when examined before the East India Shipping Committee, that in situations the most favourable for ship-timber (the Weald of Kent, for example), the most profitable time to cut Oak was at 90 years old; as, though the largest scantlings were produced at 130 years' growth, the increase in the 40 additional years did not pay 2 per cent (*Gard. Mag.*, vol. xi. p. 690)."

rates for wood, he may expect, for soil of the quality he takes his land to be, the following yield (*net* money value in each case) from the land per acre :—

1. *Intermediate Returns* (*Thinnings*).—Thinnings at 40 years worth £4, at 50 years £5, at 60 years £6, at 70 years £7, at 80 years £8, and at 90 years £9.

2. *Final Yield* (*Mature Fall*).—Clear-felling at 80 years of age, £183 ; or at 100 years, £266.

The cost of planting is £5 an acre, and the general expenses of supervision, protection, and rates and taxes annually amount to 5s. an acre.

The rate of interest being taken as 3 per cent, which would prove the more profitable rotation ?

(1) For the 80 years' rotation, the present value of the ultimate income from all these future returns is—

$$=\frac{183+(4\times 1{\cdot}03^{40})+(5\times 1{\cdot}03^{30})+(6\times 1{\cdot}03^{20})+(7\times 1{\cdot}03^{10})-(5\times 1{\cdot}03^{80})}{1{\cdot}03^{80}-1}-\frac{0{\cdot}25}{0{\cdot}03}$$

$$=\left[\frac{(183+13{\cdot}0480+12{\cdot}1365+10{\cdot}8366+9{\cdot}4073)-53{\cdot}2045}{9{\cdot}64}\right]-8{\cdot}33$$

$$=\frac{175{\cdot}22}{9{\cdot}64}-8{\cdot}33=18{\cdot}17-8{\cdot}33=9{\cdot}84=\text{£}9,\ 16\text{s. } 9\text{d. per acre.}$$

(2) For the 100 years' rotation it would be—

$$=\frac{\left\{\begin{matrix}266+(4\times 1{\cdot}03^{60})+(5\times 1{\cdot}03^{50})+(6\times 1{\cdot}03^{40})+(7\times 1{\cdot}03^{30})+(8\times 1{\cdot}03^{20})\\ +(9\times 1{\cdot}03^{10})-(5\times 1{\cdot}03^{100})\end{matrix}\right\}}{1{\cdot}03^{100}-1}-\frac{0{\cdot}25}{0{\cdot}03}$$

$$=\left[\frac{(266+23{\cdot}5664+21{\cdot}9195+19{\cdot}5720+16{\cdot}9911+14{\cdot}4488+12{\cdot}0951)-96{\cdot}0930}{18{\cdot}22}\right]-8{\cdot}33$$

$$=\frac{278{\cdot}50}{18{\cdot}22}-8{\cdot}33=15{\cdot}28-8{\cdot}33=6{\cdot}95=\text{£}6,\ 19\text{s. per acre.}$$

The 80 years' rotation would therefore be the more profitable.

The case is different when a landowner wishes to consider whether a crop that is 80 years old can more profitably be cut now, or 5, or 10, or 20 years hence. The method of reckoning then employed will be subsequently explained (in section 6 below).

It is easy to see that in the results given by the above formula, other factors remaining unchanged, the indicated capital value will be all the more, the greater the value of the thinnings and of the mature yield ; and it will also be all the greater, the less the cost of regeneration and of the annual expenses for management and rates. It is equally clear, too, that the lower the rate of interest represented by p, the higher will be the estimated value of the capital invested in the woodlands.

So far as concerns the question when it will be most advantageous to fell and regenerate wood-crops now approaching maturity, the matter is much simpler and less dependent on arbitrary factors. The present condition of the crop and the measurement of its rate of growth will give the necessary data for determining in a common-sense practical manner whether it be more profitable to harvest it now or to wait for some years before felling it and converting it into money. Where the rate of growth is still good, the present upward tendency in the price of timber will certainly point to advantage in permitting well-grown crops to develop into stems of large dimensions.

6. **Sylvicultural and Actuarial Considerations affecting the Management of Woodlands.**—Owing to the uncertainty affecting, in a greater or less degree, each of the various factors with which the calculation must be made,

it is impossible to determine beforehand with accuracy what rotation will really prove most profitable. Where a particular rotation has been customary for any given kind of wood, there are usually good grounds for its having been adopted; and careful consideration should be given to the benefits likely to be derived before changing it into any higher or lower rotation. To lengthen the rotation means to increase, out of savings made in the annual falls, the capital invested as the growing-stock; and to diminish it is to obtain a larger annual yield temporarily, while decreasing the amount of timber required as the normal capital in wood. The temporary advantage obtained in the latter case is nothing more than liquidating part of the capital. That this is not self-evident is solely due to the fact that in forestry the bulk of the capital (*wood*) is indistinguishable *per se* from the mature product (*timber*) which it yields (see p. 221).

One of the main things to be considered, both as to forestry in general in Britain and with regard to fixing the rotation with which woods should be worked, is, of course, **the probable tendency of future prices**. The demands for timber are gradually increasing, more quickly than its place can be taken by other materials (iron, &c.), while the available supplies which can be brought to market with profit are diminishing; hence prices naturally show an upward tendency. In some parts of Britain the rise in the local rate for timber has recently been as much as 25 per cent; and the present condition of the existing sources of supply being considered (chiefly the Baltic countries, Scandinavia, and Canada), it seems very probable not only that this recent rise will be permanent, but also that the market value of timber in Britain will very probably soon be considerably higher than it has ever been before. In view of this upward tendency it therefore seems certain that the most profitable systems of management must be such as will produce clean, straight, well-grown timber, and the most profitable rotations will be those that can yield timber of the dimensions best satisfying the requirements of the local markets; because timber is so bulky and heavy a raw material that the advantages of the higher prices of far distant centres of consumption can, in the majority of cases, only be made available when there is cheap transport by water (drifting and rafting). But even when what seems the most profitable rotation has been considered and determined, circumstances may afterwards occur to make a deviation from it desirable. Thus, if any crop should be damaged by wind, insects, &c., sylvicultural considerations may necessitate its being felled prematurely; while, if the prices for large timber are specially good, the fall will naturally be delayed for several years if the wood is in vigorous growth and the annual fall can more conveniently be made in some of the other woods.

Besides the condition of the local market, the other chief matters to be considered are the *soil and situation* generally, the *kind of crops*, the *distribution of the various age-classes*, and the *actual condition of the growing-stock*. Woods growing on good soil and in a favourable situation can be worked profitably with a longer rotation than those on poor land, whether in a sheltered or a high and exposed position. Here the increment culminates and begins to sink sooner than on good soil, and the rotation must be fixed so as to obviate danger of deterioration and consequent decline in productivity.

The kind of crop selected should, of course, be such as will best suit the market. Thus, though well-grown Spruce crops yield about 15 per cent more wood than Scots Pine, yet in Britain the advantage will clearly be on the side of the latter, because its timber commands a considerably higher price. Douglas Fir produces larger crops than Spruce, Pine, or Larch, and yields wood ranking between Larch and Scots Pine in quality; and there can be no doubt that this is, under judicious treatment, likely to prove the most remunerative of all the woodland crops that can be grown in Britain. Again, Ash commands a good and ready sale from the size of poles upwards, and this should be the strongest possible argument for encouraging its growth on a large scale among all hardwood crops, whether treated as highwoods, copse, or coppice. And the rotation, as well as the sylvicultural treatment in thinnings, &c., must of course accommodate itself to the requirements of whatever particular tree is intended to be the ultimate crop. In mixed woods where Oak forms the main crop, the various operations for promoting its development must be conducted with a view to the special requirements of the Oak rather than of the trees grown in admixture with it; and so also as regards fixing the rotation. In Beech-woods the rotation must consider the maturity and the regeneration of the Beech itself rather than that of the Oak, Ash, Maple, Larch, &c., sprinkled throughout it to increase the profit yielded. And the same holds, too, in mixed conifer crops of Douglas Fir, Larch, Pine, Spruce, &c., the rotation being determined solely by considerations as to the main portion of the crop. And, of course, any sylvicultural operations which increase the quantity and value of large-sized timber, such as partial clearance with simultaneous formation of underwood, will require special consideration when the practical question of clearing and regenerating has to be decided.

The actual distribution of the age-classes in woodlands is in so far of influence that, where the crops are mostly young, a low rotation may seem desirable in order to give the landowner, as soon as possible, the full advantages of a regularly sustained annual yield; while, on the other hand, an excess of old woods beyond what are required for the normal capital or growing-stock must either lead to a long rotation being fixed on, or to the capital being reduced by annual cuttings in excess of the actual annual increment throughout all the crops. But as this would mean increased income for several years, till the excess of actual growing-stock over normal capital is consumed, no landowner would be likely to hesitate in such a matter. It is not a case that will be general, though it may not infrequently be found with regard to large wooded estates on which plantations have been made at various times during the early part of the past century, without following any fixed scheme of management or regular plan of felling and regenerating or replanting from year to year or period to period.

The actual condition of the woods is a matter which must exert a very important influence in determining the fall and harvesting of most of the woods now to be found in Britain. In consequence of injudicious thinning, most of the crops now reaching maturity are so branching, incomplete, and irregular in many respects as to make it desirable that they should be regenerated and cleared—or cleared and replanted, as the case may be—as early as convenient, so as to make way for crops to be managed on more business-like principles than hitherto. Excessive branch development, badly-formed boles, unproductive blank spaces, and general want of density in the cover or leaf-canopy overhead, are characteristic of most of the British woodlands; and where such conditions obtain, they can certainly not be the most profitable system of management for the woodlands in question. It is only when the clearance of such crops is being considered that there will be any necessity for fixing the future rotation, as must, of course, be done in drawing up a scheme of management to form the general instruction for practical work. But the actual condition of the existing woods must be the chief thing to be considered with regard to harvesting those of them which should be felled within the next ten or twenty years. And this particular consideration can, of course, only be properly given in connection with the local market rates for timber and the general circumstances of the estate.

In the great majority of cases in Britain the owners of woodlands are content to work their forests without any regular sort of management, or they prefer to treat them by casual or sporadic falls (so-called *selection fellings*) for æsthetic reasons, or desire to regard them mainly as game-coverts. In all such circumstances, whatever annual income is obtained must, of course, be less than would be received under management on commercial principles, while the method of working adopted must adapt itself chiefly to the specific object desired by the proprietor. So far as the practical question regarding the fall of woods approaching maturity is concerned, the rate of growth ascertained for each crop will show whether it has a satisfactory increment or not. If this is not quite so good as it ought to be, the next thing is to consider whether the crop can be made more profitable by means of partial clearance and underplanting, or if it is not best to clear the timber and form a new crop.

The percentage of increment in cubic contents is easily ascertained by dividing the amount of the current annual increment by the whole cubic contents of the crop and multiplying the result by 100—

$$p = 100 \times \frac{\text{increment}}{\text{cubic contents of crop}}$$

The percentage of increment in value, or current rate of interest afforded by the crop as an investment, is also easily calculable from year to year by means of the simple formula—

$$p = 100\left(\frac{F_{m+1} - F_m}{F_m + L + G}\right)$$

as is explained on opposite page. Now, if p in this case is greater than the rate of interest the woods are supposed to bring in, it must be profitable to let the crop continue growing; if it is equal to that, it will be equally profitable to clear it or to let it grow on; and if it is less than the arbitrary rate of interest, the crop can no longer be grown with profit, but should be felled and utilised.

Example.—An 80-year-old Larch crop, with 7500 cb. ft. to the acre, shows a current increment of 150 cb. ft. per acre: what is the percentage of increment?

$$\text{Here } p = 100 \times \frac{150}{7500} = 2 \text{ per cent.}$$

If the present net value of the crop is £300 an acre, and it is estimated that its net value next year would probably be £307, 10s., what will be the rate of interest it would yield during the year, the capital value of the land (L) being taken as £20 an acre, and the capital sum required to cover the annual general expenses $\left(\frac{g}{0{\cdot}0p} = G\right)$ being £13?

$$p = \frac{(307\tfrac{1}{2} - 300)\,100}{(300 + 20 + 13)} = \frac{750}{333} = 2\tfrac{1}{4} \text{ per cent.}$$

Another method—the evolution and precise signification of which will shortly be described (p. 247)—gives p as an *indicating percentage* in a simpler formula, which can easily be used in practical work in the forest for determining whether woods of marketable dimensions should be felled or allowed to stand for 5 or 10 years longer. According to it—

$$p = \frac{F_{m+n} - F_m}{F_{m+n} + F_m} \times \frac{200}{n}$$

Here F_m signifies the net money value of the crop or fall at present, and F_{m+n} represents its net value n years hence—*i.e.*, next year in this case.

If this formula be used for the case in the above example, then the "indicating percentage" would be

$$p = \frac{307\tfrac{1}{2} - 300}{307\tfrac{1}{2} + 300} \times \frac{200}{1} = \frac{7\tfrac{1}{2} \times 200}{607\tfrac{1}{2}} = \frac{3000}{1215} = 2{\cdot}46 \text{ per cent.}$$

For exact actuarial calculations made with great circumstantiality a much more scientific system has, of course, been evolved in Germany and embodied in formulæ. Thus Faustmann's formula can be employed for the purpose, the present and the future results after n years being worked out and compared. Or, again, take the case of a wood having a crop or fall of timber F, that is m years of age, and whose present net monetary value, if now felled, is Fm, whereas, if allowed to grow on for another year, its net value will be $Fm+1$. Before any definite idea can be formed as to whether the increase during the year will be profitable or not, the other factors that must be considered are the value of the land, L, and the capital, G, covering general annual expenses $\left(G=\frac{g}{0{\cdot}0\,p}\right)$ (see pages 394 and 388). The current rate of interest or percentage of increase in monetary value during the year will therefore be found by dividing the difference between F_{m+1} and F_m by the total of F_m+L+G, and multiplying by 100 as shown in the formula above—

$$p=100\times\frac{(F_{m+1}-F_m)}{(F_m+L+G)}$$

If, however, in place of reckoning thus from year to year, we wish to compare the present financial position of the crop with what it will be after n years, then we have two gross capital sums to deal with—namely (F_m+L+G) at present, and $(F_{m+n}+L+G)$ at n years hence, when the crop of wood having the present net value, F_m, will not only give a larger, but also a more valuable, net yield, F_{m+n}. The problem to be solved therefore obviously is to try and determine the precentage or rate of interest at which (F_m+L+G) must increase annually in order to attain the value of $(F_{m+n}+L+G)$ in n years. The equation will therefore be

$$(F_m+L+G)\ 1{\cdot}0\ p^n=(F_{m+n}+L+G).$$

Here the left-hand side represents the gross capital which would be available for investment during the next n years if the crop were felled at once and converted into money; while the right-hand side represents the gross capital similarly available on harvesting the crop n years hence. Reducing the above equation

$$1{\cdot}0\ p_n=\frac{(F_{m+n}+L+G)}{(F_m+L+G)}$$

$$\therefore 1{\cdot}0\ p=\sqrt[n]{\frac{(F_{m+n}+L+G)}{(F_m+L+G)}}$$

$$\therefore p=100\left(\sqrt[n]{\frac{(F_{m+n}+L+G)}{(F_m+L+G)}}-1\right)$$

Whatever value is thus shown for p is what Pressler, the pioneer of the purely financial principles of forestry in Germany about a generation ago, called the "*indicating percentage*," showing whether any particular crop has reached its full financial maturity or not. So long as the *indicating precentage* is higher than the normal rate of interest at which the woods are supposed to be worked, it will be profitable to let the crop grow on; if equal to this, it is financially immaterial whether the fall be made now or n years hence; while, if less than the accepted rate of interest, the wood has passed the profitable stage and should be felled as soon as convenient to make room for a new crop. If the *indicating precentage* be greater than the normal rate of interest when $n=5$ years, but less than that when $n=10$ years, this would show that the financial maturity or most profitable time of felling the crop has not yet arrived, but that 10 years hence it will already have been passed, so that the wood should be harvested between 5 and 10 years from now.

For general purposes of management n can most conveniently be taken at 10 years. If a thinning should be necessary during the 10 years thus included, the financial effect it produces on the equation must be calculated by capitalising its money yield from the time of the thinning till the end of the 10 years. In this case the F_{m+n} in the above equation would be the money value of the then remaining final crop, plus the previous thinning capitalised from the time it was made to the end of the period of 10 years at the rate of interest with which the woods are supposed to be worked, and in the same way as is done in Faustmann's formula (p. 239). The *indicating precentage* would then be

$$=100\left(\sqrt[n]{\frac{F_{m+n}+(T_a\times 1{\cdot}0\ p^{n-a})+L+G}{F_m+L+G}}-1\right)$$

Here F_{m+n} must of course be a different quantity from what it would be if no thinning takes place, and the p used for capitalising the return from the thinning is the rate of interest at which the woods are supposed to be worked.

To simplify calculations of the *indicating precentage*, Graner (*Forstbetriebseinrichtung*, 1889, p. 123) has drawn up the following table, based on the formula for prolongation ($1{\cdot}0\,p^n$) :—

The period for which comparison is made being years :—								The *indicating percentage* is
5	10	15	20	25	30	40	50	
and the quotient of $\frac{(F_{m+n}+L+G)}{(F_m+L+G)}$ being :—								
1·03	1·05	1·08	1·10	1·13	1·16	1·22	1·28	½ per cent.
1·05	1·10	1·16	1·22	1·28	1·35	1·49	1·64	1 "
1·08	1·16	1·25	1·35	1·45	1·56	1·81	2·11	1½ "
1·10	1·22	1·35	1·49	1·64	1·81	2·21	2·69	2 "
1·13	1·28	1·45	1·64	1·85	2·10	2·69	3·44	2½ "
1·16	1·34	1·56	1·81	2·09	2·43	3·26	4·38	3 "
1·19	1·41	1·68	1·99	2·36	2·81	3·96	5·58	3½ "
1·22	1·48	1·80	2·19	2·67	3·24	4·80	7·11	4 "
1·25	1·55	1·94	2·41	3·01	3·75	5·82	9·03	4½ "
1·28	1·63	2·08	2·65	3·39	4·32	7·04	11·47	5 "

Example.—Suppose an 80-year-old Larch crop has a present net value of £300 an acre (*i.e.*, net monetary return, free from cost of felling, selling, and extracting), and average yield tables and local market rates justify the conclusion that at 90 years of age it would probably be worth £400 an acre net value. If the capital value of the land is assessed at £20 an acre, the annual general expenses $\left(\frac{g}{0{\cdot}0p}=G\right)$ represent a further capital of £8 an acre, and the woods are worked under the impression that they should yield 3 per cent, whether will it be more profitable to clear the crop now or to let it grow to 90 years of age ?

Here $n=10$ years, and

$$\frac{F_{90}+L+G}{F_{80}+L+G}=\frac{400+20+8}{300+20+8}=\frac{428}{328}=1{\cdot}30$$

From Graner's table this result corresponds with an *indicating percentage* of somewhat less than 3 per cent, therefore the proprietor will either have to fell the wood in question or else be contented with less than that rate of interest on the capital invested in continuing the growth of this crop.

Pressler himself saw that it was desirable to do away with the necessity for using logarithms, so he endeavoured to simplify the calculation of the *indicating percentage.* The increase in value which takes place in the crop being the combined result of three separate factors—namely, a the percentage of increment in cubic contents, b the percentage of increment in quality or market value, and c the percentage of rise or fall in the local market value for timber of similar dimensions—this total increase in value within any given time will be

$$F_m\left(\frac{a+b+c}{100}\right)$$

But it is evident that the difference between the net value of the crop now and n years hence must be compared, not only with the present net value of the crop, but also with the total capital employed in its production. Hence the following proportion is established :—

$$(F_m + L + G) : F_m \left(\frac{a+b+c}{100}\right) = 100 : p$$

$$\therefore p = \frac{F_m}{F_m + L + G}(a+b+c).$$

To simplify the calculation of a, the yield or cubic contents y, which becomes Y in n years, is reckoned (see also p. 322) as being expressed in percentage of the mean quantity $\frac{Y+y}{2}$ at the middle of the period n; hence $\frac{Y+y}{2} : Y - y = 100 : a \times n \therefore a = \frac{200}{n}\left(\frac{Y-y}{Y+y}\right)$.

The percentage of increment in quality, b, arising through the increase in the technical value of the crop as it increases in dimensions, and consequently in the market price per cubic foot, is also calculated in the same manner, hence $b = \frac{200}{n}\left(\frac{Q-q}{Q+q}\right)$ where q is the value per cubic foot of the present crop, and Q the value of the wood of a crop n years older. So, too, with regard to c, the percentage of rise or fall in the local market value of wood of the given kind and dimensions, for $c = \frac{200}{n}\left(\frac{V-v}{V+v}\right)$, where v represents its present value per cubic foot, and V its value n years hence.

The history of past and present prices shows that c will usually be a *plus* quantity; but, under certain circumstances, it can be a *minus* quantity by which $a + b$ will have to be reduced in finding the *indicating percentage.* Anything that will increase the local demand for timber, or that will enable the wood from a particular estate to be put more cheaply on the market than formerly (*e.g.*, opening out roads, railways, &c.), will tend to raise the percentage of value in timber; while any fall in the demand or abnormal increase in the supply (*e.g.*, through extensive windfall, as in November 1893 in parts of the Scottish Highlands) will of course lower the percentage. If the existing balance of demand and supply be disturbed by the local markets being temporarily glutted, as after the storms of 1893, c may then be so much of a *minus* quantity as to outweigh both $a + b$ in the reckoning; yet common-sense will indicate, more plainly than any *indicating percentage* reckoned out scientifically, that it would be folly to fell the crop in the meantime unless absolutely forced by other reasons to do so. And in any case a, the growth in mass or cubic contents, is what can be estimated with the closest approach to accuracy, hence it is the chief factor for practical purposes. If a crop approaching maturity shows a present annual rate of growth of 1·25 per cent of its cubic contents, then it is not likely that this rate will sink suddenly (except in case of accidents, like heavy windfall or snow-break, insects, &c.) during the next 5 to 10 years.

But Pressler's simplification of the formula for finding the indicating percentage may in turn be very much simplified and made far more suitable for practical use. Applying the same method as above used for determining a, b, and c, the whole crop or fall may at once be reckoned with, when

$$p = \frac{F_{m+n} - F_m}{F_{m+n} + F_m} \times \frac{200}{n}.$$

Here a is the main factor taken into account; and as long as it does not extend to large differences, it affords a good practical means of determining, for short periods of 5 or 10 years, whether any particular crop is financially mature or not.

Applying this rough-and-ready practical method to the example given on the opposite page, we have

$$\frac{F_{90} - F_{80}}{F_{90} + F_{80}} \times \frac{200}{10} = \frac{400-300}{400+300} \times \frac{200}{10} = \frac{100 \times 200}{700 \times 10} = \frac{20{,}000}{7000} = 2{\cdot}85 \text{ per cent},$$

and this is just a little in excess of what the more intricate original formula gave as the *indicating percentage.*

The practical use of the *indicating percentage* may advantageously be confined to typical crops, so that at any rate the general tendency in the management of the forests should be in the financial direction indicated by it. And this method of reckoning can be applied not only to whole crops of highwoods, but also to individual age-classes, such as old standard trees in copse or the older classes of trees in woods treated by selection fellings.

Again, its use can be applied either to determine the financial maturity of a single crop—*i.e.*, the most profitable time for felling it, or else in comparing several crops with regard to the most profitable time for bringing them severally to the fall. In the former case the calculation is made for different periods, and the financial maturity of the crop will be when the *indicating percentage* is equal to the rate of interest at which the woods are supposed to be worked. But, in the latter case, the calculation is made for different crops, n being the same in each case (and usually 5 or 10 years), and those should first be harvested for which the *indicating percentage* is least.

7. Subdivision of the Woodlands into Working-Circles and Compartments.—Throughout Britain the woodlands are usually scattered about different parts of estates in groups or blocks of varying size, and generally bearing distinct local names. And when these blocks are of any considerable size, different parts of them have also their special names. For general purposes these blocks and local subdivisions are very useful, but the scheme of forest management can rarely be made to depend entirely on them, though they should of course be utilised so far as is practicable. Again, many large properties consist of two or more separate estates, for each of which separate estate accounts are kept; while a block system of working is applied to the management of the whole property, or of each of the different estates forming it. Hence the use of the term "block" with regard to British forestry might probably be rather confusing, if it were intended to convey any other idea than merely that implied in the common expression of such and such woods "forming a block," or of one of them being "in a block by itself."

There must, however, be some sort of definite unit recognised in order that any scheme of management may be properly framed, and subsequently carried out as intended; and this is found in the subdivison of the whole of the woodlands into **compartments** or **units of area** (though not necessarily of equal area) for purposes of management, supervision, and ordinary work in the woods.

Working-Circles.—The scheme of management or working-plan may, and usually will, apply to all the woods owned by one proprietor that are situated in the same part of the country and are under one administration. It may therefore apply either to a whole property or merely to one or more of the separate estates forming a large property. But, on nearly all large properties, the woodlands in different portions will show such variations in kind of crop, rotation, method of treatment, and special objects of management, that they may have to be divided into *working-circles*, each of which will comprise within itself the whole of the regular series of *annual* (*or periodic*) *falls* of the woods, subject to the same details of treatment, and forming a complete self-contained series of crops. It stands to reason that such provisions of a working-plan as apply to highwoods cannot also be applied to copse or coppice; and it is equally clear that the details of management recommended for Beech-woods worked under a rotation of 120 years with natural regeneration must differ very materially from those suitable to the proper treatment of pure or mixed conifer crops intended to be cleared completely and replanted every 60 to 70 or 80 years. Again, on the great majority of British estates there are almost sure to be parts of the wooded tracts which the owner desires to exclude from commercial treatment, as, for example, the woods near the mansion-house, those specially regarded as game-coverts, woods having special value for shelter, or woods on very steep rocky localities or exposed situations. Such areas, however, even though excluded from intensive economic treatment, can easily be included within the scheme of management so as to form a separate working-circle to be treated by *casual or sporadic* (*selection*) *fellings* in such manner as may best meet the object in view of the proprietor. The annual fall has to be calculated separately for each working-circle, and all the data requisite for this purpose must be collected and tabulated separately.

Compartments.—As the compartments are the permanent framework upon which the scheme of management has to be built up now, and upon which it will continue to rest in the future, the subdivision of the woodlands into compartments of suitable size for convenient working is the first step which requires to be taken. Wherever it is apparent that different working-circles will have to be formed, the endeavour should be made to accommodate the boundaries of the compartments to the boundaries of the working-circles. It is therefore necessary, before dividing the whole area into compartments, to consider the various local circumstances first of all, and to make some sort of rough sketch of the general scheme of management; because on this the formation of working-circles will depend, and the boundaries of these often determine the position of the boundaries of compartments and the position of the main lines of transport, the broad green lanes, and the narrow rides necessary for general working and management, as well as for sport. It is, however, of far more importance to obtain good serviceable boundaries for compartments—*the permanent subdivisions of the woodlands*—than that these should be made to deviate from the best lines merely in order not to include within them portions of crops varying in one way or another from those growing within the rest of the compartment.

The objects and advantages of forming compartments are obvious. They enable all parts of the woods to be accurately described and shown on the map, while any particular locality can easily be found, both in the forest and on the map; and this is important, not only for the general management, but also for those having work or business of any sort in the woods—*e.g.*, timber-merchants. They simplify the location, the measurement, and the revision of the annual or periodic falls, as the boundaries are formed by roads, green lanes, or rides. For the same reason they open up the woods and make the extraction of timber easier. Wherever roads or green lanes form the boundaries, the outer edge of the crop becomes firmly rooted and capable of resisting high winds if the crops to the windward of them have to be felled. The roads, green lanes, and drives forming the boundaries often of themselves prevent the spreading of ground fires, while they always form convenient bases from which measures can be taken to extinguish fire that has broken out inside the compartment. And lastly, they are very useful for sporting purposes, the green lanes and rides being necessary, indeed, for battue-shooting.

As the compartments are intended to be of a permanent nature, care should be taken in forming them that they may each, so far as may be practicable, consist of land of about the same quality, so that, although actual differences should happen to exist as to the present crop on the ground, the future crops throughout all the compartments may consist of one and the same class of wood subjected to the same method of treatment—that it will, in fact, all form part of one working-circle.

In hilly country the boundaries of the compartments must, to a certain extent, follow natural lines formed by ridges and valleys. But the subdivision into compartments should likewise take into consideration the existing system of roads or any new network that is being projected, and should also be based on this, as the roads are of course of great importance with regard to the easy extraction of wood on timber-carts. Hence the roads and the natural features of the woodland tracts are the main factors in determining the boundaries of compartments, and also their size; and it is of far more importance that the formation of the compartments (these being permanent in their nature) should take place in such manner as may be of most advantage for future management than that they should prejudice this by trying to follow the boundaries of different crops which now happen to be on the ground. So far as necessary, with regard to the boundaries of working-circles, the limits of growing crops (*e.g.*, highwoods of Beech and conifer crops) will be followed in making the compartments; but mere want of uniformity in the kind or age of the existing crops (*e.g.*, highwoods of Oak or Beech, Larch or Pine) would be no sufficient reason for making the different compartments vary greatly from what would otherwise seem the most desirable shape and size to give them.

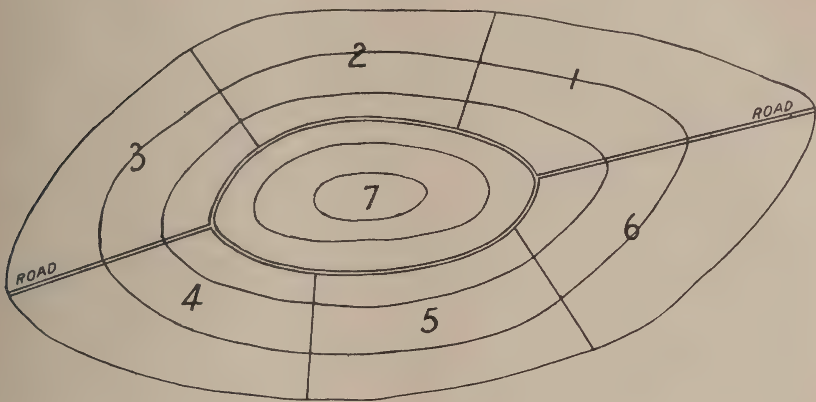
Where such differences of crop, as to kind, age, or method of treatment, are very marked, they can be met by the temporary formation of *sub-compartments;* but the idea to be kept in view is that such differences will be ultimately made to disappear, if possible, so that the whole of each compartment will, in course of time, be stocked with woods of the same kind, belonging to the same working-circle, subjected to the same treatment, and differing from each other in age only by the number of years corresponding with the regular series of falls coming into operation in this particular compartment. It is therefore desirable that the compartments or units of area for management, supervision, and ordinary forest work should have suitable boundaries, easy to describe and to ascertain, that they should be of the size most convenient for the given conditions of the woodlands, and that their boundaries should be permanently demarcated and easily traceable. So far as possible, boundary lines forming acute angles should be avoided, a rectangular shape being most advantageous for the extraction of timber, &c.

Both the shape and the size of the compartments are, however, to a considerable extent determined by the nature as well as the extent of the woodlands, the ruling principles in the matter being modified in practice according as the woods are on comparatively level, hilly, or mountainous tracts. On level land and gentle slopes artificial boundaries may with advantage be adopted, while in hill tracts and mountain ranges the lines of demarcation must always be mainly determined by natural features.

On level ground and gently sloping land the compartments can be laid down with artificial boundaries either in the form of squares or of rectangles, having sides in the proportion of 2 to 1 or 3 to 2 (see Figs. 195 to 197). Squares, being more compact, have less area taken up by green lanes and rides, but the mean distance for extracting the wood is greatest in them; hence rectangular compartments are best, and even in hilly country this shape should be adopted so far as practicable. If the long side of the rectangle be placed at right angles to the direction of the most dangerous wind prevailing locally, this will assist in natural regeneration, and will afford most protection in exposed localities to young seedling crops or plantations when the annual falls take place in narrow strips; while, if the narrow side be made to face the prevailing wind, the timber can then more easily be extracted to the main roads, because the annual falls being always made in the direction opposite to that of the prevailing dangerous wind, and the main roads and green lanes also following the same direction, the narrow sides will run at right angles to these.

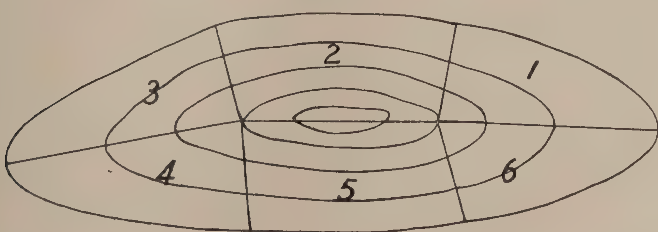
In hilly or mountainous tracts any such stencil-like arrangement of compartments is of course out of the question. The conditions as to soil and situation,

Fig. 190.



dangerous winds, and consequent method of treatment and allocation of the annual or periodic falls, vary so frequently and so essentially within short distances that any such artificial method would only soon lead to disastrous results. But, so far as is practicable, an endeavour should be made to give the compartments a convenient rectangular or trapezoid form by means of natural boundaries, such as valleys, streams, ridges, by existing roads, or by lines cut through the woods. Exposed hill-tops must, if of sufficient extent, be placed in a compartment by themselves—to be worked by casual (selection) fellings if they cannot be treated

Fig. 191.



as an ordinary part of the working-circle to which the adjacent compartments belong—by means of a horizontal boundary, unless some existing road can be used for the purpose (Fig. 190). And, in the same way, plateaux requiring different treatment from the surrounding compartments must also be separated by horizontal boundaries for special treatment; while on extensive plateaux several regular (artificial) compartments can easily be made if necessary. Long narrow hills, if not too steep, can best be divided by means of a main line following the ridge, from which lines are laid down projecting slopes so as best to differentiate between the usually marked variations in the quality of soil and situation (Fig. 191).

The hillsides themselves are next divided into compartments of convenient size and shape by means of lines following the spurs, or sometimes the chines and brooks, towards the base of the hill, where the main roads, streams, or other lines of transport lie, to which the timber has to be brought out. As the wind follows the course of the valleys and the annual falls proceed in the opposite direction to that, and therefore at right angles to the sole of the valley, these boundary lines are not only of use in extracting timber, but also afford convenient points for ensuring that the series of falls can take place in regular succession.

Size of Compartments.—So far as the size of compartments is concerned, it has in the great Continental forests been found that compartments varying (according to circumstances) from 25 to 50 acres form the most convenient area to deal with. Where artificial boundaries can be laid down, as on flat tracts and gentle slopes, a very convenient size for general purposes of management on large estates is 30 chains (660 yards) by 15 chains (330 yards), giving an area of 45 acres. Of course, the larger the compartment, the less is the proportion of the total area left unproductive as roads and green rides. But their size must, to a very great extent, be regulated by the total area of the woodlands; by the manner in which the woods are scattered in groups or blocks over the property; by the configuration of the soil; by the nature of the crops and the specific system under which they are managed; and, more especially, by the size of the working-circle to which they belong.

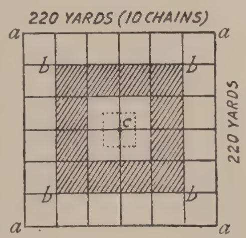
In extensive compact woods the compartments will of course be larger than when the crops are in scattered patches; they will be larger in woods regenerated naturally than in small woods that are clear-felled and replanted; they will be larger in tracts easy to work than on winding hillsides where the quality of the soil is variable; they may be larger in broad-leaved woods generally than in conifer woods, where danger from windfall, insects, and fire is greatest; and they may be larger for copse and coppice than for highwoods, unless managed by casual (selection) fellings.

In short, the compartments can be largest in woods that permit of large annual falls being made, or in several annual falls being combined to form periodic falls. As the compartments are intended to consist ultimately, if that be possible, of crops of one kind, under similar treatment and not differing much in age, it is desirable that all the latter should be capable of being regenerated, or replanted within a period of twenty years from the oldest portion of the compartment being felled. The smallest compartments in highwoods or large estates on the Continent are those stocked with Spruce, and therefore most exposed to damage from windfall and insects. Here small compartments of about 25 to 30 acres have been found best, the felling taking place (when the crops are mature) at intervals of 5 years (on account of beetles), with annual falls of about $6\frac{1}{4}$ to $7\frac{1}{2}$ acres each, so that the harvesting and replanting may be completed within 20 years (falls in 1, 6, 11, 16, and 21 years).

In British Woodlands it will often be most convenient, having special regard to battue-shooting as well as to felling, extraction, and replanting, to make 10-acre compartments with sides of 220 yards (10 chains), or in very extensive woodlands to make compartments of 20, 30, or 40 acres each, divided into two, three, or four sub-compartments of 10 acres each. In this case the central point (Fig. 192, *c*) is 110 yards from each edge, and the *average* dragging-distance for thinnings and mature timber is reduced to $18\frac{1}{3}$ yards over $\frac{20}{36}$ or $\frac{5}{9}$ of the whole area (a, a), while it is only 55 yards over other $\frac{12}{36}$ or $\frac{1}{3}$ of the whole (b, b), and about $91\frac{2}{3}$ yards on the average from the central part (c) forming the remaining $\frac{4}{36}$ or $\frac{1}{9}$ of the area.

Breadth of Compartments.—As soon as the boundaries of compartments have been fixed, lines have to be cleared along them so as to form a network of green lanes and narrow rides. These are in any case required for management and supervision, and are often extremely useful for the storing and extraction of timber, for protection against fire, for battue-shooting, &c. So far as they merely serve as boundaries, narrow rides of about 6 to 8 ft. in breadth in copse and coppice, or 8 to 12 or 14 ft. in highwoods, are amply sufficient; but where they are intended to serve the purpose of dividing two series of falls, and to be used as roads for the extraction of long timber, they must be roadways or green lanes having a breadth of from about 18 to 30 ft., so that the edges of the adjoining compartment thus exposed to the wind may become firmly rooted and capable of resisting storms. They require to be broadest in conifer crops where there is danger either from windfall, as in Spruce-woods, or of fires spreading over large areas, as in Pine-woods. In all exposed situations and in middle-aged and older conifer crops, where the opening up of broad green lanes would be dangerous, only narrow lines are cleared and temporarily demarcated until the woods come to the fall; but in broad-leaved crops in sheltered localities the opening up of green lanes at once is not so hazardous an operation. It is safest of all in thickets, however, where the broad lines should be cleared at once to their full breadth. The main roadways or the broad green lanes or drives which are required as the boundaries of working-circles and of different series of falls should run in the same direction as the annual falls, that is to say, to windward—*i.e.*, in the opposite direction to that of the prevailing dangerous winds (hence usually from E. to W., or N.E. to S.W.), unless the configuration of the ground necessitates some other direction.

Fig. 192.



The narrow rides forming the remaining boundaries of the compartments are, from the manner in which they are selected, necessarily more or less at right angles to the broad green lanes and main roadways, and to the windward direction in which the annual falls proceed. They are parallel to the annual falls themselves, and form boundaries for a series of falls or resting-points for part of a series. They are bases from which the annual falls can be laid out, and need not be broader than is necessary for merely marking off the boundary of the compartment.

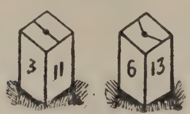
"The width of cross rides at the time of planting need not be more than 12 ft., while main rides should have a width of 24 ft., so that sun and air may keep them dry and well covered with grass or heather, as the case may be, which aids considerably in bearing up wheeled traffic, and that width avoids the necessity of its being kept in the same track in wet weather.

"On wet or swampy ground rides should follow the line of main drains as much as possible, both in order to keep them dry and to avoid unnecessary crossing or bridging. In large plantations the ultimate formation of roads on the main rides will probably have to be undertaken, and care should be taken to lay them out on the firmest ground possible, even if their regular distribution should be interfered with thereby. The difficulty of removing heavy timber from wet woods is a serious obstacle to good prices being obtained, and every means should be employed to facilitate the formation and maintenance of serviceable roads and rides as much as possible.

"On undulating or hilly ground the laying out of rides is a more complicated affair, and must be carried out according to circumstances. They should follow the easiest lines from the high to the low ground or the adjoining highroads by which the timber must be removed, avoiding steep gradients and steep side slopes as much as possible. As a general rule all main rides or roads must be laid out along or near the bottoms of valleys into which the timber can be dragged or rolled from the slopes above. Lines which avoid the necessity for bridging rivers and ravines as much as possible should also be selected. As dragging must be largely employed in the removal of timber from hilly ground, the laying out of many side rides or tracks may be deferred until the necessity for them arises, and only the main rides should be studied at the time of planting."—(A. C. Forbes, *The Adaptation of Land for Afforestation*, Prize Essay of Carpenters' Coy., 1904, p. 42.)

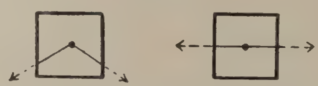
Demarcation of Compartments.—The boundaries of compartments should also at once be permanently demarcated with squared stones projecting about a foot above the ground, and so placed that they can be easily found when hidden by young thickets, windfall wood, or the like; and the sides of each stone may bear the numbers of the compartments which they face. Where the boundaries are formed by long lines, one or more intermediate stones will have to be placed at convenient distances, or where an angle is formed by a change in the direction of the line; and in such cases it will be useful to show on the flat head of the stone the direction taken by the line, thus—

Fig. 193.



Numbered boundary stones.

Fig. 194.



Heads of stones showing direction of boundary lines.

To obviate damage to such boundary marks while timber is being carted away, the stones should always be systematically erected at one particular side of the boundary lines. Thus, in Saxony they are always placed on the east side of narrow rides, and on the north side of broad green lanes. They are more easily found when one knows on which side to look for them.

Numbering of Compartments.—The compartments should receive specific numbers (1, 2, 3, &c.), which should run serially throughout all the woods included under the scheme of management. They should not be confined to one series for each working-circle, as this might easily create confusion. It is more convenient if the series of numbers is continuous, so that each compartment may be contiguous to the compartments respectively bearing the next lower and the next higher number.

In Saxony, the system at present in force is to make the numbers run in such a manner (usually from E. to W.) as to indicate at once the direction in which the falls proceed. But this method has the very obvious disadvantage that buyers of timber at auctions, cartmen working out timber, and others who have business in the woods, have difficulty in finding the compartments they may be looking for. They naturally expect to find compartment 14 next to compartment 13, whereas under the existing system of numeration it may perhaps be in quite a different direction and next to compartment 1. So great has this inconvenience been found in practice that the introduction of the system of regular succession of numbers for adjoining compartments is now under consideration for all the State forests.

If the woods happen to be grouped together in blocks having local names, this will be of use in giving a general indication as to the locality in which special compartments lie—*e.g.*, "Blackmoor Wood, Compartment 9."

The simplest and one of the best methods of **marking compartments** in the woods is to paint with white oil-paint small patches of about 6 in. square on corner stems at about 10 or 12 ft. above the ground, and to stencil the serial number of the compartment on this with black paint. Where the woods are too young for this simple method to be adopted, then corner-posts have to be erected and similarly marked, or small boards bearing the numbers have to be nailed on to them. By these means one's position in the forest can easily be located on the map, or any given point can be found in the woods.

As has previously been remarked, each **working-circle** dealt with in a scheme of management consists of a regular self-contained series of annual (or periodic) falls, upon which there now are, or there ultimately will be, a regular gradation of age-classes of woods formed of crops subjected to the same details of treatment. And for each such working-circle or unified independent series of woodland crops the rotation must of course be fixed before the annual yield (*i.e.*, the area of each of the annual or periodic falls), and consequently the number of the age-classes, can be arranged. To be of normal condition, each working-circle should have, for the given rotation with which it is to be worked, a regular series of age-classes on equal (*i.e.*, equally productive) areas, with normal density of crop and normal increment; while the annual (or periodic) falls should be so distributed as to lie in the proper direction of the fall (which proceeds in the opposite direction to that of the prevailing dangerous winds—*i.e.*, usually from E. to W., or N.E. to S.W.). It is not necessary that the falls should all lie close together; but the various groups formed of compartments belonging to the same working-circle should be as near each other as is practicable.

Anything like this normal condition of working-circles can hardly possibly be found (except, perhaps, for coppices in some few cases) when a scheme of management is first being drawn up; and further, it is the ideal standard which it would be almost impossible to maintain for any length of time. In many cases, in Britain, it may be advisable to discard any idea of making working-circles on any greater differentiation than merely that of similar method of treatment and the same period of rotation. If it were possible on any estate, it would always be best to try and have merely one working-circle; but this is seldom practicable. Highwoods, copse, and simple coppice will, of course, each have to form separate working-circles, the two latter being worked by whatever mean rotation seems most profitable under the given local conditions; but broad-leaved highwoods and conifer crops will, in the vast majority of cases, simply have to be grouped together so as to form two main working-circles, for each of which the most advantageous rotation and the other details of management will have to be thought out and arranged so as best to meet the wishes of the owner and the requirements of the principal broad-leaved tree or ruling species (*e.g.*, Beech on chalk lands, and elsewhere Oak generally), or of the most important among the conifers (usually Larch or Pine at present). It is not the least of the advantages of mixed forests that they tend to reduce the number of working-circles necessary on large wooded estates; and the more the *mixed woods* system of treatment is developed, the greater is the chance of simplicity being attained in a good sound scheme of management. And, in the great majority of cases, attempts to imitate such intricate methods of arrangement and frequent divisions of total area into numerous working-circles as are often found on the Continent, and in Germany in particular, would be entirely out of place in Britain, even if for no other than the very simple reason that those in charge of woodlands have usually as yet had little experience in forestry carried out on exact commercial principles and in accordance with the details laid down in a working-plan that has been drawn up by a specialist and approved by the landowner. Besides that, a scheme of management for an estate having large woods will be all the easier to arrange, as well as to carry out, if the number of working-circles be kept as low as possible; because for each different working-circle it is necessary to make separate estimates as to crops, rate of growth, rotation, and sustained annual yield.

The size of a working-circle must depend entirely on the given circumstances of each particular case. Its maximum is determined by the total area which can be managed on one system, while its minimum depends on the annual (or periodic) falls for the given treatment and rotation being practicable areas, because it would be absurd to try and work with any system which would only give ridiculously small annual falls (see p. 259, *footnote*). Coppice and copse can be managed with far smaller working-circles than highwoods; and highwoods in which several annual falls can be grouped into periodic falls (as in Beech-woods) can be worked with a smaller total area than crops that are clear-felled when mature. And the higher the rotation, of course, the greater the total area required.

Even where there may not be more than one working-circle for highwoods on any large estates, it will seldom occur that the age-classes happen to be anything like already so well distributed as at once to yield falls of about equal amount year by year; and if there should be two or more working-circles, it can all the less be expected that the normal capital in growing-stock will ever be found properly adjusted. The extreme case may even occur that all the crops in a working-circle for conifers are immature, while those in a working-circle for broad-leaved highwoods consist for the most part of old woods already mature or approaching maturity, or perhaps even over-mature. In either case, a surplus of old woods in one circle, though they may not be of the same kind of crop, can, as a stop-gap, be drawn upon to supplement a deficit in those of the other and equalise the annual income, for the yearly falls of each working-circle must of course be calculated independently of those of the other circle or circles.

8. **Allocation of the Annual Falls.**—The working-circles having been formed, the whole woodland area having been divided into demarcated compartments, the crop measurements and estimates having been made and tabulated (according to the methods that will subsequently be described in chapters ii. and iii.), and the area of the annual falls having been ascertained

through the rotation fixed on, it is then necessary to consider how the annual falls should be allocated. Everything that interferes with the well-being of the crops and the productivity of the soil must tend to prevent the attainment of the *normal condition* of the woods to which it is intended to approximate as closely as may prove practicable.

All kinds of woodland crops are exposed to dangers of one sort or another (highwoods, copse, and coppice; some more, some less), such as frost, drought, fire, windfall, snowbreak, insects, and fungous diseases, which may be called their natural dangers, leaving out of consideration the rabbit, which is often permitted to render profitable working of woodlands in Britain impossible. In most localities the greatest and most serious of all these natural dangers is **wind**; hence it is usually desirable that the succession of falls shall be so arranged that they should proceed against the wind—*i.e., in the direction opposite to that of the prevailing most dangerous winds.* The course of the latter is greatly influenced by local circumstances, such as the trend of valleys and the configuration and position of neighbouring hillsides; but in the great majority of cases the heaviest storms and most dangerous winds throughout the greater part of Britain come either from the W. or S.W.; and in this case the course of the annual falls should be from E. to W., or N.E. to S.W., so that the exposed edges of the various crops, and especially of the older ones, should be firmly rooted and able to withstand the pressure of strong winds after heavy rainfall (see Fig. 188, p. 225). Making the annual falls proceed in the direction opposite to that of the prevailing dangerous wind is the best means of preventing windfall; while it has the additional advantage of being the best means of protecting the soil against deterioration. And that, by this arrangement, a very considerable degree of safety can be achieved is shown in the great Spruce forests on the Continent. The *necessity* for making the annual falls advance against wind is greatest in conifer crops; but it is also best for broad-leaved highwood crops, as it assists greatly in natural regeneration if the young woods lie in the shelter of the old woods, from which seeds are blown across to the area under regeneration.

Even though it should happen that the whole of any given working-circle lies in one compact mass of woodlands, in place of being grouped together in several scattered blocks, it is neither necessary nor from any point of view desirable—except as regards copse and coppice, and broad-leaved crops worked with periodic falls and natural regeneration, where fall can follow fall without danger—that the annual or periodic falls should form any continuous series (Fig. 188, *a* and *b*, p. 225). Experience, often dearly bought, in various parts of Germany has shown that, so far as Pine and Spruce forests are concerned, if the annual falls are of considerable extent, each of them should be subdivided and distributed so as to be carried out simultaneously in different compartments, and in such a way that the successive falls of timber are only made intermittently in each compartment at regular intervals (as in Fig. 188, *c*). This has been found to afford the best security that is practicable against danger from fire, insects, and wind; and in Saxony, where this system of subdividing the whole of the main series of annual falls into numerous series of regular but intermittent falls (**Felling-Series**) distributed over different parts of the working-circle has been carried out very completely, it is customary in the Pine and Spruce forests to make two successive falls in one compartment succeed each other only at intervals of 5 years or more, on account of danger from insects (weevils and cockchafers in particular). And it is being strongly advocated there that it would be better, for other reasons connected with replanting, to double the number of felling-series and make only one fall every 10 years in each compartment. The object of this is that the next fall in the same compartment should not take place until replanting has proved completely successful on the adjacent area, where the last felling was made.

In place, therefore, of making merely one large compact fall each year, it is best to subdivide the total area forming the annual fall in conifer high-woods into various subordinate series of small or partial falls, and to distribute these throughout different compartments in which the next fellings will only be made after some definite number of years. Each of these series of intermittent falls forms an independent component part of the working-circle. As each such felling-series has to be carried out in the same direction as the general course of the annual falls for the whole working-circle (i.e., *in the direction opposite to that of the most dangerous wind*), each compartment will in course of time form a separate compact group or series of small crops belonging to definite age-classes, differing from each other in age by the number of years that have elapsed between each of the successive intermittent falls (see Fig. 188 *c*, p. 225).

While these various felling-series have each, like the working-circle, a regular gradation of age-classes, they differ from it in that it is unnecessary for each of them to comprise all the age-classes from the seedling to the mature crop. It is only essential that within the compartments thus contributing to make up the total annual fall for the year the fellings should take place at suitable and regular intervals, so as to effect a regular gradation of age-classes, and that the falls should be made in the direction contrary to that of the prevailing dangerous wind.

If the working-circle is so large that the total annual fall cannot be met by the fall made in one place merely, then each felling-series can be made to comprise several groups of compartments in different parts of the working-circle in place of merely being confined to one, two, or three compartments in one locality. That is to say, while the series remains intact, each of the regular falls occurring intermittently in it can be multiplied and distributed over several compartments (well apart from each other) if the total annual fall required is too large to be met by the fall permissible in one compartment. This is, of course, practically the same as increasing the number of felling-series, and allotting two or more (in place of merely one) to the different intermittent series (1, 6, 11, &c., or 1, 11, 21, &c.)

Say, that in mixed Pine and Spruce woods worked with a rotation of 80 years it is not advisable that the falls should be repeated in any compartment oftener than once in 10 years on account of the growth of the young plantations being so slow at first that it takes this time for them to outgrow the danger from weevils, then, in place of having one simple series of contiguous annual falls, there will have to be at least eight intermittent series in each of which the falls are made only every tenth year, and the age-classes within each compartment would ultimately show differences of 10 years, as is essential for the attainment of the "normal condition" towards which it is the object of the management to approximate.

These felling-series need not be specially indicated either on the map or in the woods; but in the working-plan it must be particularly mentioned what compartment or compartments belong to the first series, what to the second, and so on.

The number of compartments over which the various series of falls require to be made in order to yield the total fall for the year depends not only on the size of the latter, of course, but also on the given circumstances of soil, configuration, and crop within the compartments, and on the size of these. Only local conditions can determine this in each given case. But in general, in drawing up a scheme of management, the actual fellings are forecast only for the next 10 or 20 years, so as to be confined to the crops that are either approaching or have already reached, or perhaps even passed, their financial maturity, or which may require to be felled for other reasons. Difficult, broken, hilly ground requires the total fall to be split up into numerous subordinate, but otherwise independent, series of complementary falls, so that each of these often consists of only 1 compartment, or of 2 or 3 compartments at most, as in Saxony, or of from 3 to 5 on the average, as in other parts of Germany. The greater the local danger from wind or fire, the more it is desirable to split up the total annual fall into numerous smaller falls, the only limit to this subdivision being that such complementary falls shall not form ridiculously small areas, but must be of sufficient size to be worked properly.[1] Subject to this limit, the size of the falls must be arranged according to the given conditions of soil, situation, and crops. Marked differences in these can best be dealt with by small falls (*e.g.*, as on the summits and plateaux of hills, unless these require to be specially treated by casual [selection] fellings), so that future operations are simplified, while the dangers to which conifer crops are especially exposed are reduced to a minimum; because the practical effect of small falls is that ultimately there will be no large compact areas covered with crops of one age, such as are most exposed to attacks from insects at all times, to epidemics of fungous disease, to damage from fire when young, and to windfall and snowbreak when old.

The essential point is that each felling-series shall permit of the annual falls being made once *in their full breadth*, either in simple regular sucession (1, 2, 3, &c.), as may be arranged in coppice, copse, and broad-leaved woods without much danger, or else in such intermittent series (1, 6, 11, &c., or 1, 11, 21, &c.) as may be best for conifer crops. In coppice or copse there may be only the one complete series of 10, 15, or 20 regular falls, and in Beech-woods worked with a rotation of

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[1] Even for very small woodlands an annual fall of less than 2×5 chains (44×110 yards) or $2\frac{1}{2} \times 4$ chains (55×88 yards), equal to 1 acre, will hardly prove workable to much advantage in actual practice.

120 years there need be only 6 regular periodic falls of 20 annual falls each ; but in conifer crops, and especially Pine or Spruce, it will be necessary, for safety, to have as many such intermittent series as local circumstances may recommend. Here again, however, as with regard to forming separate working-circles, judicious mixture of Larch, Pines, and Firs, with or without any broad-leaved trees suitable to the locality, will tend to obviate the necessity for forming a large number of separate felling-series.

Suppose, for example, that it is not advisable to have the annual falls broader than 50 yards, on account of damage from wind, that adjacent falls should only be made once every 8 years to allow the young crops to establish themselves thoroughly and outgrow the main risk of damage from insects, and that the woods are to be worked with a rotation of 80 years—then the *minimum* number of felling-series required will be $\frac{80}{8}=10$, while the *maximum* total linear extent of each of the here necessary 10 series of intermittent falls will be $50 \times 10 = 500$ yards ; and its total area will depend on the length of the compartment or compartments in which the various intermittent falls are periodically made. If the compartments have been made in the shape of rectangles in the proportion of 3 : 2, the longer side being at right angles to the direction of the main wind, then, in the above case, each compartment would require to have an area of 500×750 yards, or about 77½ acres, in order that all the intermittent falls belonging to this particular felling-series could be accommodated within one compartment ; and consequently the total area of the working-circle would, in this case, have to be about 775 acres. But as it is difficult to arrange for compartments of so large a size, it is usual to spread each felling-series over two (in Saxony) or more compartments, whose total area would make up the required 77½ acres. If a normal breadth of only 30 yards were found most suitable with an 80 years' rotation and an intermission of 8 years between adjoining falls as above, then the total linear extent of each felling-series would be $30 \times \frac{80}{8} = 300$ yards ; and, if the compartments were of a roughly rectangular shape, having sides of about 450 and 300 yards, in the proportion of 3 : 2, then the total area of each intermittent felling-series would be about 28 acres, and of the whole working-circle about 280 acres ; and each such series could easily be incorporated in one compartment. Otherwise each felling-series has to be distributed over two or more complementary series to make up the complete annual fall for the whole working-circle.

Lest the preceding may seem to suggest that the size and the number of the subordinate series of falls can in any way affect the area of the working-circle, it must be expressly stated that such is not the case. On the contrary, the total area of each working-circle and the rotation in which it is to be worked mainly determine, along with other local conditions as to soil, situation, and dangers to which crops are exposed, the number of subordinate felling-series required. Now, these are the same factors as had previously to be taken into consideration before dividing the whole woodland area into permanent compartments ; hence they are likewise what really must decide whether each intermittent felling-series can be comprised within one compartment, or may require two or more.

To take a very simple example, let us suppose that a scheme of management has to be drawn up for a working-circle consisting of about 800 acres of conifer-woods in the Scottish Highlands, intended to be worked with a rotation of 80 years, in a district where danger from windfall, insects, fire, or snowbreak—or a combination of any or all of these—is such that (1) the breadth of the falls made in the woods should not exceed 2½ chains (55 yards) ; that (2) it has been decided that a 5 years' interval between each two successive falls in any compartment must be allowed for reproduction, or for young plantations to establish themselves successfully and outgrow risks from weevils ; and further, that (3) the configuration of the ground is such that the compartments have been made of about 40 acres each, in a shape roughly approximating squares, having sides of about 20 chains (440 yards) long and about 20 chains (440 yards) broad. Then (1), the number of compartments included in this working-circle will be $\frac{800}{40}=20$;[1] (2), the number of falls permissible in each separate intermittent felling-series will be $\frac{80}{5}=16$; while the *minimum* number of these felling-series required must be $\frac{80}{16}=5$; and (3) the total extent of each annual fall will be $\frac{800}{80}=10$ acres.

So far it is easy enough, but now practical difficulties come. As the falls may only be $2\frac{1}{2}$ chains (55 yards) broad, the total breadth or depth of each separate intermittent series in the felling direction must be $2\frac{1}{2}\times 16=40$ chains (880 yards), and the area which can be cut once every 5 years, in any one compartment, will be $2\frac{1}{2}\times 20=50$ square chains, or 5 acres. But the whole annual fall required is 10 acres, and this would necessitate the falls being extended to a depth of 40 in place of only 20 chains, so that the complete felling-series would have a frontage of 40 chains in the windward direction, and a total depth or breadth of 40 chains at right angles to this, while the total acreage required would then be $40\times 40=1600$ square chains, or 160 acres—*i.e.*, the total area of four compartments. If, however, four compartments were thus grouped together to form one compact block or series of intermittent falls, this would in part frustrate the very objects with which one had gone to the trouble of making the 40-acre compartments; hence it is preferable to make 10 separate felling-series in place of 5, so that the falls in these need only be made once every 10 years (which will be all the better for the young plantations and the different age-classes) in place of once every 5 years, and to set apart two compartments (or 80 acres) for each of the 10 series of intermittent falls at intervals of 10 years. Each series will now have a linear breadth of $2\frac{1}{2}\times 8=20$ chains (440 yards) or the depth of one compartment, and a windward frontage of 40 chains (880 yards) or two compartments.

This is the method adopted in Saxony; and as the working-plans are there arranged in detail only for periods of 10 years, it enables the various crops to be harvested just when each happens to be about financially mature, as shown by their *indicating percentage* (see p. 244).

In the great Scots Pine tracts of the North German plain, where regular compartments can be easily formed, and where the forests are mostly worked with a rotation of 100 years, divided into 5 periods of 20 years each (those of the I. period, or 80 to 100 years old, being felled within the next 20 years, and so on, down to the crops now of 0-20 years of age, which will not be harvested till the V. period, 80-100 years hence), protection from westerly winds is obtained by a method, known as Reuss's **Stencil Arrangement** (Figs. 195 and 196; proportion of sides 3 : 2), of making every compartment vary by two periods from the adjoining compartment immediately to the windward of it, and by one period from the flank compartment adjoining on the side from which wind is next most to be feared. Clearing the crops in periods and working according to this scheme must in the course of one rotation lead to the normal distribution of age-classes; but it can only be introduced for the first time at a considerable sacrifice in existing crops.

Reuss's arrangement can also easily be utilised to show how the intermittent falls in 5 felling series can be allocated during the I. period of 20 years, so that each fall is allowed 5 years' rest (to enable the young plantations to establish themselves thoroughly

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[1] It is of course self-evident that if falls are allowed to remain unsown or unplanted for 1, 2, or more years in order to avoid danger from weevils in tracts where the stumps cannot be grubbed up and where the annual fall is large, then the area of the latter will be $\frac{\text{whole area of working-circle}}{\text{years in rotation}+\text{years of fallow.}}$ The danger from weevils is best obviated by having numerous small independent felling-series and by burning over the area before replanting.

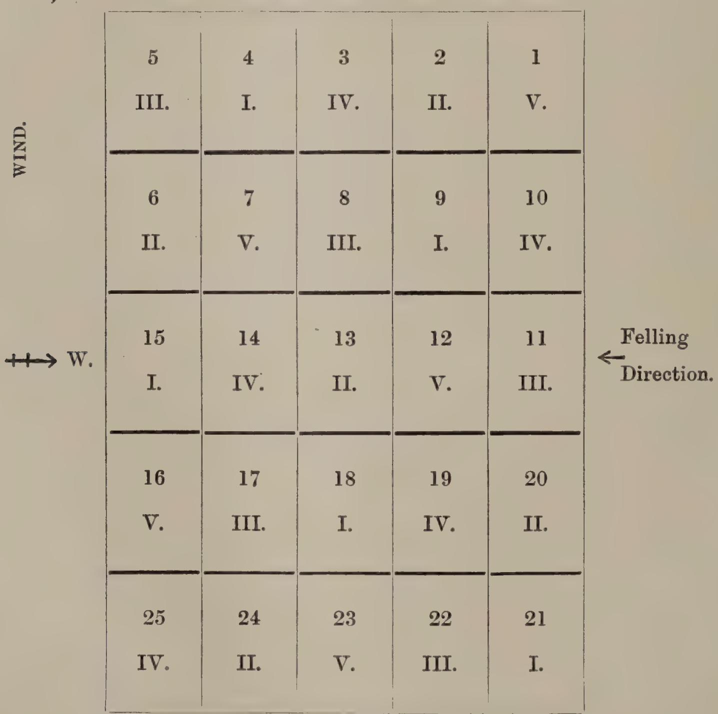
and outgrow danger from weevils and cockchafers) before the adjacent fall takes place (Fig. 197).

It must again be stated that the *necessity* for such intermittent felling-series is practically confined to conifer crops, in which dangers from wind, fire, insects, snowbreak, and fungous diseases are greatest. But as these must form the chief woodland crops capable of being grown for profit in many parts of Great Britain and Ireland, the above subject is here dealt with at greater length than would otherwise have been desirable. And the opportunity may also again be taken of calling attention to the fact that judiciously mixed crops, even if formed almost only of conifers, will contribute considerably to the security of the woods from these various dangers.

Fig. 195.

N.W. Most dangerous wind, W.; next dangerous wind, N.W.

Periods I., II., III., &c. Compartments 1, 2, 3, &c.

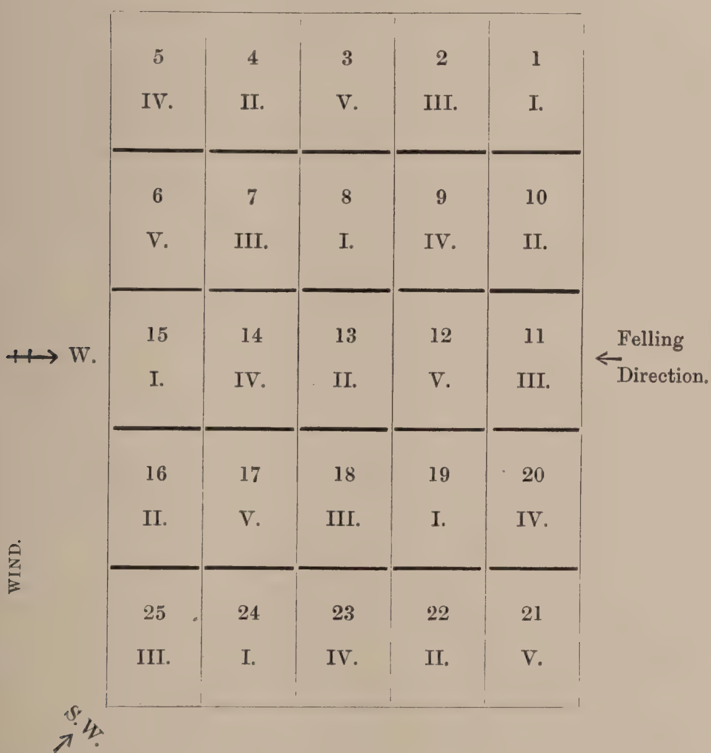


Denzin, in 1880, recommended for forests on the plain, whose compartments are marked off by regular rides or paths crossing each other at right angles, that the apex of the angle, and not, as hitherto had been the rule, the long side of the compartment, should be turned towards the W., so that the rides or divisions between the annual compartments should run from N.E. to S.W., and from N.W. to S.E., in place of from E. to W. and S. to N. In the former case only two sides of the compartment, those towards the W., are endangered, and they can be protected against storms by judicious allocation of the annual falls and arrangement of the crops, while in the latter case there are three sides to protect—namely, on the W., S., and N.

The advantages of having several small separate intermittent felling-series can only be fully attained when each is so shaped and placed that the falls can be conveniently suited to the configuration of the ground and continued in the proper direction against the wind, and when the falls in one series can be made independently of those belonging to any neighbouring series. This necessary measure of independence can only be achieved by safeguarding the edges of the falls, and by ensuring the protection from windfall of the crops lying to the lee of that felled. The edges or ends (N. and S., or N.E. and S.W.) of the falls are protected by the broad green lanes laid out parallel to the direction of the most dangerous wind on level ground, or following the trend of the ridges in hilly tracts, when forming the network of compartments (see p. 251) along the fringes of which the trees become firmly rooted and capable of offering successful resistance to heavy storms coming from either side (N. or S.)

Fig. 196.

Most dangerous wind, W.; next dangerous wind, S.W.
Periods I., II., III., &c. Compartments 1, 2, 3, &c.



If, at the time of a scheme of management coming into operation, the age-classes were distributed in anything like the *normal* manner which the formation of various felling-series aims at establishing, then the falls in each series would simply begin at the narrow rides lying to the lee-side of the one, two, or more compartments forming the series, and would proceed gradually in the windward direction by means of narrow falls made intermittently, and these would at once form permanent felling-series. But, in actual practice, this ideal standard of independent felling-series, with *normal distribution of the age-classes*, can never be found. It must first be created, and this only after at least one full rotation of the crop. In this case, the felling-series would simply be commenced as if the normal condition prevailed, and would be continued regardless of any financial consideration as to whether or not the crops coming to the fall had attained their full maturity. As this would, of course, lead to very substantial loss, it is therefore totally at variance with the principles of commercial forestry. Hence, with regard to a good many of the intermittent felling-series, a temporary or provisional series of falls will have to be made during the first rotation for the purpose of

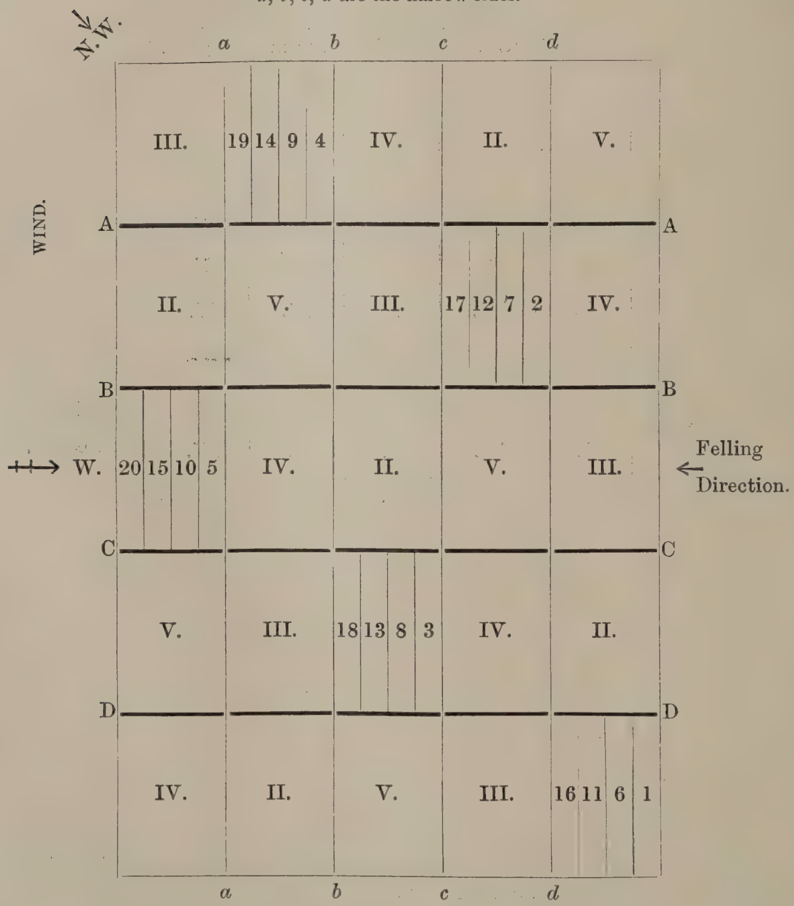
Fig. 197.

Most dangerous wind, W.; next dangerous wind, N.W.

Periods I., II., III., &c. Compartments, or annual falls, 1, 2, 3, &c.

A, B, C, D are the drives, or broad green lanes, or else roadways.

a, *b*, *c*, *d* are the narrow rides.



removing irregularities in the crops with the least possible loss, till more regularity has been attained in the distribution of the age-classes. Temporary modifications of felling-series may likewise, at any time, have to be made wherever or whenever unforeseen disturbances have taken place in the management (*e.g.*, windfalls). The necessary temporary arrangements of this nature can only, however, be forecast when a stock-map has been made showing the present distribution of the different crops on the ground (as will be described in chapter iii.)

In opening out new falls where, for any given reason, a commencement cannot be made at the ride to the lee-side of a compartment, such lines of operation should be selected as will least expose the crops lying behind them to the danger of being thrown by wind on the fall being made (as, for example, ravines on hillsides, or where old crops stand to the windward of young thickets), because, in the general direction of the fall against the wind, protection for crops lying to the leeward can only be found by enabling them to become firmly rooted on the windward side, as takes place naturally when there is a proper alternation in the age-classes.

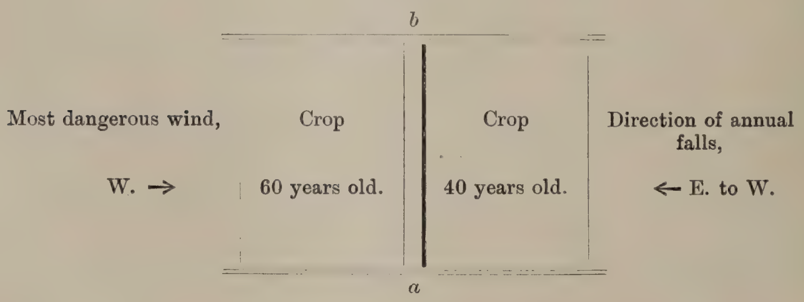
Whether a permanent felling-series has to be begun in large compact woods, all of about the same age, or a temporary felling-series has to be arranged so as to save immature crops in vigorous growth from being felled prematurely, measures will often have to be taken to protect the leeward crops from being thrown by wind on becoming exposed to the violence of storms. Wherever any felling-series has to be begun where there are not already sufficiently broad roads, ravines, or other conditions ensuring a strong development of the root-system, then the protection of the crop to the leeward of this must be ensured by its being cut free by means of a **Protective Fall** or **Severance** (Ger. *Loshieb*). Such protective falls are of course nothing else but a necessary evil, and a temporary substitute for the natural security obtainable by a proper distribution of age-classes. They consist in clearing a strip of about $\frac{1}{2}$ to 1 chain (11 to 22 yards) in breadth in the older crop, in front of the part of the wood that requires protection. In very young woods this may be done in one fall, but in older pole-crops and in exposed situations it is best to make two falls at intervals of 5 or 10 years. Such severances or protective falls are quite unnecessary for copse or coppice, and are only rarely required in broad-leaved highwoods grouped in periodic falls.

Protective Falls or **Severances** should always be made broadest for shallow-rooted Spruce crops, and should then be clear-felled; while for Pine and Larch it may often be sufficient simply to open up the back part of the older crop by a heavy thinning or partial clearance. But it is best to make a clean fall along the strip and then replant all of it except the narrow ride (if the severance takes place along the boundary-line of a compartment), and preferably with some broad-leaved kind of tree—*e.g.*, Birch in Pine-woods. This will utilise the ground and give additional protection. As there is, of course, always a certain element of danger in venturing on such protective falls, they should only be made in places where the risk of windfall is not imminent, and at an age (if possible) when the trees along the edge of the crop to be cut free are still young enough to develop their root-system considerably—*i.e.*, before the crop has cleared itself from branches, as the expansion of the root-system is dependent on the coronal development. And as this condition is again dependent on other factors, such as the soil and the kind of tree, it would be rash to suggest any fixed age as that up to which protective fellings may be made. In most cases they can be successfully made up to about 50 or 60 years of age in the German forests (see also chap. iii. p. 342).

In order to be effective, the severance should take place at least 10 years before the regular fall has to be made in the older crop lying to the windward; but it is all the better if the measure can be carried out about 15 or 20 years in advance. Hence, in drawing up a working-plan which may perhaps only be meant to apply in its exact details for a period of 20 years, the protective falls required to give a freer hand to the management in the succeeding 20 years can usually be foreseen and thus provided for, the severance being made along the lines where the felling-series will then have to begin. It is of course essential that the falls for severance should invariably be made in the older crop to the windward of that to be protected. To cut into the latter—along the edge of a green lane, for example—in a place where the root-systems of the outside trees must already be stronger and better developed than those of the trees 30 or 50 yards inside the woods, would often prove a fatal mistake.

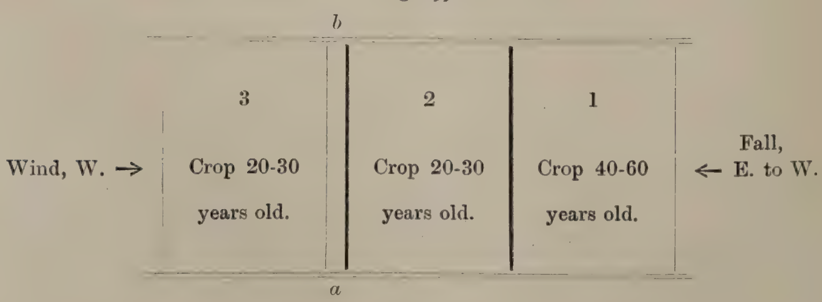
Examples.—(1) A crop of 40 years old (Fig. 198) lies in the lee of a crop 60 years old, which will probably have to be felled about 20 years hence, before the former is mature. For the protection of the 40-year-old crop, when the annual fall cuts into the mature crop (then 80 years old) 20 years hence, the former should now (*immediately*) be cut clear by a protective fall or severance (*a b*) being made to a breadth of ½ a chain to 1 chain in the latter; and this cleared strip should be at once planted up.

Fig. 198.



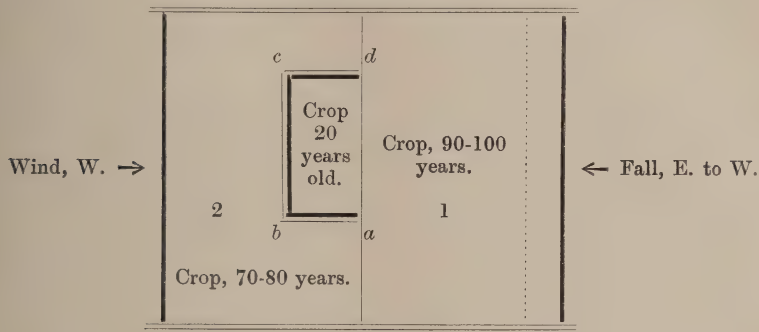
(2) Three adjoining compartments (1, 2, and 3) of a working-circle (Fig. 199) have crops respectively aged 40-60 years (in 1) and 20-30 (in 2 and 3). On account of the felling-series fixed on, and for other reasons, it is desired that fellings should begin in compartment 3 about 30 years hence and before the felling-series carried out in compartment 1 shall have reached the W. end of compartment 2. To protect the windward edge of compartment 2, 30 years hence, the severance fall *a b* should now be made in compartment 3.

Fig. 199.



(3) In two adjoining compartments (1 and 2) belonging to the same felling-series of a working-circle (Fig. 200), the crop in compartment 1 is 90-100 years old and mature, while that in compartment 2 is mostly 70-80 years old, but also comprises a young plantation 20 years old. The felling-series now commencing at the east end of compartment 1 (see dotted line) will reach compartment 2 in about 20 years' time, or long before the plantation is fit for felling. It can be preserved and protected from windfall by now making the protective clearance (*a b c d*) in the old crop to windward of it.

Fig. 200.



9. **Different Methods of Fixing the Annual Fall.**[1]—Even though most of the woodlands in Britain have hitherto not been managed on methodical lines, yet the fellings necessary in copse and coppices must of themselves have almost mechanically produced a more or less regular, though not a *normal*, arrangement of the annual falls. And the same may be said to be the case with regard to the self-sown Beech-woods on the chalk-hills, which have been worked on simple lines for centuries. But it must be different with regard to crops dating from the first third of the nineteenth century, when many landowners (and particularly in the Scottish Highlands) formed large plantations now mature. As these plantations were made on land which had previously been cleared of their original forest covering—mostly of Pine, no doubt, on the hillsides—and as their formation was not regularly spread over a long period of years, so that in course of time there might be something like a rough gradation of age-classes, they may either be treated as separate woods, each to be harvested when financially mature, or else they may be grouped together and worked as a whole. In the former case no particular scheme of management is necessary. Each crop will be felled at what seems to be the most profitable time, or the most convenient time for the owner, as the returns will only come in irregularly. In the latter case, however, if anything like a regularly sustained income is desired, some sort of working-plan, which need not necessarily be of any elaborate nature, is required to ensure this object and to regulate the annual fellings. Such

[1] This word **fall** is the good old English term of forestry dating back for centuries, and it seems in every respect preferable to newly coined words, or French or German terms. A "fall of timber" may be correctly spoken of as being "of so many acres," or as yielding or being of "so many cubic feet (or tons, or loads) of wood."

regulation can be effected by determining the annual fall according to one or other of methods based upon—

(1) *The Woodland Area alone.*
(2) *The Yield or Cubic Contents of the Crops.*
(3) *The Combination of Area and Yield.*

} In each of these three methods the annual falls are grouped into periodic falls of 20 years each, and special attention is paid to the yield during the first period (or during the first 10 years only, as in Saxony).

(4) *The Proportion found to exist between the Actual and the Normal Increment and Growing-Stock in the Woods.*

(1) **Fixing the Annual Fall from the Woodland Area alone.**—This is unquestionably the oldest and the simplest of all the methods of regulating the annual fall in woodlands, and it has the advantages and the disadvantages inherent in a rough-and-ready arrangement. The leading idea in this method is that regularity in the annual fall must be established and maintained if the whole area be divided into as many equal portions as there are years in the rotation, and one such fall be made annually, because a normal distribution of the different age-classes will then be effected in the course of one rotation.

This very simple system has two great disadvantages. If there is not already something like a normal distribution of the various age-classes, considerable loss may be incurred through having to harvest either immature or over-mature crops during the first rotation ; and it does not take into consideration the variations in the fertility of the soil, which are almost certain to be found in woods of any large extent.

This latter drawback can, however, be remedied by estimating, from the growing crops, the quality of each such annual fall, and increasing or reducing its area proportionately. But this method can only be applied in practice when the state of the crops seems to show that marked differences exist as to fertility. Any opinion thus formed should, if possible, be confirmed or modified by ascertaining from the estate books what has been the yield of the different falls in the past, though estate books will seldom be found to furnish exact *data* of this sort, going back accurately for any length of time. Both of these estimates should, indeed, be considered to determine whether or not the variations in the out-turn are due mainly to differences in the quality of the land, or are due to damage by ground game. But, in general, a very fair estimate as to the fertility of the soil can be formed from the nature of the weeds covering the ground in coppice-woods that stand thin on account of rabbits, and the annual falls may be proportionately increased or decreased in area (in the inverse ratio to their fertility), so far as the existing conditions permit of this. But it would be absurd to try and force matters in this direction if, as must usually be the case in British copses and coppices, the areas forming the different annual falls are definitely marked out by consisting of scattered patches or blocks surrounded by fields, &c. In such circumstances the annual falls can often, in actual practice, merely be arranged so as to extend to approximately equal (or equally productive) areas.

If substantial differences in quality appear really to exist, then the proportionate increase or decrease in the area can be made by assessing the fertility of each area (and best according to local average yield tables, if available), reducing the whole tract to one common standard, and then reckoning the proportionate area of each annual fall. Regarding a full yield from a crop on *very good* soil as Class I., the other classes would be

Good II., *Medium* III., *Inferior* IV., and *Very Poor* V., and the corresponding factors for conversion of area would respectively be 1·0, 0·8, 0·6, 0·4, and 0·2 of the highest class, on the supposition that inferior land will only yield one-half the fall obtained from good land, and only 0·4 of that from very good soil.

Example.—Supposing a working-circle of coppice or copse has an area of 100 acres and is worked with a rotation of 10 years, then the annual fall would be $\frac{100}{10}=10$ acres. If, however, differences of quality in the land are so marked that 30 acres are classifiable as Class II., 50 as III., and 20 as IV., yielding respectively only 0·8, 0·6, and 0·4 of what very good Class I. land should yield, and that the owner wishes the annual falls to be made proportionate to the soil and situation, then a conversion would have to take place. Reducing these areas to the "normal" or very best quality of land, they would respectively be equal to $30\times0{\cdot}8=24$, $50\times0{\cdot}6=30$, and $20\times0{\cdot}4=8$ acres of Class I. land, and the whole extent of 100 acres will only yield the out-turn that $24+30+8=62$ acres of Class I. land would produce. Hence the factor of conversion will be $\frac{62\text{ (acres)}}{10\text{ (years)}}=6{\cdot}2$, and the proportionate annual falls will respectively be for land of Class II. $\frac{6\cdot2}{0\cdot8}=7\tfrac{3}{4}$ acres, for Class III. $\frac{6\cdot2}{0\cdot6}=10\tfrac{1}{3}$ acres, and for Class IV. $\frac{6\cdot2}{0\cdot4}=15\tfrac{1}{2}$ acres; while the number of annual falls in each class will be $\frac{30}{7\frac{3}{4}}=4$ for II., $\frac{50}{10\frac{1}{3}}=5$ for III., and $\frac{20}{15\frac{1}{2}}=1$ for III. The 30 acres of Class II. will therefore yield falls for the first four years, the 50 acres of III. for the fifth to ninth years, and the 20 acres of III. will form the fall of the tenth year—or in whatever other order the age of the crops on the land may indicate to be best; and as there is a shortage of $\frac{1}{4}$ or $\frac{1}{3}$ acre in each of the falls from the first to the ninth year, this is, for convenience, thrown into the tenth fall, which consequently exceeds the true proportionate area by just so much.

Or the falls may be worked out in another, but a similar, manner. Say, in the above example, that the estate accounts for the last 10 years show the net income from the 30 acres of the good land II. to have been £4 an acre, from the medium land III. £3, and from the inferior land IV. £2½; then the average net income has been

$$\frac{(30\times4)+(50\times3)+(20\times2\frac{1}{2})}{100}=\frac{320}{100}=£3{\cdot}2,$$

and the converted total proportionate areas would be

$30\times\frac{4}{3\cdot2}=37{\cdot}5$ acres, $50\times\frac{3}{3\cdot2}=46{\cdot}9$ acres, and $20\times\frac{2\cdot5}{3\cdot2}=15{\cdot}6$ acres; while the proportionate conversions of the average fall of $\frac{100}{10}=10$ acres would be $10\left(\frac{3\cdot2}{4}\right)=8$ acres for II., $10\left(\frac{3\cdot2}{3}\right)=10$ acres for III., and $10\left(\frac{3\cdot2}{2\cdot5}\right)=13$ acres for IV., and II. would yield $\frac{30}{8}=3\tfrac{3}{4}$ falls, III. $\frac{50}{10}=5$ falls, and IV. $\frac{20}{13}=1\tfrac{1}{2}$ falls. During one year there would consequently be a shortage in one of the falls in Class II., which would have to be made up by cutting part of IV., if anything like absolute equality were desired.

This simple method of fixing the annual fall by area alone is only applicable to copse and coppice, for which it is certainly the most practical and satisfactory system of management. But it is unsuitable for highwoods, even if worked with a low rotation. It might certainly easily be applied to such crops as mixed conifer plantations, worked with a comparatively low rotation for the production of pitwood in mining districts by clearing and replanting; but even then the damage occurring every now and then from wind, snow, insects, or fire would almost to a certainty, sooner or later, interfere with the regular course of the falls. Again, it would be almost hopeless to endeavour to carry out the falls regularly and at the same time expect to obtain about an equal yield annually, to harvest the different crops at the most profitable time, and to arrange a proper sequence of falls (in the windward direction) with land varying much in fertility, and crops scattered about in groups of different age, quality, and rate of growth. And still more unsatisfactory and impracticable would this method prove in the case of woods (*e.g.*, Beech-woods) where large areas must be taken in hand at one time for natural regeneration, while the parent trees are only gradually removed during a shorter or longer term of years, according to the necessity of the seedling crop on the one hand and the advantage of the proprietor on the other.

Although, for highwoods, the division of the whole area into annual falls cannot be applied in all its original simplicity, yet the principle underlying the system can easily be adapted to suit highwoods of different kinds. The rotation of the woods forming any working-circle having been fixed on, this can be divided into as many **periods** of 10 or 20 years as may be contained in it, and the various crops may be allocated in approximately equal (or equally productive) areas to the different periods in whatever may, after due consideration of their age, general condition, rate of growth, relative position to each other, &c., seem the most profitable manner. Thus, while the management of the working-circle is forecast for a whole rotation so far as the areas now intended to come successively to the fall are concerned, the details as to the annual falls need only be specially determined with regard to the next 10 or 20 years forming the I. period.

This modification of the primitive original method of actual division of the woodlands into annual falls has the great advantage that while one can foretell fairly accurately in what particular period given crops are likely to become mature, yet it leaves a free hand for harvesting at the most profitable time the crops which are now approaching their full maturity and should come to the fall within the next 10 or 20 years.

In this improved method of management by area, the subdivision of the woods into equal (or equally productive) periodic falls—the area of each of which will be found by dividing the total area of the woods by the number of periods (usually 3, 4, or 5 of 20 years each for conifer crops, and 5 or 6 for broad-leaved highwoods)—requires only to be made on paper in a tabular form. The distribution of the areas within this is made only in the different periods, according to the age of the crops, the oldest woods and any which must be felled for other reasons being put in the I. period, and inequalities shown by the tabulation are eliminated, so far as practicable, by moving the smaller areas from one period to another so as to equalise the periodic falls.

The annual falls during the I. period are not indicated. Their size is of course equal to the acreage of the periodic fall divided by the number of years in the period, but the actual fall is made in the crop which the wood-manager thinks most suitable. So far as the total yield during the I. period is concerned, this is approximately shown in two columns at the right-hand side of the tabular form, the age of the crop and the yield anticipated (from average yield tables) being reckoned to the middle of the period.

The following very simple example (adapted from Heyer) may show how the tabular arrangement into periods is made for a conifer working-circle of 100 acres, and the yield or the fall shown during the I. period:—

Compartment.	Sub-compartment.	Present age of crop.	Age-classes in years. Over 80. / Periods, in acres. I. 1901-1920.	61–80. / II. 1921-1940.	41–60. / III. 1941-1960.	21–40. / IV. 1961-1980.	1–20. / V. 1981-2000.	Fall during the I. period. Age at time of fall.	Yield in cubic feet.
		years.						years.	
1		70		20					
2	*a*	110	14					120	112,800
	b	20					20		
3		50			13				
4	*a*	75	**6**	*6*				85	18,600
	b	25				16			
5		30				4			
6		40			**7**	*7*			
			14	*26*	*13*	*27*	20		131,400
			20	20	20	20			

Note.—The figures in thick type are those which have been moved to a different period from that to which they really belong, and in which they are shown in italics as cancelled.

Criticism of the Method.—Even this improved form of this system has some of the disadvantages of the simpler method applicable to copse and coppice. It recognises the necessity for normal distribution of the various age-classes, but tries to attain this only rigidly within the period of one rotation, although it might be more profitable either to hasten it or else to delay it longer; and it gives less consideration than other methods, or than the interests of the landowner demand, to providing an approximately equal yield during any two successive periods. While thus attaining normal distribution of age-classes it gives no consideration to the necessary capital in wood, or to any ratio between growing-stock and annual rate of growth, as commercial principles require.

As regards highwoods, it is a method which can only, in actual practice, be applied to conifer crops that are clear-felled when mature, and even to these with profit only when the woods are fairly evenly stocked, the average yield is not likely to vary much, and the various age-classes are already not far from normal. In such cases its simplicity can recommend it for small private woodlands, managed by men who have not had any technical training in forestry. But the method cannot be followed when the intention is to work forests in the most profitable manner.

(2) **Fixing the Annual Fall from the Yield or Cubic Contents of the Crops.**—This is really an older method than the improved system of fixing the fall periodically by means of area. As the primitive system, the simple

subdivision of the whole area into annual falls, was found impracticable for highwoods, owing to the difficulties which it created in management involving either variation in the yield from year to year or else compulsory departure from the limits of the annual falls, and to the fact that the best time for felling a crop could not be determined to a single year, though it might more easily be determined as falling within a period—all of these being practical difficulties which increased with the length of the rotation—it was thought preferable to fix the rotation and divide this into periodic groups of 20 years each, and to draw up a tabular working-plan in such manner that the yield to be obtained from the woods should be about equal for each period.

As in the improved method of management by area, each crop is entered in the table in that period which its age and condition indicate as most suitable, and the anticipated yield at the time of fall is estimated and entered in convenient items, these being moved from one period to another in order to obtain an approximately equal fall from period to period, while the determination of the actual annual falls is left to the manager. Here the annual fall is equal to the whole periodic yield divided by 20, the number of years in each period.

This method will easily be understood from the following example (adapted from Heyer) of the tabular plan upon which it is based:—

Compartment.	Sub-compartment.	Area, in acres.	Present age.	Age at time of fall.	Estimated yield at fall, per acre.	Age-classes in years.				
						Over 80.	61–80.	41–60.	21–40.	1–20.
						Periods.				
						I. 1901-1920.	II. 1921-1940.	III. 1941-1960.	IV. 1961-1980.	V. 1981-2000.
			years.	years.	cb. ft.	cb. ft.	cb. ft.	cb. ft.	cb. ft.	cb. ft.
1	*a*	7	90	**120** *100*	**9000** *7500*	*52,500*	**63,000**			
	b	6	42	**112** *92*	**6000** *4750*			*28,500*	**36,000**	
2		21	109	119	6250	131,250				
3		23	18	108	5800					133,400
4		17	36	106	5600				95,200	
5		16	70	100	5000		80,000			
6		24	55	105	5500			132,000		
						183,750	*80,000*	*160,500*	*95,200*	133,400
						131,250	143,000	132,000	131,200	

Note.—The figures in thick type are those which have been moved to a different period from that to which they really by age belong, and in which they are shown in italics as cancelled.

Criticism of the Method.—By endeavouring to equalise the fall during the first rotation, it gives more consideration to the present interests of the owner than the method by area; but the manner in which this is done will not necessarily lead to a normal distribution of age-classes, and still less to normal increment and a normal growing-stock being attained within that period. So far as the essential requisites for the normal condition are concerned it shares the defects of the method by area, only they are even more prominent in the method of fixing the periodic (and therefrom the annual) fall by the anticipated yield of the mature crops. Even as a rough-and-ready sort of system of management it is therefore not to be recommended; and, on the whole, it can only be said to have an historical interest.

(3) **Fixing the Annual Fall by combination of Area and Yield.**—After the primitive method of subdivision by annual area had been found unsuitable for highwoods, the method of management by basing periodic falls on the estimated yield was introduced. That likewise proving unsuitable, a move was made back to the method by area, but with the improved system of applying a convenient modification of the periodic arrangement. The various disadvantages and the difficulties in the management inherent in any system based more or less rigidly either on area or on yield alone were, however—and especially when applied to woodlands whose condition was usually very far from normal—at last seen to be absolutely insurmountable. The one method produced a normal series of age-classes in one rotation which yielded annual falls that might vary greatly in extent; the other gave about equal falls, but did not achieve what was desirable to bring the woods into normal condition. Hence it became evident that the various objects in view could only be attained by some method which took both area and yield into consideration in fixing the periodic fall (and consequently, indirectly, the annual fall), and which endeavoured to combine the advantages of both systems while obviating their drawbacks. Such a method was introduced in the early part of the nineteenth century, and is the system still in force in most parts of Germany. At first there was a pedantic striving after equality in area and yield throughout all the periods in the rotation; but long ago this was given up and their determination only fixed in detail for the first two periods.

Proceeding from the fundamental principle that the area is certainly the chief and the only unalterable factor with respect to the future management of given woodlands, this is taken as the main basis for the scheme of management. The area is a fixed quantity, not subject to fluctuations like the yield of the crops. In any case, the latter must be measured and dealt with by the out-turn per acre; and in woods of the same kind, age, quality, and condition, the annual fall throughout the rotation will be about equal if the whole woodland area is regularly stocked with crops which are mature when they are brought to the fall. So long, however, as the condition and the distribution of the crops are abnormal, the subdivision of the woodland area into approximately equal annual or periodic falls cannot of itself secure a more or less equal yield annually, and hence the necessity for combining with it some particular consideration of the crops forming the stock on the various falls.

The whole woodland area being divided into working-circles and compartments, and the method of treatment and rotation of the former having been fixed on, the area requisite for each circle is divided into as many sections as there are **periods**, usually of 20 years each, contained in the rotation; and such proportionate area of the working-circle is relegated to each of these periods as seems to consist of the most suitable crops, and to conduce towards attaining a normal succession of the falls. This preliminary periodic division by area serves as the basis for estimating, as accurately as is practicable, the yield of the falls during the first two periods, and for considering in how far equalisation of this can be obtained with the given conditions as to age, quality, and position of the crops coming meanwhile to the fall. One of the most important bases for the distribution of areas and yield in the different periods is to be found in the existing proportion of the different age-classes, hence the preparation of a table of age-classes (as will be subsequently described) is essential for arranging a working-plan according to this method of management.

The results of these considerations find their final expression in a felling-plan for the first period of 20 years. In this only the final yield of the mature fall is shown, while the areas to be thinned are merely indicated, leaving the out-turn from thinnings to be estimated by averages. For greater convenience and precision the fall for the first period of 20 years is subdivided into two sub-periods of 10 years each ($I.^1$, $I.^2$), and the most particular consideration is given to those crops to be harvested within the next 10 years. In Germany, where most of the forests are managed on this method, the Beech-woods being usually worked with a rotation of 120 years and conifers with 100 years, the working-circles are respectively divided into 6 and 5 periods of 20 years, in which the different crops are arranged according to the time when they are likely to come to the fall. Those of the first period are shown separately in detail as to area and yield for each of two sub-periods of 10 years, and the working-plan only lays down the estimated yield of the falls during each of these two sub-periods, while the specific details as to the order in which the falls shall be made, and the direction they shall take, are given in the report explanatory of the scheme of management. A revision takes place every 10 years, when the details for the second sub-period can be modified in any way that has been rendered necessary either by deviations from the plan (*e.g.*, through windfall, insects, &c.), or by the results of the past 10 years' working having shown that alterations and amendments are desirable in any respect. So far as the allocation of falls to the 5 or 6 different periods is concerned, the method is purely that of area; but when once the total fall (as to acreage) of the first period has been fixed and subdivided between the two sub-periods, then the special estimate of the cubic contents and of the increment of each crop is made, and the yield is calculated to the middle of each sub-period, before being entered into the felling-plan. The annual fall is then found by dividing the total fall for each sub-period by 10, the number of years it comprises. As this seems to me the method best suited for British requirements, it is the system which will be more fully explained in chap. iii.

Criticism of the Method.—This is a very sound and practical system, which aims at effecting a normal distribution of age-classes with normal allocation and regularity of the falls, while at the same time it seeks to avoid causing loss through allowing crops to continue growing after they have reached their maturity, and gives the opportunity of bringing younger crops to the fall if the conditions of their growth are such as to make it desirable they should be cleared soon for replantation. It has the advantages of simplicity in form, security in the bases upon which it rests, and clearness in indicating the objects of management, while it is not too rigid with regard to the specific order in which the crops coming to the fall within the next 10 or 20 years shall be harvested. The main objection to it is the theoretical one—that it gives no consideration to capital and increment, and leaves these to adjust themselves automatically in course of time.

The above is a method well adapted for large compact highwoods in Britain, because its simplicity and the ease with which it should be understood and carried out are points in its favour. This will therefore be the mode of management more specially considered subsequently with regard to practical details (chap. iii.)

A good idea of the method may be formed (see p. 276) from a simple example of a working-plan, which we will suppose applies to mixed conifer crops of 240 acres, intended to be worked from now with a rotation of 80 years, divided into four periods of 20 years each. The woods are supposed to consist of 7 scattered blocks, each of which is formed into one permanent compartment; but several of them show such differences in age, or in relative position to each other, among their crops as to require subdivision into temporary sub-compartments during the first rotation. The woods consist of crops in which the age-classes are abnormally distributed. There is an actual excess of capital in growing-stock on the ground, because some of the crops are not felled till considerably above 80 years of age, and the older crops are relatively much more numerous than those of younger age. Hence the actual condition of the crops is that at present they consist of a rather larger capital in wood than is required for an area of 240 acres worked with an 80 years' rotation. That the actual increment at the present time happens to be greater than the normal increment of the normal growing-stock is due to the fortuitous arrangement of the age-classes, and could not possibly be maintained so as to give a regularly sustained annual fall exceeding that of the normal increment for the normal capital in wood.

The Saxon System of Management, introduced by Judeich about 1860 as an improvement on an older system (Cotta's) long in use, is in reality a modified form of the method of combining area and yield in order to fix the annual falls for a short period of 10 years only, towards the end of which a revision takes place, when the fall is fixed for the following 10 years. Proceeding from the very sound idea that there is not much practical use in distributing (on paper) the whole of the periodic falls over the next 80, 100, or 120 years, it determines, according to the rotation, the proportionate area of a working-circle to be utilised within the next 10 years, and confines itself to the special consideration of the crops thus destined for the fall. Special investigations are made into the condition, yield, and increment of what appears, *primâ facie*, to be the mature marketable crops, and the endeavour is made to so arrange the falls among these within the next 10 years that each crop harvested should be cut just at the most profitable moment.

This is ascertained by the use of the *indicating percentage* (previously explained on p. 247), by means of which the rate of interest yielded during the next n (here 10) years on the present capital value of any given crop is shown by the simple formula—

$$\frac{(\text{Value } n \text{ years hence}) - (\text{present value})}{(\text{Value } n \text{ years hence}) + (\text{present value})} \times \frac{200}{n}$$

This formula being applied to various apparently mature crops, the results show which of them are yielding the best rate of interest, and may therefore be allowed to continue growing, and which of them are yielding least profit and should therefore be cleared for natural regeneration or replanting, unless thinnings or partial clearance will make it more profitable to retain these rather than some of the other crops.

So far as fixing the proportionate area to be dealt with in the next 10 years is concerned, the Saxon system of basing the fall on investigations made on the crops is purely the method of determining the periodic (and, indirectly, the annual) fall by area; and the principal difference is that the scheme of management only concerns itself with the proportionate area forming the annual falls during the next 10 years. Within this 10 years' period it fixes the fall by the yield, and in such a way that it shall not only be about equal in amount, but will also bring in the maximum of profit from the crops to be felled. By dealing thus with the whole area, a regular distribution of the normal age-classes is attained in course of time; and given these, along with normal increment, the normal growing-stock is also in course of time attained automatically. The present Saxon system is merely an improvement on an older method introduced by Cotta during the early part of last century, on the principle that it was of far more importance to have

WORKING-CIRCLE FOR CONIFERS

Woodland Area.				Growing-Stock in 1900: Age in Years.														
No., name, and description of compartment.	Sub-compartment.	Area.	Quality of land.	Description of crop.	Age. †	Yield and increment per acre.	Over 60.		41–60.		21–40.		1–20.		Areas felled for replanting.		Blanks and land fit for new plantations.	
		acres.	class.		years.	cb. ft.	acres.	cb. ft.	acres.	cb. ft.	acres.	cb. ft.	acres.	cb. ft.	ac.	c.ft.	ac.	c.ft.
1. Briar Hill=37 acres. *Situation.*—Gentle N.E. slope, protected. *Soil.*—Clay of medium depth, somewhat stony, fresh and fertile.	*a*	16	II.	Pine, Larch, and Spruce	85	8200 +85	16	131,200 +1,360										
	b	12	III.	Do.	74	6800 +80	12	81,600 +960										
	c	9	II.	Do.	62	6400 +130	9	57,600 +1,170										
2. Greenwood=36 acres. *Situation.*—E., moderate slope, protected. *Soil.*—Deep, fresh, fertile, clayey loam.	*a*	21	II.	Pine, Larch, and Spruce	59	6200 +132			21	130,200 +2,772								
	b	15	I.	Scots and Corsican Pine	55	4000 +125			15	60,000 +1,875								
3. Round Hill=47 acres. *Situation.*—In *a* and *b*, N.E., well protected; in *c* and *d*, N.W., rather exposed; moderately steep, and steep. *Soil.*—Clay soil in *a* and *b* of medium depth, fresh and fertile; in *c* and *d* shallow, somewhat stony, and dry.	*a*	18	III.	Larch and Pine	33	2500 +100					18	45,000 +1,800						
	b	16	III.	Larch and Spruce	30	2200 +100					16	35,200 +1,600						
	c	5	II.	Douglas Fir	20	1350 +110							5	6,750 +550				
	d	8	II.	Larch and Douglas Fir	17	1100 +105							8	8,800 +840				
4. Gorse Cover * = 24 acres.		24	I.	Larch	78	7500 +80	24	180,000 +1,920										
5. Oakwood *=33 acres.	*a*	10	III.	Pine and Spruce	54	3600 +130			10	36,000 +1,300								
	b	16	III.	Do.	45	3000 +100			16	48,000 +1,600								
	c	7	III.	Do.	31	1800 +90					7	12,600 +630						
6. Rushton Brake *=31 acres.	*a*	13	II.	Larch, Pine, and Spruce	19	1300 +100							13	16,900 +1,300				
	b	18	II.	Do.	18	1200 +100							18	21,600 +1,800				
7. Frampton Hill *=32 acres.	*a*	27	II.	Pine and Spruce	12	500 +50							27	13,500 +1,350				
	b	5	II.	Just felled.											5			
Total . .		240	II.	Actual growing-stock .			61	450,400 +5,410	62	274,200 +7,547	41	92,800 +4,030	71	67,550 +5,840	5			
				Normal distribution of periodic age-classes .			60		60		60		60					

Normal growing-stock $=\frac{240}{80}\times 7000\times\frac{80}{2}=840{,}000$ cb. ft.; normal increment $=21{,}000$ cb. ft. per annum.

* Details as to soil and situation should here also be included, as in 1 to 3.
† Where the exact age is not known, the approximate age should be entered as 80-90, 70-80, 60-70, &c.

ON THE FRAMPTON ESTATE.

FELLING-PLAN FOR MIXED CONIFER HIGHWOODS.

I. Period (1901-1920). 1. Sub-period (1901-1910). Fall.	Yield. Per acre.	Yield. Total.	2. Sub-period (1911-1920). Fall.	Yield. Per acre.	Yield. Total.	II. Period (1921-1940). Fall.	Yield. Per acre.	Yield. Total.	III. Period (1941-1960).	IV. Period (1961-1980).	REMARKS AS TO TREATMENT.
acres.	cb. ft.	cb. ft.	acres.	cb. ft.	cb. ft.	acres.	cb. ft.	cb. ft.	acres.	acres.	
16	8625	138,000									In this working-circle only two felling-series are required—(1) Compartments 1, 2, 3; (2) Compartments 4, 5, 6, 7.
			12	8000	96,000						
			9	8350	75,150						The falls in 1st series should precede those in 2nd series.
Thin			Thin			21	10,160	213,360			With such small annual falls as are here provided, the danger of damage from insects by having felling every alternate year, and replanting after one year's rest, seems too slight to require special measures of protection.
Do.			Do.			15	7,750	116,250			
Thin			Thin			Thin			18		
Do.			Do.			Do.			16		Areas to be replanted during the 1st sub-period are in thick figures—**16**, **15**, and **(5)**=**31**+**(5)**.
Do.			Do.			Do.				5	*Note.*—Wherever protective fellings or severances are required, these should be specified and entered in the 1st sub-period, with the remark that they should be made immediately.
Do.			Do.			Do.				8	
15[1]	7900	118,500	9	8700	78,300						[1] To be planted with Larch and Douglas Fir at $4\frac{1}{2} \times 4\frac{1}{2}$ ft.
Thin[2]			Thin			10	7,500	75,000			[2] Many of the Spruce will require to be cut out in favour of the Pine.
Do.			Do.			11	6,000	66,000	5		
Do.			Do.			Thin			7		
Thin			Thin			Thin			13		
Do.[3]			Do.			Do.			Thin	18	[3] There are a good many sporadic Birch, which should be cut out whenever interfering with the conifers.
Thin			Thin			Thin			Thin	27	
(5)[4]			Do.			Do.			Do.	5	[4] Area already clear-felled for planting with Larch and Douglas Fir at 4×4 ft.
31		256,500	30		249,450	57		470,610	59	63	

I. Period = 61 acres = 505,950 cb. ft.

Actual growing-stock = 884,950 cb. ft.; actual increment = 22,827 cb. ft. per annum.

woods properly laid out and arranged for continuous management than to try and fix the future periodic and annual falls a long time ahead. Judeich, the founder of this improved modern system, thus described it :—

At each revision of the existing scheme of management a new working-plan is drawn up for the next 10 years. In this only a general indication of the direction of the falls is given in connection with the existing subdivision of the woods into compartments, unless amendments seem called for in this respect. In fixing the new annual fall, the special instructions of the new working-plan for the next 10 years utilise the experience gained in the past 10 years' working, but they are not necessarily based on the instructions contained in the last plan. As revision follows revision every 10 years, the whole work of management and determination of annual yield becomes more regular and certain. The calculation is made so as to ensure continuity in the fall, but without degenerating into the petty artifices of a system based on an unsatisfactory theoretical principle, the three chief factors being the normal annual fall, the proper proportion of age-classes, and felling as soon as is most profitable. This does away with the necessity for spreading the various crops over all the future periods.

When estate books and accounts relative to past working fail to give satisfactory data for framing a scheme of management for the first time, nothing, of course, remains except to cast a look far forward into the future in order to have some proper sort of idea of the area of the periodic fall and the yield of the annual fall ; but a felling-plan for the next 30, or at most 40, years should suffice for this purpose.

Definite instructions for each given case and a special scheme for the determination of the annual fall cannot be laid down, as in other methods of management, because the best course to adopt can only be decided on when the given circumstances are known. The chief aim of this system of management is to attain an approximately normal distribution of the age-classes as to area and allocation. This result may be achieved in different ways, and each case must be considered by itself. In the calculation of the fall the yield of the mature crop is mainly taken into account, although the intermediate yield from thinnings need not necessarily be left out of consideration in fixing that.

For this Saxon system of management the subdivision of each working-circle into suitable compartments is necessary, so that short independent series of falls can be arranged ; because, although the annual fall has no influence on the subdivision of the woodlands, the subdivision of the latter into suitable compartments has a very direct influence on the allocation of the annual fall.

In reckoning the size of the annual fall care must be taken to ensure a regularly sustained yield of about equal amount from year to year, though equalisation is not carried out to any ridiculous degree. Like all other methods of management, the Saxon system aims at bringing each crop, compartment, and working-circle into an approximately normal condition in the shortest possible space of time, and in the most profitable manner—viz., by endeavouring to build up a normal series of age-classes, with normal increment.

The subdivision of the woods into working-circles and compartments having been accomplished, this forms the basis for a general plan (by area) ; but no special distribution of the different compartments into periods is made, as long experience in Saxony has shown this to be both uncertain and unnecessary. Within the framework of these compartments a normal distribution of age-classes is aimed at by felling first of all the over-mature and then the mature crops, always paying the necessary attention to the proper felling direction (against wind). The *indicating percentages* and the approximately most profitable rotation are found by careful investigations in characteristic crops, the rate of interest expected of the woods not being over 3 per cent (see pp. 240, 391) ; and the results of these investigations, with the assistance of the stock-map, enable the various crops to be selected and tabulated which ought to come to the fall within the next 10 to 20 years, unless unforeseen calamities (*e.g.*, windfall) or special objects of management desired by the owner dictate otherwise. The special selection of the crops to be felled first of all may best be given in Judeich's own words :—

Due consideration being given to the general direction of the falls and to obviating danger from windfall or difficulties with regard to extraction, the first felling-plan would include—

1. Protective falls rendered necessary for purposes of management—*e.g.*, all severance cuttings (p. 265) for shortening the length of the different intermittent series of falls.

2. All fully mature crops, whose "indicating percentage" has undoubtedly sunk below the rate of interest which the woods are supposed to give, so far as it is possible to fell in them and still follow the general felling direction. A fully mature or over-mature crop, whose clearance might lead to windfall in middle-aged woods growing to the lee-side, would, for example, not be felled in the meantime.

3. All crops which must be sacrificed in order to maintain the proper felling direction, such as small, middle-aged woods enclosed within fully mature crops—*e.g.*, a small 60-year-old pole crop completely enclosed within a wood of 120 years.

In the crops coming under 2 and 3 it will often be doubtful whether it is a greater sacrifice to let an over-mature crop stand or to fell an immature one. As a rule the greater or less extent of one or the other will decide the point—*e.g.*, one would not fell an over-mature crop on 1 acre if this meant exposing a 50-acre crop of good younger wood to danger of windfall, nor would one delay felling a 50-acre crop of mature wood for the purpose of letting 2 or 3 acres of younger wood in it attain larger size. The more difficult it may be to decide in such cases, the less will be the sacrifice involved ; hence, in all hard cases, it will be best to decide in favour of what is best for keeping to the general felling direction.

4. Those crops about whose maturity their "indicating percentage" leaves one in doubt, so far as these lie within the areas about to be felled over. These are the crops in which it is desirable to make exact investigations regarding the "indicating percentage," but in respect of which any mistakes made on account of slight differences of calculation lead to the smallest actual loss.

When the crops enumerated under 1 to 4 have been tabulated and their yield fixed for the next 10 or 20 years, their total gives the fall in area and cubic contents.

For small woodlands, where insistence is not made on a regularly sustained annual yield, no further check is required. For extensive areas, however, intermittent working is out of the question for various reasons (*e.g.*, special considerations regarding local markets and the staff of woodcutters, &c.), while considerable fluctuations in the annual out-turn are also, to say the least, undesirable. Here the total fall, made up of the different crops, must be subjected to a modifying regulator. The simplest is to be found in the approximate normal annual fall for the given rotation, if the distribution of the age-classes is anything like normal. But if this be not the case, then in place of merely taking the size of the annual fall, some other regulator must be chosen with special regard to the nature of the deviations from the normal condition. Thus, it will be a somewhat larger area if there be an excess of old woods, and a rather smaller area if these be in deficit. It is not here a question of any definite area, but merely of noting the maximum and the minimum acreage of the possible fall. Now, if the fall calculated from the crop investigations lies within these limits, then it may be regarded as quite safe. But if the total area of the crops noted for felling is less in acreage than the minimum of the possible fall or more than its maximum, then a correction is necessary ; and this can easily be made by means of the woods enumerated under 4, which are those about whose maturity there is some doubt. . . .

For subsequent revisions the actual yield obtained from these annual falls is the best and simplest regulator for checking the estimate of the future falls.

It is self-evident that in this method the preparation of a special working-plan is essential, and that revisions must be carried out every 10 years at least.

The yield of the anticipated intermediate returns (thinnings, &c.) are estimated separately for the next 10 years, and are usually entered simply as one quantity. Their amount is generally taken from average yield tables, or from the estate books, or from returns from similar woods.

Criticism of the Method.—The Saxon system has the advantage of attaining a sustained yield with proper arrangement of crop and falls, while duly considering dangers threatening the woods (especially wind and insects), details regarding extraction, and the financial position of each of the crops nearing maturity. But these are, all of them, practically cardinal points in the method of fixing the fall by combination of area and yield, because the crops destined for felling are naturally those of mature age or indifferent quality, while woods still in vigorous growth and giving a good return on the capital they represent are allowed to remain growing. That is only a matter of common-sense.

Particular stress is laid on the formation of short felling-series, on making protective fellings or severances, and on selecting or preparing numerous lines where the various felling-series can begin, so that the management may have a considerable degree of freedom and elasticity in place of being hampered by the rigidity of long felling-series. But the necessity for having numerous short intermittent series of falls, in place of only two or three long series in large woods, is just as great in the other method as in the Saxon system.

One apparently essential difference in the two systems is that more is said about financial considerations in the latter than in the former. But, wherever forestry is carried on as a business, the choice of the crop to be grown, the system adopted, and the rotation fixed on, are of necessity based on financial considerations. And when one comes to examine the "indicating percentage," one finds it nothing more than the ordinary common-sense of a man of business. So long as it stands before one in this simple and intelligible form all is well (see p. 247); but when once it begins to pose as being a compound of (a) *quantitative increment*, (b) *qualitative increment*, and (c) *increment in value per cubic foot*, this is really attempting to deal definitely with three unknown quantities, each incapable of being fixed with mathematical precision. Under every sound system the over-mature woods and those desired to be harvested for protective purposes or for other definite objects of management must be the first to come to the fall; and, *cæteris paribus*, the selection of the others to be included—*i.e.*, those whose maturity the "indicating percentage" shows to be doubtful—must be made by some common-sense method. But the "indicating percentage" is excellent common-sense, so long as it is not allowed to degenerate into anything impracticable. Supposing, for example, that there is a difficulty in completing the estimate for the fall during the next 10 years, and that a choice (which, say, need depend on nothing but the pure question of profit) must be made between two crops, one of which has a present market value of £100 per acre and an anticipated value of £140 an acre 10 years hence, while the other is now worth £120 an acre and will probably be worth £165 an acre in other 10 years. Which is it more profitable to include in the fall? Here we can very conveniently apply the simplest or common-sense formula to ascertain that

$$\frac{140-100}{140+100}\times\frac{200}{10}=3{\cdot}33 \text{ per cent, and } \frac{165-120}{165+120}\times\frac{200}{10}=3{\cdot}15 \text{ per cent.}$$

This indicates that it is better to fell the latter crop during the next 10 years, and to let the former grow on till the falls of the subsequent 10 years. If the owner is in want of ready money, however, he will naturally prefer to fell the crop which will sell for most, as the "financial considerations" of the £20 an acre extra in this case outweigh the 0·18 per cent of difference shown by the "indicating percentage." But this application of business principles is just as suitable to the method of combining area and yield as to the Saxon system, and all the more so as the anticipated increment in cubic contents for the next 10 years, which must form the main factor in any safe estimate, has in any case to be calculated for the former method.

Even if calculations of this sort be not actually made, an experienced forester will generally have no difficulty in determining not only what crops must in any case (on account of age, condition, or position with regard to the felling direction) be brought first to the fall, but also in those doubtful cases in which the "indicating percentage" is applied in Saxony; because, as a matter of fact, the indications given by the general appearance and condition of the crop, its more or less vigorous growth, and its position with regard to other crops and to the general direction of the fall, can just as safely be followed as the results of a calculation based on a combination of factors each in themselves liable to fluctuations. And if an occasional mistake should perhaps be made in the former case, its effects are no worse than if error had crept into the calculation in the latter case.

In one respect, however, there is a characteristic difference between the two systems. Whereas the method of combining area and yield divides the rotation into equal periods of 20 years and endeavours to fix the fall both as to extent and quantity for the first two of these (and also separately for each half of the first period), in the Saxon method the working-plan merely fixes the fall for the next 10 years, towards the end of which there is a revision and a new working-plan for the following 10 years; there is no formal division of the rotation into periods. Now, this is all very well for highwoods managed by casual (selection) fellings, but it does not do for highwoods under any more regular system of management. Although it stands to reason that definite measures cannot be accurately foretold for crops maturing only 40 to 80 or 100 years hence, yet there are very distinct advantages to be derived from merely allocating the younger crops by area only to the periods in which they will presumably attain maturity and come to the fall.

This can easily be proved. First of all, if the age-classes are rather abnormally distributed, their inequalities can only be properly estimated when the crops are arranged chronologically, so that the different periods show where there is an excess above, and where a deficit below, the normal proportion. Without such knowledge it is impossible to make sound well-considered recommendations for equalising the distribution of the age-classes, because the measures to be adopted with this object must always influence, in a greater or less degree, the area and yield to be assigned to the next older and next younger periodic falls. Again, where Oak-copses or Beech-woods, hitherto managed more or less on the casual (selection) felling system, are to be transformed into highwoods with regular periodic falls for purposes of natural regeneration, it is essential for proper management that it should be definitely laid down when the woods, or when particular portions of them, should be transformed—*e.g.*, during the II., III., or IV. period, because the treatment of the crop until then will very materially depend on when the contemplated change in the method of management is desired to take place. And, thirdly, the various protective and sylvicultural methods—such as protective falls or severances, heavy thinnings, partial clearance with underplanting, &c.—required in order to ensure the regular course of falls, say, 20 to 40 years hence, can only be clearly seen and provided for at the proper time, if the probable progress and course of the future falls are clearly forecast in this manner.

(4) **Fixing the Annual Fall by means of the Proportion found to exist between the Actual and the Normal Increment and Growing-Stock in the Woods** (*i.e.*, **by means of Theoretical Formulæ**).—The various suggestions for management which have been founded on the above principle are usually known as "**the formular methods**," because they are all capable of being expressed by short *formulæ* or equations of algebraic appearance. So far as British Forestry is concerned, these methods have little or no practical value; but, as some acquaintance with their theoretical principles is desirable, the three most important of them may here be very briefly treated of—namely, (1) **the Austrian Method**, (2) **Hundeshagen's "Rational Method,"** and (3) **Heyer's Method**.

1. **The Austrian Method or "Œsterreichsche Cammeral-Taxe."**—This is the oldest and one of the best of the so-called formular methods. Originally formulated in a decree of 1788, not for the purpose of estimating the annual fall but as a means of making a valuation of the State forests, it directed that the value of each forest should be calculated by capitalising the normal income from it, the annual yield being at once found by dividing the growing-stock by the number of years in the rotation, if the growing-stock or "*fundus instructus*" was normal. Obviously, however, the annual yield ought to be larger if the actual

growing-stock exceeded the normal, and it would be less if the contrary were the case. To decide this it was in every case necessary to estimate the normal and the actual growing-stock, and to compare them with each other. The edict consequently decreed that the normal growing-stock should be found by multiplying the yield of the proportionate annual fall of the future crop (as the incorporation of the increment of all the woods throughout a year) into half the number of years in the rotation, *i.e.*—

$$\textbf{normal growing-stock} \text{ or } \textbf{wood-capital} = \left(\text{mature annual fall} \times \frac{\text{rotation}}{2}\right).$$

No special directions were given for calculating the actual growing-stock; but, by analogy, it was presumed to be estimated by adding together the products shown by the area, age, and actual average mature yield of the various crops. The equation thus established gave the formula—

$$\textbf{annual fall} = \text{annual increment} + \frac{(\text{actual growing-stock}) - (\text{normal growing-stock})}{\text{number of years in rotation.}}$$

Here the *increment* obviously intended is the average increment represented by the proportionate crop maturing annually, because what was in the decree called the *normal increment* was in reality the actual yield obtained on the fall of the mature crops. At that time it could not have been otherwise, with the then existing knowledge of increment. The *normal growing-stock* was found from this increment (*i.e.*, from the mature yield per acre) by means of the formula

$$\left(\frac{\text{total area}}{\text{years in rotation}}\right) \times (\text{actual yield per acre mature}) \times \left(\frac{\text{years in rotation}}{2}\right);$$

while the *actual growing-stock* was found by multiplying the proportion of the mature fall corresponding with each given age into the acreage of crops having that age. In the true sense and intention of the Austrian method the equation really was that the

$$\textbf{annual fall} = \text{actual yield of the proportionate mature crop} + \frac{(\text{estimated actual growing-stock}) - (\text{estimated normal growing-stock})}{\text{number of years in rotation.}}$$

If the *actual growing-stock* of the woods corresponded with the *normal growing-stock* reckoned from the actual yield of the mature fall each year, then the woods were in *normal condition* as to the growing-stock they contained; but if the distribution of the various age-classes was such that older woods predominated, then the fall had to harvest more than the proportionate area for one year as found in the quotient of

$$\left(\frac{\text{total area}}{\text{number of years in rotation}}\right);$$

while if younger woods predominated, a smaller fall had to be made till the differences on either side had been adjusted. Consequently, within the course of one rotation, differences existing between the normal and the actual growing-stock would gradually be automatically adjusted. No regular working-plan was prescribed for this method. It was subsequently seen that this formula could be used for removing, in the interest of the landowner, such differences within a much shorter period than a whole rotation by simply modifying the equation so that it assessed the annual fall as follows for purposes of forest management:—

$$\text{Annual fall} = \text{annual increment} + \frac{(\text{actual growing-stock}) - (\text{normal growing-stock})}{\text{number of years in period of adjustment.}}$$ [1]

The above may easily be illustrated by a few examples, in which the annual increment is taken as really normal according to average yield tables, and not in the original sense of the Austrian Cammeral-Taxe.

[1] This modification was the leading principle in an intricate method formulated by Carl Heyer in 1841 (see p. 284). It is also the formula given in the Instruction of 1878 for the Management of the Austrian State Forests.

A Pine-wood of 400 acres, worked with a rotation of 80 years, is estimated to have a normal increment of

$$6000 \text{ cb. ft} \times \frac{400}{80} = 30{,}000 \text{ cb. ft.},$$

and a normal growing-stock of

$$\frac{400}{80} \times 6000 \times \frac{80}{2} = 1{,}200{,}000 \text{ cb. ft.},$$

while the actual growing-stock is estimated to be 1,312,000 cb. ft. The annual fall would therefore be

$$= 30{,}000 + \frac{1{,}312{,}000 - 1{,}200{,}000}{80} = 31{,}400 \text{ cb. ft.}$$

If, however, the actual growing-stock were only supposed to be 1,112,000 cb. ft., then the annual fall would be

$$= 30{,}000 + \frac{1{,}112{,}000 - 1{,}200{,}000}{80} = 28{,}900 \text{ cb. ft.}$$

But if it were desired to wipe away the differences within a period of 20 years, then the annual fall in the former case would be

$$= 30{,}000 + \frac{1{,}312{,}000 - 1{,}200{,}000}{20} = 35{,}600 \text{ cb. ft.},$$

and in the latter

$$= 30{,}000 + \frac{1{,}112{,}000 - 1{,}200{,}000}{20} = 25{,}600 \text{ cb. ft.}$$

2. **Hundeshagen's "Rational Method"** was suggested in 1826 as an improvement on the Austrian method. The idea upon which it is based is that the actual fall should bear such proportion to the actual growing-stock as the normal increment bears to the normal growing-stock; hence—

$$\textbf{actual fall} = \text{actual growing-stock} \times \frac{\text{normal increment}}{\text{normal growing-stock.}}$$

This modifying factor, the quotient of $\frac{\text{normal increment}}{\text{normal growing-stock,}}$ he called the *percentage of utilisation;* and by multiplying the total actual growing-stock with this the fall is ascertained which can rationally be harvested. The *percentage of utilisation* can easily be calculated from average yield tables by taking the normal increment (*i.e.*, the cubic contents of the mature fall) for the given rotation and dividing it by the normal growing-stock corresponding with the same—*i.e.*, the sum of $\left(\text{mature fall} \times \frac{\text{rotation}}{2}\right)$. By making only *rational* proportionate falls (to be immediately replanted) differences between the actual and the normal growing-stock and increment become adjusted automatically within the course of one rotation. But, as those differences were constantly varying with each year's fellings, Hundeshagen specially stipulated that the annual fall thus calculated should only be considered to hold good for 10 years. No regular plan of management is required, and it was thought to be an advantage of this method that the wood-manager had a free hand in allocating the falls whose extent only was thus indicated.

In the example given under the Austrian method the normal increment was estimated at 30,000 cb. ft. per annum, giving a normal growing-stock of 1,200,000 cb. ft. for an 80-years' rotation. Here the "percentage of utilisation" is $\frac{30{,}000}{1{,}200{,}000} = 0{\cdot}025$. In the case of the actual stock being calculated to be 1,312,000 cb. ft., the "rational" annual fall would be $1{,}312{,}000 \times 0{\cdot}025 = 32{,}800$ cb. ft.; while if that were merely 1,112,000 cb. ft., then this would only be $1{,}112{,}000 \times 0{\cdot}025 = 27{,}800$ cb. ft. The fall might therefore be fixed at this for the next 10 years, when a fresh calculation would have to be made to fix the fall in the following 10 years, and so on till differences between actual and normal growing-stock became adjusted in the course of one complete rotation.

This plausible method is based on the erroneous assumption that the annual fall of wood must bear the same proportion to the actual growing-stock as the normal increment bears to the normal growing-stock. Now, as a matter of fact, this is only true if the distribution of the age-classes is normal, because the actual rate of growth is usually much quicker in woods between 30 and 70 years of age than in those under or over that. Hence, if the woods are principally of age-classes belonging to the most active period of growth, their percentage of increment will be much higher than if the woods contain an abnormally large proportion of very young or of mature or over-mature crops. And, in the former case, one would reasonably wish to restrict fellings till the timber acquired its full marketable value; while in the latter, one would wish to clear off the over-mature woods as soon as convenient in order to replace them by young and vigorous crops.

3. **Heyer's Method,** published in 1841, was based upon the Austrian Cammeral-Taxe. As was pointed out with reference to this, if any abnormity between the actual and the normal growing-stock were desired to be adjusted within a fixed period of years in place of exactly within one rotation, then the

$$\textbf{annual fall} = \text{annual increment} \div \frac{\text{(actual growing-stock)} - \text{(normal growing-stock)}}{\text{number of years in period of adjustment.}}$$

From the principle that in a fully normal condition of woods in a working-circle the fall must be equal to the actual increment, and to the normal annual average increment shown by the mature crop, he deduced the fact that, given the normal growing-stock, but only with abnormal distribution of age-classes, a normal distribution of the latter would be obtained if the actual current annual increment were harvested each year from the oldest crops.[1] If, however, the actual growing-stock varies from the normal, then the abnormity can be adjusted either by savings to fill up a deficit, or by excess fellings to consume a surplus, instead of simply utilising the actual increment. And this adjustment ought to be made during such period of years as best suits the existing condition of the woods. During this period of adjustment the annual fall would be

$$= \text{actual increment} + \frac{\text{(actual growing-stock)} - \text{(normal growing-stock)}}{\text{number of years in period of adjustment.}}$$

This would, however, lead to constant variation in the annual fall, because the actual increment (and therefore also the annual fall) would change gradually from year to year as abnormal woods came successively to the fall. Hence, if the annual fall were to be a constant quantity during the period of adjustment, it would be

$$= \frac{\left\{\begin{array}{c}\text{(actual growing-stock)} + \text{(total actual increment during period of adjustment)} \\ - \text{(normal growing-stock)}\end{array}\right.}{\text{number of years in period of adjustment.}}$$

The period of adjustment chosen was to be divided into minor periods of 10 to 20 years only, at the end of each of which a new calculation had to be made. Future falls and reproduction were to be arranged in a working-plan giving a rough general idea of the probable areas and yield that would form the falls.

If the annual fall could possibly have been fixed once for all by means of a calculation based simply upon the period of adjustment, then this would be a good practical system. But that is impossible. Say an 80-acre wood, worked in 80 years' rotation, has a soil

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[1] This forms a difficult problem in integral calculation, but the correctness of the above was proved by Professor Clebsch of Göttingen in 1868 (*Allgemeine Forst und Jagdzeitung, Supplement*). Heyer himself remarks of this: "Strictly speaking, this method only attains the normal condition in infinity, but the abnormity is so slight after a few rotations that it may be neglected for practical purposes." But "a few rotations" mean a few centuries,—and further criticism is unnecessary.

from which one may expect 7000 cb. ft. an acre as the normal mature fall, then the normal growing-stock would be $7000 \times 40 = 280,000$ cb. ft. Supposing, however, the actual stock is estimated as only 248,000 cb. ft., and the actual increment at 5400 ft., then the annual fall would be

$$= \frac{248,000 + 432,000 - 280,000}{80} = \frac{400,000}{80} = 5000 \text{ cb. ft.}$$

But when fresh calculations of the actual growing-stock and increment have to be made every 10 or 20 years (and the shorter the period, the more nearly precise will the result be) this method becomes laborious, while at the same time the bases upon which it rests are insecure. It therefore never came into any extensive use. Heyer was himself aware of this defect, for he remarked of the method :—

"These simple principles merely show *arithmetically* how the normal condition of the woods can be brought about and assured in general; but it does not follow that it is possible to carry out this method *thoroughly* in all cases. Indeed, one must not think *that the annual fall can practically be fixed with advantage within the narrow limits of any mathematical formula*. Again we repeat that the manifold differences in the condition of woods, the various necessities and desires of their owners, the many concrete circumstances affecting the yield, and other influences that cannot be determined in advance, may suggest or even necessitate deviations from a normal condition which may perhaps only have been attained after much trouble."

Heyer was therefore in this respect, and with regard to the fact that a rough working-plan was necessary for the proper application of his formula, in the main an adherent of the method of combining area and yield, much in the same way as is the case in Judeich's Saxon system.

Criticism of the Formular Methods.—These methods, of which there are several others besides those above described, all regard the attainment of a fully stocked condition of the woods, with a regular distribution of age-classes, as the ultimate object of management. The essentials for this normal condition are of course a definite normal growing-stock and normal increment, from which the actual growing-stock and the actual increment are usually found to deviate to a greater or less extent. Now, the formular methods aim at accomplishing these objects by means of reckoning the annual fall in such a manner as will gradually, or within some fixed period, adjust existing differences between the actual and the normal growing-stock, and the actual and the normal increment. And in doing this they, with one exception, overlook the necessity of having a regular working-plan taking into special consideration the areas that will be brought to the fall by means of the formula. They do not expressly say that such a detailed working-plan is unnecessary, but only one of them—Heyer's, a most complicated, ingenious, and mathematically correct, but rather unpractical system—distinctly stipulates for a plan in which the woods are arranged in age-classes, so that, after the fall has been fixed quantitatively in cubic feet by means of the formula, those crops may be selected for harvesting and reproduction in which the timber is mature or over-mature. Even here, however, the plan can only be made out as to yield for the short space of 10 years, during which the annual fall is fixed by the formula for each given sub-period of the total period of adjustment.

Unless there be a working-plan showing the mature crops, or, what amounts to the same, a definite understanding that the fellings are only to be made in mature woods, the formular methods would lead to results quite too ridiculous for practical work—*e.g.*, when the normal growing-stock and the normal increment (as calculated for the formular methods) are present in the shape of crops having, say, the age of half the rotation, or otherwise consisting of immature woods. Here the annual fall would be equal to the full normal increment, and yet any attempt to fell would be merely a sacrifice of immature crops. All of the formular methods are weak in respect of laying too much stress on the normal growing-stock and not paying adequate attention to the actual distribution of very abnormal age-classes.

Now, as a matter of fact, the annual fall—say, for the next 10 or 20 years—is not fixed by the increment on the whole of the age-classes, but by the acreage of the crops now mature or approaching maturity. And these can only be properly noted for consideration when tabulated in some such system as obtains in the method of combining area and yield in fixing the annual fall.

Again, all deductions made exclusively from estimates regarding cubic contents of growing-stock and increment are fallacious, because these essential factors for correct calculations can only be approximately ascertained, and we can never be sure that they are absolutely correct in any given case. This is the rock upon which the formular methods all split.

Hence it is much safer to adopt the area, the only absolutely certain quantity the forester has to deal with in each working-circle, as the basis in fixing the annual fall. And this is a basis so secure that, even if the yield connected with it cannot be determined with mathematical precision, when area is duly considered in regulating the annual falls, greater security is attained than by the formular methods for the maintenance of a sustained yield and of the highest income from the woods.

10. **The Method of Management recommended for British Woodlands.**—There can be no doubt that for copsewoods and coppices the division of the total area into equal (or equally productive) annual falls is the best method of management in Britain; while as regards highwoods, and more especially conifer crops, the choice must practically lie between the Saxon system and the method of fixing the annual fall by combining area and yield.

The Saxon system has proved admirably satisfactory for the given circumstances in Saxony. There, forest management has been carried out on economic principles for considerably over a century; hence the distribution of the age-classes is by no means so abnormal as will usually be found to be the case throughout Britain. For this reason, and also because the majority of our land-agents, managers of woodlands and foresters, have had no special technical training in the business of forestry, the method of fixing the fall by combining the area and yield (in detail for the first two periods of 20 years, and in rough suggestion of area only during the subsequent periods) seems to be by far the preferable system of management for Britain. It has, as compared with the Saxon system, the advantage of readily conveying to those concerned with the general control of the estates and the carrying out of work in the woodlands a tolerably clear view of the objects of management and the methods of attaining them, and these advantages can be so easily obtained by a little time and thought that it would be a great pity to forego them. And, finally, for the circumstances of most British woodlands, the Saxon system, with its entirely new working-plan framed once every 10 years (which would probably have to be drawn up by a specialist in forestry), would, even from the financial considerations alone that form one of the guiding principles in fixing the fall, prove less suitable than the other method regulating the falls for the next two periods of 20 years each, and specially separating those of the I. period into two sub-periods of 10 years each.

This method of combining area and yield is all the more to be recommended as the system best suited for Britain, because most of our woodlands vary very considerably from the normal condition. Even in Germany, the home of forestry, it is the system mostly in use, and it is considered to have the advantage of giving more consideration than any other to the actual conditions found in forests, while it does as much as is possible to adjust the variations in the periodic falls, which would be unavoidable if any mere subdivision by area were adopted.

Under this, the clearance of over-mature or unsatisfactory crops, protective falls, &c., are provided for exactly as in the Saxon system, and the determination of the financial maturity or otherwise is just as feasible in that as in this, so that the advantages above noted remain to speak in its favour. But it must be distinctly borne in mind that the yield forecast for the II. period, and the areas likely to come to the fall in the later periods, are not to be regarded as anything more than mere probabilities and suggestions intended to be of assistance in the management meanwhile.

There is one other special advantage which the method of combining area and yield seems to have above any other method. Where woodlands exist to any great extent on large estates they will often be looked to, so far as the law of entail or other title to possession admits of this, as a fund to be drawn upon to meet succession duties. Such being the case, it is self-evident that the woods will be least damaged and crippled as producers of income (*i.e.*, that the interests of the present and of the future owners will best be safeguarded) if they are being managed according to a well-considered scheme; and the method of management by combining area and yield in fixing the fall shows much clearer than any other system (1) *exactly where the woods can best be made to furnish the money specially required*; (2) *how this will affect the falls for the next* 20 *or even* 40 *years, if the making good of the deficit be spread over so long a time*; and (3) *what this is in reality likely to cost the owner.*

If the conditions of the local timber market may permit of this, fellings to the extent of the whole of the falls of the first sub-period of 10 years could be made, and those intended for the second sub-period could be spread over the whole 20 years, so that the full income-producing capacity of the woods would be resumed from the commencement of the second period. This would, of course, be at variance with what is usually the main object of a working-plan—viz., the securing of a regularly sustained annual fall; but, after all, the *raison d'être* of a scheme of management is to indicate how the desires and intentions of the owner may best be attained or provided for.

Were woodlands good legal assets upon which money could be borrowed to pay the succession duties and the like, then it would always be preferable and easier to borrow on the strength of a well-considered working-plan; and in place of making a very big fall of timber at once, the excess fellings could be spread over a number of years with advantage to the woods, unless the older woods were present to more than the normal extent. But various other measures might also be suggested. By restricting fellings slightly, a reserve of marketable wood might be built up for contingencies such as these, if the present owner desired to do so. Yet this is not a procedure to recommend. Nor would the fixing of a somewhat higher rotation than is likely to prove most profitable—say, working with a rotation of 100 years when 80 or 90 would probably be more remunerative—be true economy, because each of these two procedures would, in reality, be failing to utilise the woodlands to their full extent as producers of income. They would increase the capital in growing-stock above what is really necessary for working the given area, as indicated by the most profitable rotation. A much better method would be simply to put aside a certain small percentage of the net income received each year from the woods and invest it on bank deposit or otherwise, so as to form a fund for this specific purpose.

In conclusion, the system for fixing the annual fall by combining area and yield seems to be so distinctly the method of management required generally for highwoods in Britain, that it will be the system to which the details regarding practical work in chap. iii. will be confined.

CHAPTER II.

THE MEASUREMENT OF TIMBER-CROPS.

1. **Measurement of the Cubic Contents of**—(1) *Felled Trees or Timber in the Log;* (2) *Standing Trees;* (3) *Whole Crops of Wood.*
2. **Estimate of the Age of**—(1) *Felled Trees;* (2) *Standing Trees;* (3) *Whole Crops of Wood* (*Mean Age*).
3. **Measurement of the Increment or Rate of Growth**—(1) *Factors determining the Increment;* (2) *Measurement of Past Increment on Felled Trees and Logs;* (3) *Measurement of Past Increment and Estimate of Future Increment on Standing Trees;* (4) *Estimate of Past, Present, and Future Increment on whole Crops of Wood.*

1. **Measurement of the Cubic Contents** is made by means of measuring-tapes, compasses or callipers, and "hypsometers" or instruments for measuring heights. The measurements are made in lineal feet and inches, and the results obtained by multiplying these into each other, as below explained, are expressed in cubic feet.

(1) **Measurement of Felled Trees or Timber in the Log.**—The true cubic contents of any log of wood are found approximately enough for practical purposes by measuring its length and its girth or diameter midway between both ends, calculating the area of the section such girth or diameter represents, and multiplying this by the length. Expressed briefly, the formula is—

Cubic contents = length × superficies of middle section.

Example.—A log is 18 ft. long and 24 in. in diameter midway between the two ends. Its actual cubic contents are therefore 18 ft. × 3·14 sq. ft. = 56·52 cb. ft. If sectional tables are not at hand, the calculation can easily be made approximately from the diameter alone, found from the girth, if necessary, by dividing by $\pi = \frac{22}{7}$. Thus, cubic contents = length × mean section = length × $\frac{\pi \text{ diameter}^2}{4}$ = length × (square of diameter × 0.785). But as 0·785 is inconvenient to use, the product of length × square of diameter can be multiplied by 0·8, and the result reduced by 2 per cent. Thus, 18 × 4 = 72; 72 × 0·8 = 57·6; 57·6 − $\frac{2}{100}$ (57·6) = 56·45 cb. ft.

In Britain, however, timber in the log is not measured, bought, or sold by true cubic contents, but by a quaint system (which makes an allowance of 21½ per cent for wastage in sawing) known as "**square-of-quarter-**

girth measurement," the girth being measured, as above, midway between the two ends. Hence the usual British formula, used also in all British possessions, is—

$$\textbf{Cubic contents} = \text{length} \times \left(\frac{\text{mean girth}}{4}\right)^2$$

Example.—A log is 20 ft. long and 8 ft. in mean girth. Its contents (by customary trade measurement) are $20 \times \left(\frac{8}{4}\right)^2 = 80$ cb. ft.,—whereas the true cubic contents are $20 \times \frac{8^2}{4\pi} = \frac{1280}{12 \cdot 566} = 101 \cdot 8$ cb. ft.

In the previous example the girth would be $2 \times 3 \cdot 14 = 6 \cdot 28$ ft., and the cubic contents would be 18 ft. $\times \left(\frac{6 \cdot 28 \text{ sq. ft.}}{4}\right)^2 = 44 \cdot 36$ cb. ft. If this result be compared with the actual cubic contents, a shortage of 12·16 cb. ft., about 21½ per cent, will be found—viz., 56·52 : 44·36 = 100 (true cubic contents) : 78½ (British measure), or 56·52 : 12·16 = 100 : 21½.[1]

The above is the method in practical use. It is not strictly accurate, but it serves all practical purposes for calculating the contents of logs or timber in the round. For measuring the cubic contents in timber of sample stems felled to determine the growing-stock of crops, it is usual to divide the stem into sections of 9 or 10 ft. and to cube each according to the length and mean girth ; while the branchwood is worked up into the usual form, as faggots, &c. Where greater accuracy is required, as, for example, in making experimental investigations for scientific purposes, the log can be divided into more numerous sections (say of 5, 4, or 3 ft. long), and each of these can be calculated by multiplying the length into the square of the quarter-girth of the superficies in the middle of each section.

If the quarter-girth be taken in inches and the length in feet, then by squaring the former, multiplying it by the latter, and dividing the result by 144, the **customary cubic contents** will be found (*e.g.*, in the above example, $24^2 \times 20 = 11{,}520 \div 144 = 80$ cb. ft.) And in the same way the **Customs Measurement** or **true cubic contents** will be found by using the divisor 113 (*e.g.*, 11,520 ÷ 113 = 101·9 cb. ft.) The **Die-square Measurement,** showing the maximum cubic contents the log can yield when squared, is found by using the divisor 181 (*e.g.*, 11,520 ÷ 181 = 63·6 cb. ft.)

In the **Calliper Measurement** in use at the Government dockyards, the diameter in inches is measured and squared, then multiplied into the length in feet, and divided by 183 (*e.g.*, in the above case the diameter would be 30·5 in., and $30 \cdot 5^2 \times 20 = 18{,}605 \div 183 = 101 \cdot 6$ cb. ft.), which corresponds almost exactly with the true cubic contents found by multiplying the mean superficies into the length. Calliper measure is not used in the trade at all, nor on the railway (see also p. 511).

It is self-evident that, in order to obtain correct results, the girth or diameter must be accurately measured. If the girth be measured, care should be taken to see that the tape (or band, or string) be applied at right angles to

[1] True section $= \pi r^2 = \frac{\pi d^2}{4} = \frac{\pi^2 d^2}{4\pi} = \pi^2 d^2 \times \cdot 0795 = \text{girth}^2 \times 0 \cdot 0795$.

$$\text{Usual British measure} = \left(\frac{\text{girth}}{4}\right)^2 = \frac{g^2}{16} = \text{girth}^2 \times 0 \cdot 0625.$$

$$0 \cdot 0795 : 0 \cdot 0625 = 100 : 78 \cdot 6,$$

i.e., true cubic contents : British measure = 100 : 78·6.

$$\text{Hence, British measure} = \text{true cubic contents} \times \frac{78 \cdot 6}{100};$$

$$\text{and, true cubic contents} = \text{British measure} \times \frac{100}{78 \cdot 6}.$$

the axis of the log, otherwise the perimeter measured must be elliptical rather than circular, and consequently the calculation will be in excess of the true contents. An error of this sort can best be avoided by pulling the tape from side to side so as to get it into as correct a position as is practicable.

Results approximating more nearly to the true cubic contents are obtained when the superficies is calculated from the mean of two diameters measured at right angles to each other, as this tends to eliminate error in measuring the girth. Sometimes the mean girth cannot be conveniently measured, when the only thing that can be done is to measure the girth or diameters (and preferably two diameters at right angles to each other) of the top and bottom ends, and take the mean of these as the equivalent of the girth or diameter at the middle of the log.

When timber is measured over the bark it is in most localities customary to make a bark-allowance of $\frac{1}{12}$ of the mean girth—*i.e.*, 1 inch for each foot, or $\frac{1}{2}$ an inch for every 6 inches, of the quarter-girth; but in very many cases this is really an excessive allowance.

This represents a reduction of 16 *per cent on the total contents of the log, as shown by the customary square-of-quarter-girth measurement.* Thus a 20 ft. log, with a mean girth of 6 ft. 6 in. over bark, contains 52·8 cb. ft., while a bark-allowance of $6\frac{1}{2}$ in. reduces the contents paid for to 44·4 cb. ft.; and 44·4÷52·8=0·84, thus showing a diminution of 16 per cent on the over-bark contents (see pp. 511-515).

Throughout the British Isles generally, the buyer pays nothing for tops and branchwood below timber-size. Such small stuff (the "**lop and top**") is considered his, to take or to leave, without further payment than for the wood which falls within the local description of "timber"; and this generally means wood from 6 in. diameter upwards. But the definition of "lop and top" varies locally. In conifer districts, where pitwood can be sold down to $2\frac{1}{2}$ in. diameter under bark, the "lop and top" is confined to ends below 3 in. diameter over bark (see also p. 292). In stacks of timber of small dimensions, such as pitwood, smaller branchwood, fuel faggots, &c., the cubic contents can most conveniently be taken from average results.

Tanning bark is usually sold by weight in Britain. The yield varies greatly, but may be averaged at about 10 cwt. per load of 50 cb. ft. (quarter-girth measurement) of big Oak-trees, and about 16 or 17 lb. per cubic foot, or about 7 to 8 cwt. per load, of coppice growth. **Firewood** is usually sold in cords or stacks of 128 cb. ft. (8×4×4), or 144 cb. ft. (12×4×3), or 108 cb. ft. (12×3×3), or 96 cb. ft. (8×4×3), according to local custom.

The factors for conversion of stacked measurement into actual cubic contents that have been accepted by the German experimental stations for forestry investigations are :—

Pitwood and poles	0·75 to 0·8	Small branchwood (conifers)	0·5
Split fuel	0·75	" " (other trees)	0·35
Fuel faggots	0·6 to 0·7	Roots and stumps	0·5

(2) **Measurement of Standing Trees.**—The height and cubic contents of trees, and often the contents of whole crops of timber in Britain, are habitually estimated by ocular measurement—an unreliable system, leading

sometimes to errors of large amount. As instruments for measuring height and girth or diameter can be so easily used, actual measurements are much preferable, because anything like correctness in ocular estimate depends on constant practice and immediate opportunity of comparing the results with the actual contents of the trees.

"In estimating the contents of standing timber considerable experience is necessary. Our British trees are not as a rule of great height, and the length of the stem can be judged fairly accurately by the eye, with the occasional assistance of a jointed 20-ft. rod. The quarter-girth is then estimated at a point half-way up. Sometimes the judgment can be assisted by measuring the quarter-girth as high as one can reach, and calculating the difference or "fall-off" between that point and the proper girthing-place. An experienced timber-valuer will, of course, readily estimate the contents of the tree without the help of rod or staff."—(R. Anderson, *The Conversion of Home-grown Timber* (p. 5), in *Jour. Roy. Agri. Socy. Engl.*, vol. 64, 1903.)

For hedgerow, field, and park timber, requiring only a rough estimate, I have found it best to measure the girth at 5 ft. up with a tape-line, then to estimate the "timber-height" to 6 in. diameter (equal to about 20 in. girth), treat this as the length of the log, and take the mean of the girth (measured) at 5 ft. and at timber-height (20 in.) as about equal to the girth at the middle, then make the usual bark-allowance, square the net quarter-girth, and multiply into the length. With the use of an easily-prepared table, the contents can be very quickly estimated and the tree valued, while it is being blazed and numbered with white paint.

In comparison with the more logical and correct Continental system of timber measurement explained below, this essential business part of British forestry is at the very first step met with the two great practical difficulties —(1) that there is no generally recognised definition of "*timber*," and (2) that consequently the methods and details of measurement vary according to local habit and custom.

Theoretically, **timber** includes *all wood used for technical purposes*, a definition which distinguishes it from wood used as fuel. But there are legal differences and distinctions, varying locally according to "*particular custom*" and often perplexing, which determine whether or not the wood of certain kinds of trees is classifiable as timber.[1] Thus Oak, Ash, and Elm are everywhere legally regarded as timber trees, while Beech in England is only timber in the eye of the law in the southern counties having chalk-hills on which Beech-woods are worked as regular crops. But the former are in some parts only timber when 20 years old or upwards (see p. 233), while in others they require to girth 2 ft. a little above breast-height, and in others, again, they are only thus classifiable when containing 10 cb. ft. or more of wood. The general practice in England at present is to class as timber all trees measuring 6 in. in quarter-girth (*i.e.*, 2 ft. in girth, or above 7½ in. in diameter) at 5 ft. above the ground, or equal to about 8 in. in diameter at breast-height. What is of more practical importance, however, as regards the measurement of trees for sale or valuation, is the local habit and custom recognised in transactions with wood-merchants in respect of what shall be measured and what shall be excluded in the way of top-pieces and small branchwood.

The local custom obtaining in Perthshire, and throughout most of the well-

[1] Under three Acts of Parliament, passed in 1766 and 1773, Oak, Beech, Hornbeam, Chestnut, Walnut, Ash, Elm, Cedar, Fir, Larch, Aspen, Poplar, Lime, Alder, Maple, Sycamore, and Birch were all made classifiable as *timber trees*. (See also vol. i. p. 58.)

wooded tracts of Scotland, is for measurement to be made only up to the point where the stem has a diameter of 6 in., free of bark, or practically 7 in. in actual diameter. All below that, the "top and lop" of the branchwood, goes to the purchaser without any payment, to be removed, disposed of, or left on the ground as he feels inclined. Just as the quarter-girth system of measurement probably originated in making allowance for wastage in conversion, so too this ancient custom, common to most parts of Britain, was probably intended to be a set-off against the cost of felling the tree. It is a remnant of old usage which might well be abolished near large towns where there is a ready sale for faggots and fuel; but in outlying districts it will continue till small wood becomes more valuable.

Where pitwood is saleable, the timber measurement of conifers can be made to 3 in. diameter, the props being sold in lengths of $2\frac{1}{2}$ to 3 ft., with a top-diameter of $2\frac{1}{2}$ to 5 in. under bark.

The measurement of standing trees in Britain must necessarily, at present, accommodate itself to the local custom prevailing in any particular district, due recognition being made for the local allowance on account of bark. The simplest method is (1) *to measure the girth or diameter at breast-height*, $4\frac{1}{4}$ ft. above the ground; (2) *to determine, either by ocular estimate or by actual measurement, the "timber-height" of the tree*, where it has a diameter of 6 in. free of bark (or 3 in. in the case of conifers for pitwood); (3) *to measure the height of this latter point*, and then (4) *to calculate the cubic contents* from these three factors. If the top girth be taken at 20 in. (or 10 in. measuring so as to include pitwood) and added to that at breast-height, then the mean girth will be found by dividing their sum by 2; and the cubic contents will be found by multiplying the "timber-height" of the tree into the square of the mean quarter-girth, less the allowance for bark (see remarks on last page).

Example.—Say, a Scots Pine has a girth of 5 ft. at breast-height, and has a diameter of $6\frac{1}{2}$ in. (taken as a girth of 20 in.) at 60 ft. in height; what are its cubic contents in timber?

Here the mean girth $=\frac{60+20}{2}=40$ in. Deducting 4 in. as local allowance for bark, this gives a mean quarter-girth of 9 in., and the cubic contents are consequently $=60\times\frac{81}{144}=33\frac{3}{4}$ cb. ft.

If the tree were an Ash, and the local bark-allowance were only 2 in., the cubic contents would be $=60\times\frac{90{\cdot}25}{144}=37\frac{87}{144}$ cb. ft.

Or, again, in a Larch plantation in a mining district the trees average 3 ft. 10 in. in girth at breast-height, and have an average "timber-height" (up to 3 in. diameter for pitwood) of 56 ft.; what are the average cubic contents per stem? Here the mean girth $=\frac{46+10}{2}=28$ in., and the mean quarter-girth, less allowance of 4 in. for bark $=6$ in.; hence the cubic contents $=56\times\frac{36}{144}=14$ cb. ft. per tree.

Another way is to estimate the quarter-girth (by eye), say, as 9 in. or $9\frac{1}{2}$ in. at half the (estimated) *timber-height* of the tree, and to multiply the section thus shown by the length. Here, if one estimates to sell, the quarter-girth and the length are estimated full, while if estimating for buying, they are estimated short; and on these estimates the bargaining begins, usually to be concluded by "splitting the difference" between the divergent estimates.

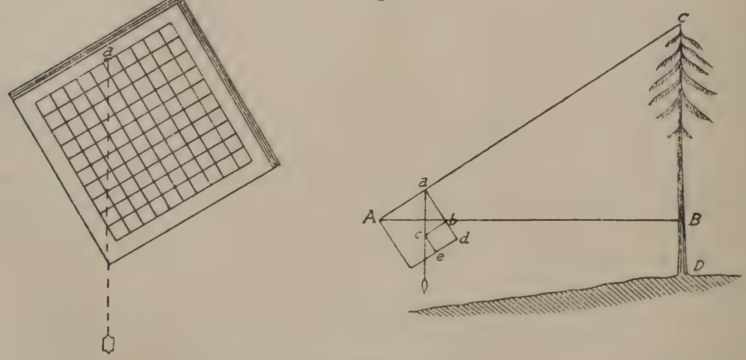
That is in the case of selling trees standing. Where, however, the sale is at so much per cubic foot, the timber is accurately measured when felled, and the price is paid according to the actual square-of-quarter-girth measurement of the cubic contents of each stem. And this is certainly the preferable method. To ascertain the contents of whole crops of trees in this manner, each stem will either have to be measured separately, or else average sample plots must be selected, the breast-height girths of all trees on these measured and classified, the girth of the true average stem ascertained, and detailed measurements made on selected, typical, true average stems, the contents of which, being multiplied by the number of trees on the area, will give the total quantity of timber on the sample plot. But the details concerning this method of estimating the contents of whole crops of timber will be more appropriately described later on.

The most practical and most convenient way of calculating with approximate correctness the true cubic contents of standing trees is to ascertain, first of all, (a) *the height*, (b) *the girth or diameter at breast-height*, and (c) *the "form-factor" or proportion which the cubic contents of the tree bear to a cylinder having the like height and basal area.* Such is the Continental method.

(*a*) **The Measurement of the Height of Trees** is made by means of instruments called **hypsometers** or **dendrometers**, of which there are many different kinds, and the simplest are the best for work in the woods. They all ascertain the height by means of the relative proportions of equal-angled triangles. Most of the methods in practical use require a base-line to be measured from the stem to the point of observation ; and the instruments of this sort which have proved most convenient for use in the Continental woods are König's *Measuring-Board*, Hossfeld's *Hypsometer*, Faustmann's *Mirror-Hypsometer*, and Weise's *Telescope-Hypsometer*,—and especially the last-named. The working of all three is based on the similar proportions of right-angled triangles, and they all require the base-line to be measured from the tree to the observer.

König's **Measuring-Board** (Fig. 201) is about 8 inches square and about an inch thick. It is divided into numerous squares numbered off in units, fives, or

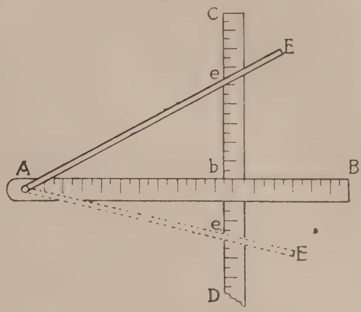
Fig. 201.



König's Measuring-Board.

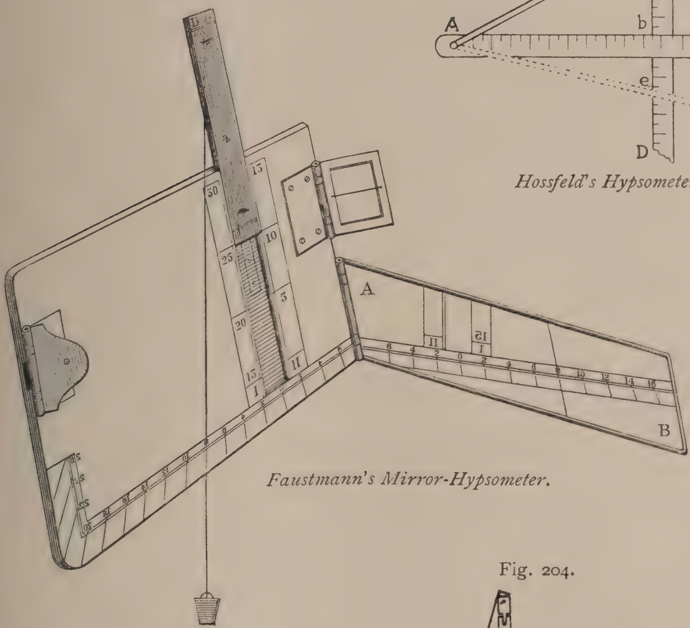
tens, and has a deep notch along the line of sight to the top of the tree. It may either be held in the hand or, preferably, fixed sideways, by a screw in the centre, to an upright staff shod with iron, which can be inserted into the ground to hold it in true position while a reading is being made. The board being adjusted so that the top line Aa meets the top of the tree C (or the "timber-height" of the stem, if this is being measured), then, in the similar right-angled triangles A B C and *a b c*, B C : *b c*=A B : *a b*. Now, as A B has been measured and *a b* corresponds with this distance, the reading *b c* will at once give B C, to which, if the observation be made on level ground, must be added the height from the ground to the eye of the observer, in order to ascertain the total height of the stem. If the measurements are made on hillsides, a double reading may sometimes be necessary, the supplementary reading being added to or subtracted from the original observation, according to the position of the observer.

Fig. 202.



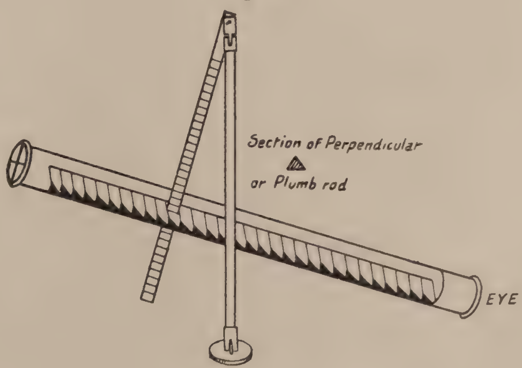
Hossfeld's Hypsometer.

Fig. 203.



Faustmann's Mirror-Hypsometer.

Fig. 204.



Weise's Telescope-Hypsometer.

The end near the eye-hole takes off, so that the upright and the weighted rod (which is triangular, to catch more easily on the toothed scale) can be placed inside the tube when not in use.

Say, for example, that A B has been measured and found to be 70 ft.; then, when A*a* has been adjusted in line with C, the reading *b c* (*b* being point 70 on the side scale) will correspond with B C, and can be read off as *d e* on the scale along the base of the board. If *d e* (=*b c*) is 45 ft., then B C is 45 ft., and the total height of the tree (B C and B D) will be 45 ft. plus the distance of the eye of the observer above the ground.

Hossfeld's **Hypsometer** (Fig. 202) is equally simple. A B and C D are similarly graded, and can be set at right angles, while the limb A E is movable. When A B is kept horizontal, and set so that A*b* represents the distance of the observer from the stem, then the readings (*b e* and *b e*) between A E to the top of the tree and A E to its base will, when added together, give the total height.

Faustmann's **Mirror-Hypsometer** (Fig. 203) is also merely another method of applying the same principle. It is a small instrument, mostly made of very light wood, which can be folded and put in a stiff paper case (about 7 in. long, 4 in. broad, and ½ in. thick) for carrying in the pocket. The distance of the observer from the tree having been measured, the movable upright arm is set accordingly. When short (0-15 yards, or multiples of 0-15 ft.), the end of this marked II. is adjusted on the right-hand scale, to form the similar triangle; while for longer distances (15-30 yards, or multiples of 15-30 ft.), the end marked I. is set against the scale on the left-hand side representing the number of yards (or multiples of feet) between the observer and the stem. In this handy little instrument the observation is made through an aperture in a small metal disc at one end, and by a hair-line stretched across a metal frame at the other end. This hypsometer can also be used for aligning forest roads, marking out drains, and the like. As in the case of the measuring-board, it can easily be fixed by a central screw behind to an iron-shod upright staff, when considerable accuracy is required. It costs only about 5s.

In the illustration the instrument is set at 26 yards, and the reading on the mirror gives the result as 8 yards or 24 ft., to which must be added the 5 or 5½ ft. from the ground to the eye of the observer in order to obtain the total height of the tree, if the observation is being made on a level with the tree. Otherwise a supplementary observation will have to be made from the horizontal to the foot of the tree, and added to or subtracted from the original reading, as the case may be.

Weise's **Telescope-Hypsometer** (Fig. 204) likewise rests on precisely the same principle as Faustmann's instrument; but it is constructed of brass, has a heavier weight to steady the free perpendicular, and has a toothed base to help to bring the perpendicular soon to rest, and thus simplify the reading off of the height. After the distance from the tree has been measured, and the movable upright arm has been set accordingly, the observation to the top of the tree (or to the "timber-height") is made through the telescopic tube. To assist the loaded perpendicular in becoming steady and true, the tube is turned gently round to the side from time to time, so as to let the perpendicular fall into the toothed scale running along the base. This toothed base is, besides construction with brass entirely, the only real difference between this and the last instrument, and it was originally suggested by Faustmann himself, to whose hypsometer a toothed plate along the base can easily be added. When the perpendicular rod is finally brought to rest, the figure or number registered by it corresponds with the height of the tree above the observer, to which, in order to obtain the total height (or "timber-height") of the stem, the usual addition or subtraction must be made, allowing for the horizontal base-line being above or below the base of the tree.

Another method of applying the same principle is Mackenzie's **Dendrometer**, which is fully described, with illustrations, in the *Trans. Roy. Scot. Arbor. Socy.*, vol. x., part iii., 1884, p. 141.

And yet another is the **Apomecometer**, which indicates the point where the height of the tree is equal to the distance of the observer from the stem (45°).

Brown made certain measurements as to rate of growth in height and in girth, which are given below (see *The Forester*, 6th edit., 1894, p. 359). But as they were made on thinnings only, and not on the poles and trees which remained to form the ultimate mature crop, they are of little or no practical value.

I. Rate of Growth in Height.

Age of trees when thinned out.	Broad-leaved trees.									Coniferous trees.				
	Oak.	Beech.	Ash.	Scots Elm.	Lime.	Sycamore.	Sweet-Chestnut.	Horse-Chestnut.	Black Italian Poplar.	Douglas Fir.	Larch.	Scots Pine.	Spruce.	Silver Fir.
	Average height in feet (but taken from thinnings only, and therefore not true average stems).													
Years.														
10	14	12	20	17	16	19	19	19	30	25	19	17	20	13
15	21	18	29	25	22	27	25	27	43	37	27	25	29	24
20	27	24	36	33	28	34	32	33	57	50	35	33	38	35
25	33	30	43	41	34	40	38	38	68	61	44	42	47	44
30	39	36	50	47	40	45	42	42	76	71	49	48	55	54
35	45	41	56	53	45	49	47	44	82	...	55	54	61	62
40	48	47	61	56	49	54	50	47	87	...	59	60	66	69
Average annual increase in height (inches).	14¼	14	18	16¾	14½	16	15	14	26	28	18	18	19¾	20½

II. Rate of Growth in Girth.

Kind of tree.	Broad-leaved trees.										Coniferous trees.									
	Oak.			Sycamore.	Ash.	Black Poplar.	Scots Elm.	Sweet Chestnut.	Beech.	Birch.	Larch.			Scots Pine.			Spruce.			Silver Fir.
Quality of soil and situation. (I.=good. II.=average. III.=inferior.)	I.	II.	III.	II.	II.	I.	II.	II.	II.	II.	I.	II.	III.	I.	II.	III.	I.	II.	III.	II.
Age.	Diameter in inches at 8 feet above the ground.																			
years.																				
10	1¼	¾	¼	2¼	1½	6	1½	2½	2	½	2½	1¼	..	1¾	1	..	2¾	1¼	..	1½
15	..	..	..	..	..	10	4	4½	4	..	5	3	2	4½	3	½	5	3	1⅓	8
20	4½	3	2	5½	4½	15	6	7	6½	2½	9	7	5	6½	4½	2½	7	5½	3¼	12¾
25	..	..	..	..	..	21	8½	8½	9	..	11	9	6	10	6	4	10	8	4½	15¾
30	9½	7	4	9½	7	26	10	10	10½	7	13½	11	7½	12	7½	5½	13½	11	5½	18
35	..	..	..	11½	9	29½	12½	11½	15	..	17	13½	8	14	9	6	15	13	6	24
40	16	12½	8	13	10½	33	14½	13½	17	10	22	15½	..	16	10½	6½	17½	15	..	28½
45	..	..	..	15	12	36½	16	14½	19½	..	23½	16½	..	17½	12	7	18¾	16	..	30
50	20½	16	9	16½	14½	39½	17½	15	21	12	24½	17	..	19	13½	7¼	20	17½	..	32
55	..	..	..	18	17	42	19	16½	22½	..	25½	17½	..	20½	14½	..	21¼	18	..	33¾
60	25½	18	10	19½	19½	43	21	17½	24	14	27	18	..	21½	15½	..	22¾	18¼	..	36½
65	..	..	..	21	22	..	22½	19	25½	..	28	..	..	22½	16½	..	23½	18¾	..	37¾
70	29	19½	11	22½	24	..	23½	20	27⅓	14½	29	..	..	23¼	17	..	24½	19	..	..
75	..	..	..	23½	26	..	24½	21	28¼	..	30	..	..	24	17½	..	25½	..	..	..
80	31½	20½	11½	25½	28	..	25½	22	29	15	..	..	..	..	..	..	..	..	..	..
85	..	..	..	27½	30	..	26	22½	30½	..	..	..	..	..	..	..	..	..	..	..
90	32¾	21½	..	29	31½	..	27	..	..	15	..	..	..	..	..	..	..	..	..	..
95	..	..	..	30	33	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
100	33½	22	..	31½	34	..	28	..	..	..	..	..	..	..	..	..	..	..	..	..

For soil and situation of average quality at Giessen (in Hesse, near Frankfort-on-Maine), G. Heyer (*Das Verhalten der Waldbäume gegen Licht und Schatten*, 1852) found, by analysis of the stems, the following to be the average rates of growth in height in woods of **normal density of leaf-canopy** for the given kinds of trees :—

Age of crop.	Conifers.				Broad-leaved trees.								
	Larch.	Weymouth Pine.	Scots Pine.	Spruce.	Oak.	Beech.	Ash.	Maple.	Sycamore.	Elm.	Aspen.	Birch.	Alder.
	Average height in feet.												
Years.													
10	20	8	6	1	3	2	1	3	2	6	10	10	7
20	46	25	21	16	18	16	17	18	15	19	30	31	21
30	66	43	41	37	36	33	36	36	33	38	48	47	41
40	84	58	54	55	51	50	54	50	52	55	62	61	58
50	96	70	69	68	64	62	66	62	64	67	73	73	70
60	...	...	80	79	75	73	75	71	74	76	81	80	79
70	...	...	87	87	83	80	82	78	80	82	86	...	84

These measurements have evidently been made (except in the case of the Larch and the Weymouth Pine) in woods that have been raised by natural regeneration.

For the **formation of mixed woods** a careful study of such a table gives invaluable information with regard to the forecast of thinning operations. But this can only be of use as a general guide ; for in all concrete cases the actual conditions of growth of the crops under consideration must be carefully studied by the forester on the spot.

(*b*) **The Measurement of the Girth or Diameter** should be made at breast-height, at a constant distance of $4\frac{1}{4}$ ft. or 51 in. above the ground. By measuring at any other than a constant height, the use of average form-factors would be unnecessarily exposed to error, and by taking any other than the above height of $4\frac{1}{4}$ ft. (1·3 metre = 4 ft. 3 in. approx.) for calculating the basal area of the stem, the good practical German tables of average form-factors could not be correctly applied to British measurements. The Continental form-factors can only, however, be used to give the true cubic contents, which will be subject to $21\frac{1}{2}$ per cent for square-of-quarter-girth measurement and, say, on a very full average, up to about 15 per cent for bark-allowance, or $36\frac{1}{2}$ per cent in all.

The girth is usually ascertained by means of the ordinary measuring-tape, made of linen or of steel ; but that made of metal is less liable to give wrong readings after much use.

In measuring the girth of standing trees the **tape** should, as when measuring logs, be drawn tightly several times from right to left and back again, so as to sit level on the far side of the stem, before the ends are brought together to read the measurement ; and care should be taken to see that it is as nearly level as possible. For approximately correct results it is of course essential that the girth should be measured as correctly as possible, and this can only be secured by care.

The diameter is measured either with **timber-callipers** made of well-seasoned wood or of metal, or with **tree-compasses** made of metal.

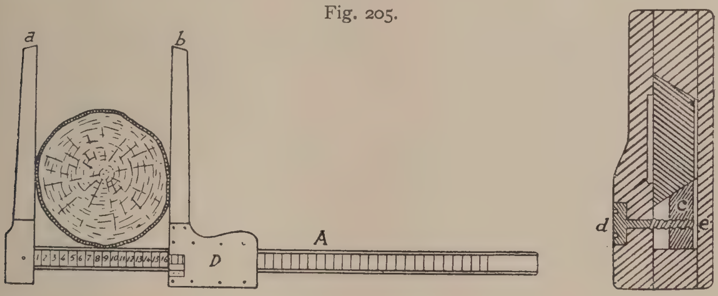
The **timber-calliper** consists of a graduated base, divided into inches, with one fixed and one movable arm, each at right angles to the base.

In graduating the base, the divisions are made from inch to inch, in such a way that from $\frac{1}{2}$ to $1\frac{1}{2}$ in. is marked 1 in., from $1\frac{1}{2}$ to $2\frac{1}{2}$ in. as 2 in., from $2\frac{1}{2}$ to $3\frac{1}{2}$ in. as 3 in., and so on, in order to simplify reading off the diameter and entering it into the measurement books.

The calliper only measures diameters; but, if girths be desired, the graduated base can easily be marked, so as to give the corresponding girth in place of the diameter actually measured. Measurement by diameter, rather than by girth, is preferable, because it can be made much more rapidly and with greater accuracy.

It is essential for correct measurement that the movable arm should be applied to the tree at right angles to the graduated base, otherwise the measurements must be either too large or too small. And, as remarked with regard to measuring logs, the mean of any two diameters $\left(\frac{D+d}{2}\right)$ measured at right angles to each other gives a more correct result than the measurement of only one diameter, because then, even if the section of the stem be elliptical in shape, its contents will be more correctly ascertained than is possible with one diameter. To obviate the trouble such twofold measurement on

Fig. 205.



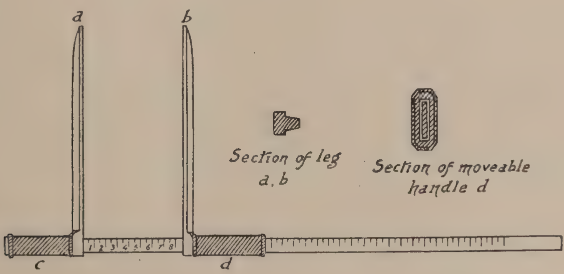
G. Heyer's Calliper.

each stem would cause, the stems can be measured alternately from N. to S. and E to W., or across the long and the short axis, because the elliptical form of the stem is generally dependent on the direction of the prevailing wind.

Unless made of well-seasoned close-grained wood (*e.g.*, pear-tree), the calliper is apt to shrink and swell with drought and rain.

One of the best callipers in use in Germany is Gustav Heyer's (Fig. 205). The movable leg b is enclosed in a case (D) so that the fixed scale (A, trapezoid in form) has a

Fig. 206.



Bessemer Steel Calliper in use in the Tyrol.

narrow free space on either side to diminish friction. The base of A rests on a metal wedge c; and according as A shrinks or expands or gets loose from use, c can be tightened or loosened by keying it up by means of the screw d e.—The best of the metal callipers is that in use in the Tyrol (Fig. 206). The handles *c d* are padded for warmth in winter and to give a better grip at any time. An aluminium calliper would of course be much lighter.

The crops, or portions of crops, to be measured should be gone through in narrow strips, and each stem measured should be marked with chalk, whitewash, or paint (or with the scribe) on the side towards the measuring party, so that no mistake may occur as to omitting stems altogether or measuring any twice over. The men using the callipers should be carefully instructed about measuring at breast-height (4¼ ft.), and if necessary this can be more practically brought home to them by tying a piece of coloured ribbon to the coat or waistcoat-button representing that height on each of them. In thick woods with close cover two calliper-men will usually be found to be enough; but among big trees the forester will generally be able to record the measurements of three, or even four, men. It is best, however, not to have more than two or three in any case, as it is then easiest to keep an eye on their work and to see that the callipers are properly applied at the right height and at right angles to the axis of the stem.

Where small poles occur among large trees, they need not be included in the measurement.

The **tree-compass** consists of bent metal legs, one being fixed and the other movable (to which a graduated scale is attached), working from a pivot, so that when the stem is fixed within the ball points at the end of the legs, the diameter (graded in inches, as in the case of the calliper) may be at once read off on a graduated scale near the two handles.

The drawbacks to tree-compasses are their weight, and the tendency there is to measure less than the true diameter. This latter drawback can be easily minimised by having fairly large hollow balls at the ends of the legs; but the true diameter is even then less easy to obtain than by the use of callipers.

As each calliper-man calls out the diameter (or girth) just measured by him, it can best be entered in the tabular record by the common tally method :—

Diameter at breast-height (4 ft. 3 in.)	Kind of tree.				Totals.				Gross total.
	Oak.	Beech.	Sycamore.	Ash.	Oak.	Beech.	Sycamore.	Ash.	
	Or in conifer crops.				Or				
	Scots Pine.	Larch.	Spruce.	Birch.	Scots Pine.	Larch.	Spruce.	Birch.	
Inches. 14	𝍸 𝍸, 𝍸 I	𝍸 𝍸, I	𝍸 𝍸, 𝍸 𝍸, I	III	16	11	21	3	51
15	𝍸 𝍸, 𝍸 𝍸, 𝍸 𝍸, II	𝍸 III	𝍸 𝍸, 𝍸 𝍸, 𝍸 II	𝍸 II	32	8	27	7	74
16	𝍸 𝍸, 𝍸 II	𝍸 I	𝍸 𝍸, 𝍸 IIII	IIII	17	6	19	4	46
17	𝍸 𝍸, III	III	𝍸 𝍸, 𝍸 I	I	13	3	16	1	33
Totals					78	28	83	15	204

(*c*) The **Form-Factor**, or the proportion which the true cubic contents of a tree bear to those of a cylinder having the same basal area and height as the tree, varies greatly for different kinds of trees, and even for one and the same kind of tree according to the conditions of its growth.

The cubic contents of such a cylinder are = (basal area × height), whereas the cubic contents of the tree are only a fraction of this sum, and consequently this fraction or **form-factor** $= \frac{\text{actual contents of tree}}{\text{basal area} \times \text{height.}}$

Form-factors may be variously calculated, but the only ones of any real practical use are those referring to the cubic contents of trees measured at breast-height ($4\frac{1}{4}$ ft. above the ground). They may be so calculated as to give the whole cubic contents (*i.e.*, timber and branchwood, exclusive of stumps and rootwood), or else only of the timber contained (*i.e.*, wood from 3 in. in diameter upwards).

These latter are the more important for purposes of forest management, as in many localities, particularly in extensive conifer tracts, only the timber has any real market value, and estimates of yield, &c., must be made accordingly. And the same will usually apply to broad-leaved trees, which have more branchwood than conifer crops, especially in copsewoods.

Form-factors play a great part in timber measurement in Germany. Of course, they vary for one and the same kind of tree, according to the nature of the soil and situation, the density of the leaf-canopy, and the age of the crop.

But as the ideal cylinder (= 1·00) is calculated for the true stem-section, and not for the square of the quarter-girth, these German form-factors will have to be corrected before they can be of practical use in Britain.

The results of the investigations made at various centres of German forestry give the following as the average form-factors for trees growing in the close canopy of woods, and they may, no doubt, be quite well used for practical purposes in Britain. They are average figures only, and, as the form-factor really varies more or less according to the height of the tree, they cannot be expected to give exact results for individual trees :—

[TABLE.

Height of tree.	Tables of average Form-factors for								Height of tree.
	Beech.		Scots Pine.		Spruce.		Silver Fir.		
	Investigated by Baur.		Investigated by Kunze.		Investigated by Baur.		Investigated by Lorey.		
	Timber only.	Total cubic contents.	Timber only.	Total cubic contents.	Timber only.	Total cubic contents.	Timber only.	Total cubic contents.	
feet.									feet.
20	...	...	0·13	0·85	0·17	0·88	0·27	0·38	20
25	0·18	0·70	0·22	0·76	0·24	0·83	0·32	0·88	25
30	0·21	0·67	0·31	0·69	0·30	0·77	0·37	0·72	30
35	0·26	0·65	0·39	0·65	0·36	0·73	0·44	0·70	35
40	0·30	0·62	0·45	0·62	0·41	0·69	0·51	0·68	40
45	0·35	0·61	0·47	0·59	0·44	0·66	0·52	0·66	45
50	0·40	0·59	0·48	0·57	0·47	0·64	0·52	0·65	50
55	0·43	0·58	0·48	0·55	0·48	0·62	0·53	0·64	55
60	0·45	0·57	0·47	0·53	0·48	0·61	0·53	0·63	60
65	0·46	0·57	0·47	0·52	0·48	0·60	0·53	0·62	65
70	0·47	0·56	0·46	0·51	0·49	0·59	0·53	0·61	70
75	0·47	0·56	0·46	0·51	0·49	0·58	0·52	0·60	75
80	0·48	0·56	0·46	0·50	0·49	0·57	0·52	0·59	80
85	0·49	0·56	0·45	0·50	0·48	0·56	0·51	0·58	85
90	0·50	0·57	0·45	0·50	0·48	0·55	0·51	0·57	90
95	0·50	0·57	0·45	0·49	0·48	0·54	0·50	0·56	95
100	0·51	0·58	0·44	0·49	0·47	0·53	0·49	0·54	100
105	0·51	0·58	0·44	0·49	0·47	0·52	0·48	0·53	105
110	0·52	0·59	0·44	0·49	0·46	0·51	0·48	0·53	110
115	0·52	0·59	0·44	0·48	0·45	0·50	0·47	0·52	115
120	0·52	0·60	...	...	0·44	0·49	0·47	0·51	120

The form-factor for Douglas Fir in Britain has been found (at Scone) to range from 0·39 to 0·46 at about 40 years of age.

To find the true cubic contents of trees from the above table, one must measure the height and the basal area of the stem (at breast-height), multiply these into each other, and reduce the amount by multiplying it with the form-factor corresponding with the given height. But as Hess remarks, from whose arrangement of the investigations the above table has been adapted: "An exact result cannot be expected for any single stem by this method of calculating the cubic contents. Yet, when the tables are used for many stems, or for whole crops of trees, these averages of very numerous measurements and calculations yield good reliable results, because the errors for individual stems cancel each other."

It should be particularly noted that, unless the basal area be calculated by the British method, the results (actual cubic contents) will have to be reduced by $21\frac{1}{2}$ per cent so far as the timber is concerned, and a deduction of other 15 per cent will also have to be made for bark.

Example.—A Scots Pine is found to be 90 ft. high, and to have a girth of 6 ft. at breast-height. It therefore contains about $90 \times 2\frac{4}{5} \times 0{\cdot}45 = 113{\cdot}4$ cb. ft. of timber, and $90 \times 2\frac{4}{5} \times 0{\cdot}50 = 126$ cb. ft. in total contents, by true measurement; or $90 \times 2\frac{1}{4} \times 0{\cdot}45 = 91{\cdot}125$ cb. ft. of timber, and $90 \times 2\frac{1}{4} \times 0{\cdot}50 = 101{\cdot}25$ cb. ft. in total contents, by square-of-quarter-girth measurement.

(3) **Measurement of whole Crops of Wood** may take place in one of four ways, according to the degree of accuracy which may be desired. These various methods consist of—

(*a*) *Measurement of all the trees in a crop*, and calculation of the cubic contents of each tree.
(*b*) *Measurement of sample trees*, selected so as each to represent the average of different classes of trees arranged according to their girth, and sometimes also according to their height.
(*c*) *Measurement of sample plots*, selected so as to represent a fair proportionate average of the whole wood.
(*d*) *Estimate of the cubic contents per acre from average yield tables*, or from the known out-turn of similar crops.

(*a*) **Measurement of all the Trees in a Crop**, and calculation of the contents of each individual tree, can only take place in practice when the area in question is small and the trees vary greatly in girth. It is therefore not a system suitable for forest work on any extensive scale.

In Germany, the contents of each stem (as the product of basal area × height × form-factor) can be taken at once from the Bavarian Average Yield Tables of cubic contents (*Massentafeln*) on the girth (or diameter) and height being known. Arranged in 1846 as the outcome of 40,220 accurate measurements, these tables give good *average* results for Oak, Beech, Pine, Larch, Spruce, Silver Fir, and Birch; but they can, of course, not be relied on to give an accurate estimate of the contents of any one particular tree.

Where large woodlands are being operated with, the use of such Average Yield Tables is advisable. Thus the application of the Bavarian *Massentafeln*, even in other parts of Germany, yielded results far superior to any that could be obtained by ocular estimate. According to G. Heyer (*Waldertrags-Regelung*, 1883, p. 147), the following differences were noticeable on the crops being actually felled and worked up on experimental areas:—

Locality.	No. of stems measured.	Percentage of Excess.	Percentage of Deficit.
		Shown by the Bavarian Average Yield Tables.	
Rüdersdorf forest	263	...	0·6
Throughout Northern Prussia	70,546	1·8	...
Würtemberg	1,340	0·003	...
Hesse	8,401	0·9	...

(*b*) **Measurement of Sample Trees**, selected so as to represent the average of different classes of trees arranged according to their girth, and sometimes also according to their height.

The cubic contents of any timber-crop may be found by adding together the cubic contents of the individual trees; and these again, as we have seen, are found by ascertaining and multiplying into each other the basal area, the height, and the form-factor. Now, if these three factors varied for every tree, there would be no other way of correctly ascertaining the total cubic contents of the crop than to calculate the contents of each individual stem and add them all together. But, as these three factors are at any rate approximately equal for many trees, all such of the latter may be united into one class as are similar with regard to basal area, height, and form-factor. The advantage is thus gained that only one tree, or only a few trees, need be carefully measured in order to ascertain the cubic contents of each class through multiplication of the contents of the sample tree,—or the average contents of the sample trees, if more than one have been investigated,—by the number of trees in that class; while the cubic contents of the whole crop are found by adding together the total contents of the different classes.

Although it is always easy enough to ascertain the diameters or girths of trees at breast-height ($4\frac{1}{4}$ ft.), yet the height of trees can only be measured in comparatively open woods where one can see the top of each tree; while, be the woods in close or in open cover, the form-factor can, in either case, only be estimated. Hence, in crops forming close cover, only the basal area (diameter, girth) of the trees can be accurately ascertained. *Observation and investigations have shown, however, that, particularly throughout woods in close cover, the height and the form-factor are approximately proportional to the basal area,*—that is to say, *all the trees having the same basal area have also approximately the same height and the same form-factor.* The measurement of the cubic contents of wood-crops growing in close cover can therefore be much simplified by forming various classes according to diameter, each of which is at the same time a class for the height and for the form-factor.

In open woods, such as the majority of highwoods in Britain, the height and the form-factor are also more or less proportionate to the basal area, but the variations to which this proportion are subject are much greater than in woods growing in close cover. If the cubic contents of such crops are to be ascertained with comparative accuracy, at least the height of the trees must be measured or estimated as well as the girth or diameter—*i.e.*, height-classes have to be formed in addition to diameter-classes. The variations are often so great that form-factor classes cannot be arranged, although some approach to this can be made by measuring accurately the contents of several trees in each diameter or height class.

It seldom happens that the height is not more or less proportional to the basal area. Even in crops of very abnormal growth there is usually some distinct sort of proportion between girth and height, only here the limits within which this varies lie further apart. These latter are generally greatest in the case of trees which have long occupied an isolated position and have reached the age when the increment is very small—*e.g.*, as in old park trees and copsewood Oaks long over-mature, when the form-factor is usually about 0·66. Unless a considerable degree of accuracy is required, it will be sufficient merely to make diameter-classes and to consider them as being at the same time height-classes; but several specimen stems of different height must be measured in order to find the mean height of each class. Otherwise, if accuracy be desired, different height-classes will have to be formed, as well as the diameter-classes. If only two or three height-classes are formed, the classification of the trees can be easily made by ocular estimate, without going to the trouble of using a hypsometer.

When the whole of the stems in the wood have been measured and tabularly recorded (as described on pp. 298 and 300) according to diameter, in classes varying from inch to inch, the total basal area must be calculated for each class—unless average yield tables of cubic contents are to be used. The mean average basal area of the stems forming the crop is then found by adding together the total basal area for each class, and dividing this sum-total of all the basal areas by the total number of stems in the crop;[1] and as this basal area is $=\frac{\pi d^2}{4}$, it therefore follows[2] that the diameter of the true mean average stem in the crop will be $=\frac{2\sqrt{\text{basal area.}}}{\pi}$

The multiplication of the basal areas for each class, and the determination of the mean girth or diameter from the mean basal area, are usually made by means of sectional tables (see Appendix I., p. 402).

The girth or diameter of the true mean stem for the whole crop being obtained, good typical trees having this girth or diameter are sought out and selected for measurement, either by means of actually felling them and measuring their contents, or else—the usual method in practice—by measuring their height and estimating the contents from the table of form-factors (Continental method).

The specimen stems to be selected for individual measurement should be such as seem to fairly represent in height and shape, in extent of crown, and in general appearance, the class to which they belong; and they should be stems as straight and as nearly cylindrical as possible, and not of crooked or forked growth.

Weise's Rule.—It was found by Weise that if 40 per cent of the total number of stems in a measurement of the whole crop (or of a sample plot of average quality, carefully measured and counted) be taken, and a count back made to this extent from the largest stems downwards, the result will invariably lead one into the diameter-class containing the mean average stem for the crop (or sample plot). This is by far the simplest and best method for use in Britain.

Diameter.	Larch.
Inches.	Total.
6	43
7	131
8	190
9	412
10	718
11	547 †
12	356
13	181
14	99
15	45
Total . . .	2722

For example, say, a 3-acre patch of Larch consists of 2722 stems as shown in the accompanying table. By Weise's very simple rule for practical use, the true mean average stem will be found by taking 40 per cent of 2722 $\left(2722\times\frac{40}{100}=1088\right)$, and then counting back for 1088 stems, beginning with the largest diameter-class.†

In this given case it will be found in the 11-in. diameter-class.† By selecting several

[1] That the basal area of the true mean average stem must be the arithmetical mean of the basal areas in all the classes can easily be proved.

If x = the cubic contents of the true sample stem, and a, b,...the number of trees in each separate diameter class, then

$x(a+b+\ldots)=a(\text{basal area}\times\text{height}\times\text{form-factor})+b(\text{basal area}\times\text{height}\times\text{form-factor})+\ldots$

But the height and the form-factor of each class are proportional to the basal area, hence $x=\frac{(a\times\text{basal area})+(b\times\text{basal area})+\ldots}{a+b+\ldots}$, and the true mean average basal area $=\frac{\text{total basal area of all the stems in the crop}}{\text{total number of stems in the crop.}}$

[2] Basal area $=\pi r^2=\frac{\pi d^2}{4}$

$$\therefore \pi d^2 = 4\times\text{basal area}$$

$$\therefore d^2=\frac{4\times\text{basal area}}{\pi}$$

$$\therefore d=\frac{2\sqrt{\text{basal area}}}{\pi}$$

good specimen trees of this class, measuring their height, and ascertaining their form-factor, these three data will give their cubic contents; and the average of these multiplied by 2722 will be the total cubic contents of the crop. Or the average height and form-factor may be found by taking the mean height of the several specimen stems selected, the contents of the mean stem being then = true mean basal area × mean height of specimen stems × form-factor of latter. The results of this method will, however, only be fairly reliable if the crop is regular and in close cover. It cannot be depended on to give satisfactory results in irregular woods with broken canopy. Otherwise the specimen stems may be felled and their cubic contents accurately measured, which is by far the best way; but the above is the only way to do when the sample stems cannot be felled.

Endeavours have also been made to tabulate form-factors for whole crops of trees, based on the mean height, so that the cubic contents could be at once estimated by multiplying the total basal area × mean height × form-factor. Tables of this sort have been formulated by Neumeister and Behm, as given below (for timber only); but measurements of the total basal area and the mean height of characteristic crops coming to the fall, and comparisons with the yield actually given, will have to be made on an extensive scale before really reliable average data can be obtained.

Kind of crop.	Quality of crop. I. Very good.	II. Good.	III. Medium.	IV. Indifferent.	V. Poor.
	Form-factors for whole crop.				
Beech	0·51	0·51	0·50	0·50	0·49
Scots Pine	0·45	0·46	0·46	0·47	0·48
Spruce	0·49	0·50	0·52	0·54	0·57
Silver Fir	0·50	0·53	0·53	0·51	...

If a greater degree of accuracy is desired than can be attained by the very simple practical method of selecting the mean average stem in the above manner, then the sample stems may be chosen for each diameter-class, their contents measured (or estimated) and multiplied by the number of trees in that class, and the whole results for all the classes added together to find the cubic contents of the crop.

As this would often be undesirable, more particularly if the sample stems be actually felled for careful measurement, 2 to 4 (or more if containing very few stems) diameter-classes may conveniently be bracketed together to form groups, for each of which the mean diameter of the average sample stem can be calculated from the total basal area of all the diameter-classes included within each group. The groups may either be so formed as to include a larger number of diameter-classes of the largest and smallest dimensions, and a smaller number of those of middle dimensions (which always form the bulk of the crop, and whose cubic contents have therefore to be ascertained as correctly as is practicable), or they may be made so as to include an equal number of trees in each group. The former method is the simpler in practice, but the latter is that adopted by the experimental stations for forestry investigations in Germany.

Various other methods have been proposed, and in certain cases adopted in Germany, for determining the number of sample stems that should be selected for measurement, or individual investigation, in estimating the cubic contents. Thus, according to **Draudt's method** (1857), a constant proportion ($\frac{1}{2}$ to 2 per cent, according to the total number of trees in the crop) of the stems in each diameter-class is selected—several of the smallest and of the largest diameter-classes being grouped together, if necessary, to yield their quota—and the stems are felled and worked up, while the total cubic contents of the crop are found at once by multiplying these results by 200 to 50, according to the percentage selected.—**Urich's method** (1862), which also necessitates the felling of the sample trees, tried to improve on Draudt's system by combining it with the arithmetical mean in such a way that each diameter-class shall include an equal number of trees, so as to eliminate the error arising from fractions of classes being exceeded or left out of consideration; but the method is very circumstantial, and not a practical one. These German systems may be thus briefly exemplified:—

Diameter at breast-height in inches.	No. of trees.	Number of sample trees to be selected and measured.		
		Draudt's Method—1 per cent being selected.	Urich's Method—1 sample tree for every 100 trees.	Forestry Investigation Method—with 5 classes of equal numbers (300 each) and a like number of sample trees for each class.
5	12	} diam. = 6 in., 1	12 }	12 }
6	62		62 } 1 stem of 6 in.	62 }
			26 }	3 stems of 7 in.
7	178	2	100 1 " 7 in.	178 }
			52, 48 } 1 " 7 in.	48 }
8	248	2	200 2 " 8 in.	200, 100 } 3 " 8 in.
9	286	3	200 2 " 9 in.	
			86, 14 } 1 " 9 in.	186, 114 } 3 " 9 in.
10	218	2	200 2 " 10 in.	104 }
			4, 96 } 1 " 11 in.	3 " 11 in.
11	190	2	94, 6 } 1 " 11 in.	190, 6 }
12	154	1	100 1 " 12 in.	148 }
			48, 52 } 1 " 13 in.	
13	86	1	34 }	86 }
14	42	} diam. = 14 in., 1	42 }	42 } 3 " 13 in.
15	14		14 } 1 " 14 in.	14 }
16	7		7 }	7 }
17	3		3 }	3 }
Total .	1500	15	15	15

The above three methods are here only briefly referred to on account of their academic interest; but they are not applied in actual practice, because Draudt's and Urich's methods can only be used when the sample trees can be at once felled and measured to ascertain the proportions of the timber and branchwood.

For practical purposes in estimating the cubic contents of crops of wood in collecting data for the preparation of a working-plan, the calculation of the true average mean stem of the whole crop is the best system to adopt in regular crops growing fairly evenly in close cover; while for woods of irregular growth, which show considerable variation in the extreme dimensions of stems, it is preferable to form diameter-classes with such differences (1 in. in pole crops, and perhaps 2 in. in some cases for large tree-crops) as seem best to suit the requirements of the given case. But, *cæteris paribus*, the more numerous the diameter-classes—*i.e.*, the smaller the differences in diameter—the more likely are the results to be accurate.

The cubic contents of the trees in the different classes are in actual practice (in Germany) usually estimated by means of form-factors (see table on p. 302), for determining which numerous sample stems are selected and their height measured. The classification of trees according to their diameter or girth is also of use for investigating the current annual increment.

Such more practical (German) methods are exhibited and compared on page 309, the diameters being taken as in the last example, and the heights being supposed to be those found by measuring one or more sample stems proportionately from each class.

In actual practice, the number of sample stems selected for height measurement, or for otherwise being operated upon, must depend upon the total number of trees and the degree of accuracy considered essential in each case. The larger the number of stems individually measured or estimated, the more likely will the average of those truly represent the cubic contents of the true average tree. But a good practical rule is to stop further measurements of mean average sample trees when the general average contents already shown are not materially altered by bringing measurements of fresh sample stems into account.

In selecting the sample trees it is better to choose the stems by means of the mean diameter taken from two diameters measured at right angles to each other, as this has been found to give more accurate results than the selection according to girth.

Sometimes it is not possible to find suitable sample trees having the precise diameter of the true average sample tree. The only thing to be done then is to select suitable stems of as nearly the mean diameter as possible, make the calculations on these, and reduce the cubic contents thus ascertained according to the ratio existing between the basal area of this false average stem and the true average stem. The reason is obvious from the proportion of the cubic contents :—

True average stem : false average stem = true (basal area × height × form-factor) : false (basal area × height × form-factor) = true basal area : false basal area ; and, as the height and the form-factor are in each case proportional to the basal area, then the cubic contents of the true average stem = contents of false average stem $\times \dfrac{\text{true basal area}}{\text{false basal area.}}$

(*c*) **Measurement of Sample Plots,** selected so as to represent a fair proportionate average of the whole wood, can only be considered a good practical method when the crop is fairly regular throughout the whole area, and when very large areas are being dealt with. In small woods it is better to make a count out of the whole crop, as already described. In any case, the cubic contents on the sample plots are ascertained as in the other method.

As the correctness of the estimate must depend on the sample plots being a true average of the whole of the wood, it is desirable to select such as will include soil and growing-stock of each quality, or to have sample plots representing each distinct class differing materially as to quality. On hillsides it is best to take sample plots right up from the base to the top, giving them a trapezoidal form (broader at the base than at the top) so as to obtain a truer proportionate area of the different quality of land forming the whole hillside. On comparatively level tracts or undulating ground the sample plots should be taken in squares or rectangles as evenly as convenient over the whole area. They should be situated in the interior of the woods, and not along the edges. The sample plots may most conveniently be of half an acre or one acre each, and may vary in number up to 5 per cent or more of the total area, according to the degree of accuracy desired in assessing the stock in old woods; but in young crops such accuracy is not necessary.

Data common to all three methods.					Determination of the cubic contents (in timber only) of a crop of Scots Pine by means of—													
		Basal area.			I. Diameter classes varying from inch to inch.			II. Diameter-classes arranged in three convenient groups.					III. The mean arithmetical or true average stem of the crop.					
Dia-meter at breast-height.	Num-ber of trees.	Per stem.	For whole class.	Height of sample trees.	Product of total basal area × height.	Form-factor.	Cubic contents.	Basal area.	Average height.	Product of basal area × height.	Form-factor.	Cubic contents.	Basal area for total crop and for mean sample stems.	Average height.	Pro-duct of basal area × height.	Form-factor.	Cubic contents for mean sample stem, and for total crop.	IV. Weise's Rule.
inches.		sq. ft.	sq. ft.	ft.			cb. ft.	sq. ft.	ft.	cb. ft.		cb. ft.	sq. ft.	ft.	cb. ft.		cb. ft.	
5	12	0·1364	1·636	43	70·348	0·46	32·360											IV. According to Weise's rule, the mean average stem will be found in the class of 10 in. diameter, by counting back 40 per cent of 1500=600 from the largest trees. By taking this basal area, ascertaining the average cubic contents of such stem from the Bavarian yield tables, and multiplying this by 1500, the cubic contents would at once be easily found with a considerable degree of accuracy. Taken from the above data, it would be = 0·5454 × 48 (= 26·179) × 0·48 × 1500 = 18,848·88 cb. ft.
6	62	0·1963	12·170	44	535·480	0·46	246·321	61·385	44	2,700·940	0·46	1,242·43						
7	178	0·2673	47·579	45	2,141·055	0·47	1,006·295											
8	248	0·3491	86·576	46	3,982·496	0·47	1,871·773											
9	286	0·4418	126·354	47	5,938·638	0·47	2,791·159	331·827	47	15,595·869	0·47	7,330 06						
10	218	0·5454	118·897	48	5,707·056	0·48	2,739·38											
11	190	0·6600	125·400	50	6,270·000	0·48	3,009·600						795·417 / 1500					
12	154	0·7854	120·951	52	6,289·452	0·48	3,018·937						=0·530	48	25·440	0·48	12·2112 ×1,500= 18,316·8	
13	86	0·9218	79·274	54	4,280·796	0·48	2,054·782											
14	42	1·0690	44·898	55	2,469·390	0·48	1,185·307	402·205	53	21,316·865	0·48	10,232·09						
15	14	1·2272	17·180	57	979·260	0·48	470·045											
16	7	1·3963	9·774	59	576·666	0·47	271·033											
17	3	1·5763	4·728	60	283·680	0·47	133·330											
Totals	1500	..	795·417	..	..	..	18,830·329	795·417	..	..	..	18,804·58	0·530	48	25·440	0·48	12·2112 / 18,316·8	

When the cubic contents of the sample plots have been worked out, the contents of the whole wood are found by multiplying those according to the proportionate area investigated.

It has been found that, as a matter of experience, the estimates of growing-stock from sample plots give results that are somewhat larger than the actual yield may prove to be, and this error can vary up to as much as about 10 per cent.

Next to the use of Average Yield Tables (see Appendix III., p. 407) in point of convenience, and with respect to correctness, comes this method of selecting average sample areas, either through making actual measurements of the quantity of timber growing on these, or else by calculating out the average stem, and then either felling and measuring its actual contents, or else estimating them by means of the form-factor.

As height, girth, and cubic contents are all different expressions of the vital energy of the trees, they are all, in properly managed woodland crops, more or less distinctly proportional to each other. The most convenient manner of ascertaining the true average class of stem will therefore be by means of the average diameter, or girth, or basal area of the stem; for that *tree* will be of *average size* whose section at breast-height is the average of the basal areas of all the trees forming the sample-plot. Hence all the trees throughout the sample-plot should be measured at breast-height, and registered in the field-book in columns varying by 1 inch in diameter (or 3 inches in girth).

When this has been done, Weise's Rule can be applied to find the average stem, whose cubic contents must be ascertained.

(*d*) **Estimate of the Cubic Contents per Acre** from Average Yield Tables or from the known out-turn from similar crops. When many crops have been measured or their actual yield is known from the results of fellings, these data can be utilised in estimating the growing-stock per acre for similar crops, due consideration being of course given to differences in the known age, height, and density of canopy or thickness of the crop.

This is a reliable as well as a convenient method, wherever proper data are available from past experience and careful tabulation of actual returns in timber from the various classes of soil and situation, and for the different kinds of trees. But, although applicable for calculations *per acre*, they cannot, as merely average statistics, be expected to give any reliable indication of the actual cubic contents of individual stems, unless the latter should happen to be the average class of stem throughout the crop.

The height of the trees is a very good standard for judging the quality of the soil, and more particularly its depth. The density is dependent on the number of the trees, their total basal area, and the size of their crowns.

Both of these main factors are of course liable to modification according to the age of the crop when they are to be used for estimating the cubic contents of woods. But if the basal area and the height have first of all to be fixed by measurement, it is better to adopt at once one of the methods already described above. Otherwise, the height is a safer factor to go by than the diameter or basal area, though the diameter or the girth is easier to measure.

Unless his local experience is sufficient to enable the framer of a working-plan to formulate Average Yield Tables for use in any particular locality, the best plan of estimating the growing-stock (and the increment) of woods is to use those prepared for Germany by the experimental stations for Forestry Investigations (see Appendix III.), making such percentage of reductions as may seem necessary locally.

These tables are drawn up for five classes, according to the concrete quality of soil and situation—viz., I. (*very good*), II. (*good*), III. (*medium*), IV. (*inferior*), and V. (*poor*); but only I. to IV. need be given in Appendix III. Their use is, at any rate, to be recommended until the time may come when tables that may possibly be used with more advantage for, say, the Scottish Highlands, will be available. The equable and relatively damper climate of Britain is, on the whole, better fitted for the production of wood than the Continental climate, but our woods are not so well grown or managed as the French and German forests; hence the yield shown in these tables will usually be greater than can at present be obtained in Britain, though it is certainly not greater than what may be expected from our woods in cases where they are being economically managed for the sole object of growing the largest possible crops of timber.

These Average Yield Tables can be used either (1) *to determine the quality of the soil and situation*, the total cubic contents or out-turn in timber being known, or (2) vice versa, *to determine the yield of timber or total cubic contents of crops of woods on land of known quality*, or (3) *for calculating the increment* (*average and current*) *of woods at different ages*, or (4) *as a basis for making financial estimates to determine the value of timber-crops at various ages, the most profitable kind of trees to grow, the most profitable rotation, and other actuarial calculations.*

In the preparation of Average Yield Tables for local use, regular crops for each kind of wood and each representative class of land, and varying by, say, 5 or 10 years of age (so as to form a complete series from time of formation to maturity), might be sought out and measured year by year for 5 or 10 years in order to obtain a full series of returns for the whole rotation. But there are probably few or no localities in Britain where satisfactory data of this kind would be at present obtainable. Perhaps the simplest method is therefore to tabulate the actual results of fellings made in crops whose age is either known or can be fairly accurately estimated from the stumps of the trees, care being of course taken to ascertain as correctly as possible the concrete quality of the land, for both the soil and the situation exert special influence on the rate of growth and the total yield of woodland crops. But, in correlating actual returns of this sort, the original distance at which plantations may have been made and the severity or otherwise in the matter of thinning must be fully taken into account. Again, crops that have been planted seldom yield so large an out-turn as those raised by natural regeneration or sowing.

Exact measurements on crops made for purposes of framing a scheme of management can also be used with regard to the cubic contents of immature crops, care being taken of course in this, as also in the above cases, to ensure that the results booked shall be those of fairly characteristic crops, or preferably the average of several such.

Where the results thus obtained are not in themselves sufficient to form a complete series for every 5 or 10 years, the missing links in the table can be easily interpolated, just as would also have to be done in finding the yield or the growing-stock at any certain year not actually entered in the table. Say, for example, that crops of Larch on I. class land have an average yield of 6000 cb. ft. per acre at 60 years of age and of 8000 cb. ft. at 80 years of age; then, by interpolation, their yield should be about 7000 cb. ft. at 70 years of age, 7200 cb. ft. at 72, 7400 at 74, &c., because here the average increment would be 100 cb. ft. per acre per annum.

In the same way, if the actual yield of woods of such known ages as 31, 43, 54, 67, 79, 82, or 98 are obtainable, they can easily be used along with the other known results for interpolating the growing-stock, or the yield, at the more convenient ages for tabular purposes of 30 to 100 years of age, at regular intervals of 5 or 10 years.

Again, if land is of a concrete quality apparently better than III., but not so good as II. (representing quality of 0·6 in the decimal system of classification), its yield and increment can also be estimated by interpolation of the mean between those two.

2. **Estimate of the Age of Individual Trees and of whole Crops of Wood.**—It is of course essential to know the age of trees and crops, in order to be able to determine from their cubic contents what their average increment or rate of growth has been, and to utilise these for the purposes of management, in framing Average Yield Tables, &c.

(1) **The Age of Felled Trees** can be told by counting the number of annual rings on a section made at the base of the tree, and making such addition thereto as will allow for the growth of the young plant up to the height of the section.

If the section be cut slanting this makes the annual rings appear broader; and if the surface be smoothed with a knife or plane, that makes them easier to count. When they are too indistinct to be easily noted thus, they can often be read by giving the part of the surface under investigation a thin wash of methylated spirit in which a little aniline is dissolved.

The rings need not be all counted along one radius, as it is seldom that the rate of growth remains a constant maximum in one direction. When the rings get too narrow to be conveniently read, a stop can be made, the point noted with a lead pencil, and the last annual ring followed round to a more convenient point, whence the counting may be continued towards the centre or the circumference, as the case may be. In counting it is also well to tick off with the pencil every tenth ring, so as to simplify the revision of the count and detect where any error has been made.

Care has also to be taken to see that "false rings," sometimes made at the flushing of the summer foliage, are not included in the counting. These may be detected by observing that they do not, like the true annual rings, go round the whole of the stem. It may also occasionally happen that two complete rings may be formed in one year—*e.g.*, as in a season when Oaks have been defoliated by *Tortrix viridana* in June, and have subsequently flushed new foliage in July or August, but they will usually be extremely narrow, and vary markedly from those in front of and behind them.

(2) **The Age of Standing Trees** can only be told with any approach to accuracy in the case of the evergreen conifers which form distinct whorls in making their spring shoots. And even among these, it is only in the case of Pines that a count back can usually be made, by means of whorls and snags of whorls, so far as for 30 to 40 years. Whenever this simple plan is feasible, the whorls are counted from the top of the tree down to the ground, and 2 or 3 years are added to carry it back to the seedling age. Unless this can be done, the age is only determinable by felling, except there be records showing when it was sown or planted. In conifer crops too old for this method, and in the case of broad-leaved trees of any considerable size, felling is usually necessary.

(3) **The Mean Age of whole Crops of Wood** can be very simply determined, in what may seem to be fairly even-aged woods, by felling a few good sample stems, ascertaining their age by counting the rings on these, and taking the average.

When woods have been formed by natural regeneration, however, the individual trees forming the crop are seldom of anything like even age. Hence it is necessary to determine the mean age of the crop—that is to say, the number of years which it would take an even-aged crop to produce the cubic contents now forming the growing-stock, which shows considerable variation as to age.

Here there are practically several different age-classes in the crop, and the mean age may be found by **Smalian's Rule** (1840), which states that "*the mean age of a crop consisting of trees of different ages will be found by dividing the cubic contents of the crop by the sum of the mean average annual increments of the several* *different age-classes.*" This means of ascertaining it is, however, only applied in scientific investigations, whereas in practice the mean arithmetical average is taken, consideration being given to the extent of the different age-classes in striking the mean.

Taking $a, a_1, a_2, \ldots$ as the ages of each of the different age-classes, and $c, c_1, c_2, \ldots$ as the cubic contents of these several age-classes, then obviously the whole cubic contents of the crop will be

$$= c + c_1 + c_2 + \ldots,$$

and the mean average annual increment of each age-class will be

$$\frac{c}{a}, \frac{c_1}{a_1}, \frac{c_2}{a_2} \ldots$$

Consequently, the **mean age** of the whole crop $= \dfrac{c + c_1 + c_2 + \ldots}{\frac{c}{a} + \frac{c_1}{a_1} + \frac{c_2}{a_2} + \ldots}$

Example.—Suppose a compartment of 12 acres consists of three small crops of 5, 4, and 3 acres, estimated to be respectively 50, 60, and 70 years of age, and to be capable of respectively yielding 4800, 5100, and 5600 cb. ft. per acre, these being slightly different contents from what is shown by Average Yield Tables. What is, for practical purposes, the mean age of the whole crop?

$$\textbf{Mean age} = \left\{ \frac{(4800 \times 5) + (5100 \times 4) + (5600 \times 3)}{12} \right\} \div \tfrac{1}{3}\left(\frac{4800}{50} + \frac{5100}{60} + \frac{5600}{70}\right)$$

$$= (5100 \times 3) \div (96 + 85 + 80) = \frac{15{,}300}{261} = 58{\cdot}6 \text{ years.}$$

For such cases as estimating the age of a whole compartment containing several sub-compartments of different ages, which it is not desired to reckon as separate crops, a very simple method is followed in actual practice. The areas of the several even-aged portions being known by measurement, and their ages being ascertained by counting the rings on stems felled for this purpose, the mean age of the whole compartment will be found by adding together the sum of the years multiplied into the acreage of each separate portion, and dividing the amount by the total acreage.

Example.—If a 40-acre compartment consists of 12 acres of 25 years of age, 15 acres of 40 years, and 13 acres of 50 years, then the

$$\textbf{mean age} = \frac{(12 \times 25) + (15 \times 40) + (13 \times 50)}{(12 + 15 + 13)} = \frac{300 + 600 + 650}{40} = 38 \text{ years.}$$

3. **Measurement of the Increment or Rate of Growth of Timber-Crops** is, like determining the growing-stock in woodlands, essential for the purpose of management. Without an adequate knowledge as to both of these, which are so mutually dependent on each other, it is impossible to frame any sound working-plan on business principles.

(1) **The Factors determining the Increment** or rate of growth in cubic contents in each year are (a) *growth in height*, and (b) *growth in girth;* and they result in (c) *the increment* or *growth in cubic contents.*

(*a*) **Growth in Height** is most active in the pole-wood stage of development, when the "struggle for existence" among the individual plants impels their vital energy to show itself mostly in the direction of shooting upwards to obtain a fuller supply of light. As this struggle proceeds weakling stems become suppressed, while the individuals of more vigorous growth (of the ultimate survivors among which the mature crop will consist) gradually form close canopy for themselves and continue the struggle for light and air. But a time comes when the growth in height culminates and then gradually diminishes, sinking practically to zero in very old trees.

The rate of growth in height is most rapid in thick crops, but overcrowding must be prevented by means of judicious thinning. The attainable height depends on the kind of tree, the method of treatment, and the quality and depth of the soil; so much so is the latter the case, that the height of the trees forms a very good guide in estimating the general quality of the land. Conifers (and particularly Larch, Spruces, and Firs; less so Pines) have a more continuous tendency to upward growth than broad-leaved trees; while the close cover of highwoods produces longer and cleaner stems than is possible in the case of isolated standards over coppice or in heavily-thinned crops. With every tree, however, there comes a time when the power of further increase in height begins to flag, and the lateral expansion becomes the greater necessity. The crop must then be thinned to permit of this to the extent desirable in the interests of the landowner. This particular stage is reached earliest by the light-demanding trees (Larch, Scots Pine, Birch, Oak, Ash). This necessity for lateral expansion usually coincides in the close cover of highwoods with the age when the trees begin to produce good germinable seed, and to exhibit a capacity for natural regeneration; but this always takes place long before the crops attain their commercial maturity and before the fall can take place, unless rendered imperative by damage from disease, insects, &c. The most rapid growth in height is attained by Douglas Fir, Menzies Spruce, Larch, and Weymouth, Corsican, and Scots Pines among conifers, and by Poplars, Willows, Birch, Alder, Robinia, Ash, Maple, and Sycamore among broad-leaved trees. In coppices the shoots are usually longest in the first season's growth after the fall, though this is not the case with the Beech.

The best growth in height is obtained in even-aged highwoods of the proper or normal density of canopy and number of stems per acre for their age, and for the quality of the land. Here the upward growth is stimulated, at the expense of the growth in girth, till the maximum height for the given circumstances is attained; and only after that is the crop thinned so far as to encourage growth in girth at the expense of further growth in height. By consistently following this method of treatment, the largest number of long, straight, clean stems, and the largest yield per acre, will be produced, although each individual stem will neither have the girth nor the cubic contents of trees grown in thinner crops or as isolated standards in copse.

The following table (adapted from Graner, but see also Appendix III.) shows the **average heights** attained by woodland crops in Germany in even-aged highwoods of normal density for the given tree, soil, and situation :—

[Table.

Age.	Mean Average Height, in Feet.										Age.
	Beech, Investigated by Baur.					Scots Pine, Investigated by Weise.					
	Quality of land.					Quality of land.					
	I.	II.	III.	IV.	V.	I.	II.	III.	IV.	V.	
Years. 40	**50**	40	33	26	20	**52**	**43**	36	30	26	Years. 40
50	60	**53**	46	36	26	63	52	**43**	**36**	30	50
60	73	63	**56**	46	33	73	60	50	43	**36**	60
70	80	70	63	**54**	40	80	66	56	50	40	70
80	86	76	70	60	**46**	86	73	63	53	43	80
90	93	83	73	63	50	93	80	66	56	46	90
100	100	86	76	66	53	96	83	70	...	...	100
110	103	90	80	70	56		86	73	...	...	110
120	106	93	83		60	100	90	76	...	...	120

Age.	Mean Average Height, in Feet.										Age.
	Spruce, Investigated by Baur.					Silver Fir, Investigated by Schuberg.					
	Quality of land.					Quality of land.					
	I.	II.	III.	IV.	V.	I.	II.	III.	IV.	V.	
Years. 40	50	36	26	20	...	46	36	30	23	16½	Years. 40
50	**63**	46	36	26	...	**60**	50	40	33	23	50
60	73	56	43	33	...	70	**60**	50	40	30	60
70	83	**66**	**50**	**40**	...	80	70	**60**	**46**	36	70
80	93	73	56	43	...	86	76	70	60	**46**	80
90	100	80	63	46	...	93	83	73	63	50	90
100	106	86	66	50	...	100	86	76	66	53	100
110	113	90			...	103	90	80	70	56	110
120	116	93	70	53	...	106	93	83		60	120

The age at which the average rate of growth culminates is shown by the heavy figures.

If it be desired to ascertain the height of a felled sample tree at any particular age, or its growth in height during any given number of years, this can be found by cutting it into sections and measuring the height at which the stem shows the proper number of annual rings in the one case (*i.e.*, total number, less the number of rings making the particular age in question), and by deducting this height from the total length in the other case.

As regards the rate of growth for the next 5 or 10 years, this may be estimated with sufficient accuracy for all practical purposes as being about proportional to what it has been in the previous 5 or 10 years, the upward or the downward tendency being, in either case, taken into account. The only error will be just at the time when the rate of growth culminates and begins to descend, but even then the difference will only be slight.

(*b*) **Growth in Girth, Diameter, or Basal Area** of any tree is more or less directly proportional to the expansion of its crown in height and breadth, and to the quantity of its foliage. The breadth of the zone of wood annually formed is smallest in the youngest stages of seedling growth, then gradually increases, and attains its maximum when the proportion between the lateral extent of the crown and the basal area of the stem exhibits the greatest difference, after which it decreases.

The annual rings are not always equally broad in all parts of the stem, as may easily be seen from pollarded trees. Suppressed or frequently pollarded trees sometimes fail to form rings in the lower part of the stem, the available quantity of elaborated sap being completely exhausted in laying on the annual zone in the upper portion of the stem ; hence their frequent club-like shape.

In woods growing in close cover the stems form their broadest annual zone at the top of the stem, and its breadth gradually decreases in the downward direction, while the opposite is the case in isolated trees, such as standards in copse. Hence timber grown in highwoods is more "full-wooded"—*i.e.*, has a higher form-factor and a greater technical value, bulk for bulk, for general purposes, than wood allowed to grow branching, crooked, and conically. And as the breadth of the annual rings may also vary on any section, this causes the stem to deviate more or less from the true perpendicular, especially when growing in comparative or actual freedom from the side shade of other trees.

The breadth of the annual ring depends on the given kind of tree and its nutrition ; and the latter is directly dependent on a variety of circumstances, such as soil, elevation, exposure, local climate, the age of the tree, its position in copse or highwood, &c. Spring and summer drought tend to decrease its breadth, and even a very hard preceding winter exerts its influence in this manner. The better the soil, the more favourable the situation, the milder the climate, and the more freely the tree can expand its crown of foliage, the broader will the annual ring be ; while it will be narrowest in crowded highwoods on poor land and in an exposed situation.

The past rate of growth in girth, or in diameter $\left(\frac{\text{girth}}{\pi}\right)$, and consequently the basal area $\left(\pi \times \text{radius}^2 = \pi\left(\frac{\text{diameter}}{2}\right) = \frac{\pi \times \text{diameter}^2}{4}\right)$, can easily be ascertained from countings made on the sections of felled stems. Hence the growth in basal area during any given period of time can readily be found by subtracting the sectional area at the age of x years from the sectional area at the age of $x + y$ years. But for estimating the past rate of growth on standing trees, whose previous girth 1, 2, or more years previously is not known, *Pressler's borer or increment gauge* (see p. 325) can be used with great practical advantage.

The **Mean Diameters at Breast-Height**, taken from the German sources already named, are as follows for trees growing in the close canopy of well-managed highwoods (*British Forest Trees*, 1892, p. 41):—

Age of crop.	Beech.		Scots Pine.		Spruce.		Silver Fir.	
	Quality of soil.		Quality of soil.		Quality of soil.		Quality of soil.	
Years.	I.	V.	I.	IV.	I.	IV.	I.	V.
	Mean diameter at breast-height (4½ ft.) in inches.							
40	4·0	...	6·4	2·8	5·6	Data not available.	5·2	2·0
60	7·6	3·2	9·6	4·4	9·2		9·2	4·0
80	10·0	4·8	12·0	5·6	12·0		12·8	6·4
100	11·6	6·8	17·2	...	14·0		15·6	8·0
120	13·6	8·4	18·0	...	15·2		17·6	9·6

Comparatively few details are available regarding the rate of growth in girth of individual stems in German woods and plantations, because the **units of consideration** are not the height and the girth and the cubic contents of the individual stems forming the crop, but the average height and average girth and average cubic contents of the whole crop per hectare. The difference between the two methods of estimating the quality of the woodland crops is, in fact, precisely what might be expected from our **arboricultural** way of looking at trees as compared with the **sylvicultural** method of treating forests on the Continent.

(*c*) **The Increment or Growth in Cubic Contents**, forming the actual addition of wood during each year, is the result of each season's growth in height and in girth. The amount of increment mainly depends, *cœteris paribus*, on the extent of the insolation (*i.e.*, exposure to light and warmth) of the crown of foliage. When trees grow with free exposure of their crowns, transpiration is greater, assimilation is much more active, circulation of the sap is more rapid, and the deposition of ligneous tissue is more vigorous; hence the total increment and energy of growth are greater than when the individual growing-space is confined and circumscribed.

The growth in cubic contents of any crop is merely the resultant or final expression of its energy with regard to growth in height and growth in girth combined. It is, of course, like each of these specific forms of vegetative activity, more energetic on soil of good general quality than on any poorer descriptions of land. Hence, whilst the average annual increment of the crop culminates earlier on inferior soil, the progressive profitable development of woodland trees is of longer duration the more the soil and situation are suited to the natural requirements of the kind or kinds of trees forming the crop. In other words, on the better classes of land there will not only be a larger out-turn in timber per acre at any given age than from poor land, but at the same time longer periods of rotation may be employed—*i.e.*, the fall of the mature timber will not, by purely financial calculations, be indicated at so early an age as on woodland tracts of an inferior description.

Wherever woods are crowded—that is to say, exceed the normal density of canopy—then growth in height is stimulated at the expense of growth in girth; and when the individual growing-space is larger than there is any necessity for, then growth in girth takes place at the expense of growth in height for each individual stem forming the crop. There must, consequently, be a certain point—varying of course in each crop according to the nature of the soil and situation, the kinds and ages of the trees, &c.—or **normal density of canopy** which unites the maximum length of stem with the maximum mean girth of bole, so as to produce the maximum cubic contents per acre that can possibly be expected from the land in question. And the maintenance of a normal density of canopy has also other advantages, in the way of forming a more full-wooded bole—*i.e.*, a stem having a better proportion of top-girth to basal area—and of maintaining the productivity or fertility of the soil against insolation and exhausting winds.

As regards both the actual increment in cubic contents and its component parts, growth in height and growth in girth, these may be distinguished as the *current annual increment* of any particular year, or the *periodic increment* as the sum of the current annual increments for a number of years, or the *total increment* representing the sum of the current annual and periodic increments up to any given age, or the *mean annual increment* representing the average annual rate of growth of any crop hitherto, as found by dividing its total increment by the number of years that have been required for its production—*i.e.*, its age. For certain purposes of management a distinction is also made between the mean annual increment of the crop as it now is and its probable mean annual increment when it attains maturity and comes to the fall.

If a 70-year-old crop of Larch contains 6300 cb. ft., and is setting on new wood to the extent of 85 cb. ft. a-year, its *current annual increment* is 85 cb. ft., its *total increment* is 6300 cb. ft., and its *mean annual increment* is $\frac{6300}{70} = 90$ cb. ft. a-year. If its stock at 60 years of age had only been 5600 cb. ft., then the *periodic increment* for the 10 years would be $\frac{6300-5600}{10} = 700$ cb. ft., or at the mean rate of 70 cb. ft. a-year during this period. If it is likely to give a mature yield of 7000 cb. ft. at 80 years of age, then its probable mean annual increment when mature may be reckoned as $\frac{7000}{80} = 87\frac{1}{2}$ cb. ft. per annum.

The current annual increment is the growth made by the tree or the crop during the season immediately preceding that in which the investigation is being made. It can either be estimated in cubic feet, or else it can be expressed as the percentage of the yield of the tree or crop—*e.g.*, in the above case the current annual increment of the 70-year-old Larch crop would have the following proportion—

$$\text{current annual increment} : 100 = 85 : 6300; \text{ hence}$$

$$\text{current annual increment} = \left(\frac{85 \times 100}{6300}\right) = 1{\cdot}349 \text{ per cent.}$$

The current annual growth in cubic contents increases year by year up to a certain age; but both its amount and its time of culmination are essentially dependent on the concrete influence of soil, situation, kind of tree, method of treatment, close or open condition of crop, age, &c. It is most rapid during the pole and young tree stages of growth, and it sinks gradually after having attained its culminating point. The mean annual growth increases more regularly than the current annual increment until it culminates (at the moment when its amount equals that of the latter, see p. 321), after which it also gradually sinks, though more slowly than the current annual increment.

As only a portion of the trees forming the crop in young woods can grow up to maturity, owing to want of space and demand for light, undesirable stems are removed in the course of the *thinnings*, while still in serviceable condition, and constitute the *intermediate* yield.

Average Returns from Thinnings have not yet been collected and tabulated for Britain. The following data are taken from Burckhardt's *Hülstafeln für Forsttaxatoren*, 1861, which had special reference to Hanover. But further data are also available from the Average Yield Tables (Appendix III.)

I. Thinnings from **Oak-Woods.**

Thickets raised from seed on good land give considerable returns in tanning-bark before their 20th year. After that the heavy thinnings required by Oak yields about 300 to 450 cb. ft. (true cubic contents) per acre during each decade. The following average yield may be reckoned :—

Under favourable circumstances,	37 to 45	cb. ft.	per acre and	per annum.
" average "	30 " 37	"	"	"
" unfavourable "	22 " 30	"	"	"

The higher yield refers chiefly to maturing crops.

When a *partial clearance* (*with under-planting*) is conducted about the 80th or 100th year, then further intermediate returns from the main crop are dispensed with or discounted; but the partial clearance itself utilises a large proportion of the crop, and accelerates the maturity of the remainder.

II. Thinnings from **Beech-Woods** (true cubic contents,[1] including small branches), in cubic feet per acre and per decade.

Age of crop.	Quality of soil and situation. I. Very good; crop very dense.	II. Good.	III. Medium.	IV. Inferior.
Up to 30 years . .	180	135	90	60
30-40 " . .	375	270	180	90
40-50 " . .	420	315	210	105
50-60 " . .	420	300	180	90
60-70 " . .	390	270	165	90
70-80 " . .	360	255	150	75
80-90 " . .	345	240	150	75
90-100 " . .	330	240	150	75
100-110 " . .	330	240	150	75
Total . .	3150	2265	1425	735
Average annual yield .	28	20	13	7

[1] The customary British (square-of-quarter-girth) measurement is 21½ per cent less than the true cubic contents; and a further reduction of about 15 per cent is customary as bark-allowance.

[Table III.

III. Thinnings from Pure **Scots Pine-Woods** (true cubic contents), in cubic feet per acre and per decade.

Age of crop.	Quality of soil and situation.		
	I. Good.	III. Medium.	V. Poor.
20-30 years . .	405	360	270
30-40 " . . .	375	330	240
40-50 " . . .	330	285	210
50-60 " . . .	300	240	150
60-70 " . . .	270	195	105
70-80 " . . .	240	150	...
80-90 " . . .	225	...	...
Total . .	2145	1560	975
Average annual yield .	24	19	14

In very dense crops on soil of fair quality from 450 to 600 cb. ft. of brushwood and small material may be removed per acre before the 20th year. When thinning only commences about the 25th to 30th year, then the quantity of material removed is, on average and good land, usually as follows :—

In full or dense crops, . . 31 to 36 cb. ft. per acre and per annum.
In crops of average density, . 24 " 30 " " "
In dense crops on inferior land, 13 " 18 " " "

If thinnings are delayed in young Scots Pine-woods, the small poles soon rot and become unsaleable.

The **Average Annual Increment** found by Burckhardt to obtain in the forests of Hanover will be found on p. 414 (Appendix III.)

IV. Thinnings from Pure **Spruce-Woods** (true cubic contents), in cubic feet per acre and per decade.

Age of crop.	Quality of soil and situation.		
	I. Good.	III. Medium.	V. Poor.
Up to 30 years . .	225	150	75
30-40 " . .	405	330	240
40-50 " . .	480	390	300
50-60 " . .	450	360	270
60-70 " . .	420	330	225
70-80 " . .	390	300	210
80-90 " . .	360	255	180
90-100 " . .	330	195	...
Total . .	3060	2310	1500
Average annual yield .	30	23	16

From the 30th to the 80th year, thinnings of 33 to 40 cb. ft. per acre and per annum are usual in crops of the average and better classes. Where there is danger from snow or ice, the thinnings should only be slight.

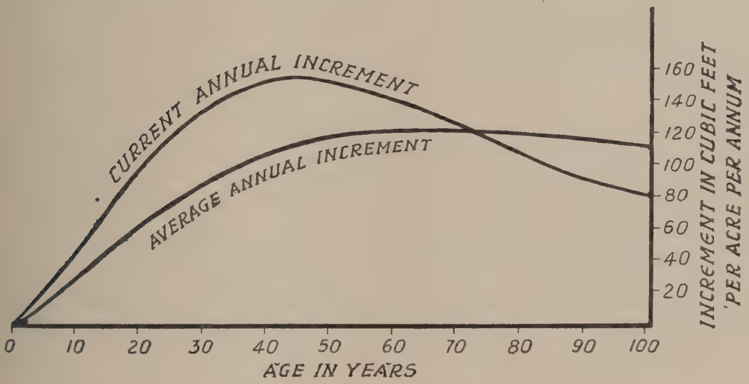
The course of the increment on single trees varies more or less according to the amount of growing-space each has had from the earlier stages of development onwards. Trees growing in complete freedom maintain, on good land, their rising current annual and average increment much longer than such as are grown in the limited space of close cover in highwoods.

In these latter, the current annual increment of even-aged crops in close canopy is so fairly proportionate to the rate of growth in height that the cubic contents per acre of woods of the same age, growing on land of similar quality, might well be estimated according to the height of the trees, and especially if these be conifer crops.

In coppices the current annual and the average increment remain fairly even throughout the usual rotation, unless this be so exceptionally high as over 20 to 25 years, or unless softwoods have to be thinned out, for the benefit of the main crop, two or three years after the fall. This is, however, compensated by the larger and more valuable poles yielded with a rotation of 20 to 25 years, and the better protection afforded to the soil.

The rate of growth in copses varies considerably according to the kinds of trees forming the crop and the quality of the soil, the number of standards, their

Fig. 207.



rotation, their distribution, and the extent to which their lower branches are pruned so as to diminish the shade cast on the underwood.

In order to know when trees or crops of trees attain their commercial maturity, their increment must be compared with their age. As the current annual increment changes from year to year, this comparison must consequently be made by means of the mean average annual increment; and it is therefore necessary to ascertain the relation which the current annual and the mean average increment bear to each other (Fig. 207).

The results of the investigations made by G. Heyer were as follows:—

(i) So long as the average annual increment rises, the current annual increment exceeds it in quantity; but if the former is already falling, then the current annual increment must be smaller than the mean average increment. The immediate deduction from this is that—

(ii) The current annual increment is greater than the average annual increment before the latter reaches its culminating point; but when once this has been passed, the average annual increment is then always greater than the current annual increment.

If, in place of reckoning the increment in years, infinitesimally small periods of time were reckoned with, then—

(iii) The mean annual increment would at the time of its culmination be exactly equal to the current annual increment.

(iv) From (ii) it follows that the current annual increment has begun to sink before the average annual increment culminates; hence the former must reach its culminating point before the latter culminates.

(v) From (ii) and (iv) it is clear that the average annual increment can still be rising, while the current annual increment is already falling.

The Average Yield Tables for Germany show the following differences between the culmination of *current* and *average* annual increment:—

Kind of crop.	In woods growing on soil of medium quality.	
	Current annual increment.	Average annual increment.
	Culminates at about years of age.	
Scots Pine . . .	20	40
Spruce	50	70
Silver Fir . . .	50	80
Beech	60	100

As has already been mentioned in chap. i. (p. 246), the increment of woodland crops may be regarded as to its *quantity*, its *quality*, and its *appreciation* or *depreciation in price* or monetary value per cubic foot.

The **quantitative increment** is usually expressed as a percentage of the crop, or present yield of any given wood. If the amount of the present yield of the crop be y in one year and Y in the next, then the increment for that year is $Y - y$, and the precentage of increment, p, is found thus:—as growing-stock: increment $= 100 : p$, or $y : Y - y = 100 : p.$,

$$\therefore p = 100\,\frac{Y - y}{y} = 100 \times \frac{\text{increment}}{\text{present crop.}}$$

This is just the same formula as would be obtained if y were regarded as a capital which could be put out at a rate of interest p for one year, when

$$Y = y \times 1{\cdot}0\,p, \text{ and } p = 100\,\frac{Y - y}{y} = 100 \times \frac{\text{increment}}{\text{present crop.}}$$

The percentage of increment must obviously decrease in course of time, because the cubic contents increase steadily from year to year (unless heavy thinnings be made), whereas the current annual increment gradually sinks after culminating at a certain age.

But, as the current annual increment for one year gives very little information as to the true rate of growth, it is better for purposes of forest management to estimate it for 5 to 10 years, seeing that it does not alter suddenly in amount, except in case of accidents. Thus, if the contents of the crop n years ago were y, and it now is Y, the average annual increment of the last n years must be

$$\frac{Y - y}{n}, \text{ and } Y = y \times 1{\cdot}0\,p^n,$$

just as if y were a capital put out to interest for n years at the rate of the percentage of increment, p.

$$\text{Consequently, } 1{\cdot}0\,p^n = \frac{Y}{y}, \therefore 1{\cdot}0\,p = \sqrt[n]{\frac{Y}{y}}, \text{ and } p = 100\left(\sqrt[n]{\frac{Y}{y}} - 1\right).$$

Now, if p be reckoned with reference to the cubic contents at the middle of the term of n years, then the equation becomes

mean contents of crop : mean current annual increment $=100 : p$,

i.e., $$\frac{Y+y}{2} : \frac{Y-y}{y} = 100 : p, \therefore p = \frac{Y-y}{Y+y} \times \frac{200}{n},$$

a formula which combines the advantage of simplicity with sufficient accuracy for practical purposes (see also p. 247).

Example.—A wood has a growing-stock of 4200 cb. ft. per acre at present, and will probably have 5500 in 10 years' time. What is the percentage of the current annual increment during that time?

$$\frac{5500-4200}{5500+4200} \times \frac{200}{10} = 2 \cdot 68 \text{ per cent.}$$

The **qualitative increment**, or higher technical value which a crop of timber may acquire within a term of years, may also be dealt with in precisely the same way. If the qualitative increment is q now and Q in n years hence, then

$\frac{Q-q}{Q+q} \times \frac{200}{n}$ expresses its percentage with reference to the mean of $\frac{Q+q}{2}$ at the middle point between now and n.

Example.—Suppose, in the above case, the present crop of 4200 cb. ft. per acre consisted of 3600 cb. ft. of timber at 6d. a cb. ft., and 600 cb. ft. of branchwood worth only 5s. per 100 cb. ft., and that 10 years hence it is probable that, *at present market rates*, the crop of 5500 cb. ft. will consist of 4800 cb. ft. worth 7d. a cb. ft., and 700 cb. ft. of branchwood worth 5s. per 100 cb. ft. What would the percentage of qualitative increment be?

Here $$q = \frac{(3600 \times 6) + (6 \times 60)}{4200} = 5 \cdot 23 \text{ pence,}$$

while, $$Q = \frac{(4800 \times 7) + (7 \times 60)}{5500} = 6 \cdot 18 \text{ pence.}$$

Consequently,

$$\frac{Q-q}{Q+q} \times \frac{200}{n} = \frac{6 \cdot 18 - 5 \cdot 23}{6 \cdot 18 + 5 \cdot 23} \times \frac{200}{10} = \frac{0 \cdot 95}{11 \cdot 41} \times \frac{200}{10} = 1 \cdot 66 \text{ per cent.}$$

So, likewise, with regard to the **appreciation or depreciation in price or monetary value per cubic foot**, which may affect the marketable value of the crop per cubic foot during any period of n years. That fluctuation, too, may be calculated precisely by the same method as above, so that the percentage of increment with a present value of the crop per cubic foot v rising (or falling, as the case may be) to V in n years

$$= \frac{V-v}{V+v} \times \frac{200}{n}.$$

In the above case, supposing there be a rise of 20 per cent in the price of timber locally during the next 10 years, then

$$\frac{V-v}{V+v} \times \frac{200}{n} = \frac{(5 \cdot 23 \times 1 \cdot 20) - 5 \cdot 23}{(5 \cdot 23 \times 1 \cdot 20) + 5 \cdot 23} \times \frac{200}{10} = \frac{1 \cdot 046}{11 \cdot 506} \times \frac{200}{10} = 1 \cdot 81 \text{ per cent.}$$

And, finally, **the whole market value of the crop or fall** can be summarily dealt with, and very conveniently so for the practical purposes of management, by means of the same simple formula, so that for any individual tree or woodland crop the percentage of increment in actual net monetary value, free from the cost of felling and extraction, will be found

$$= \frac{\text{future net value} - \text{present net value}}{\text{future net value} + \text{present net value}} \times \frac{200}{\text{No. of years in period of calculation.}}$$

From the very nature of this formula, it stands to reason that the results it gives will be likely to approximate more closely to the actual course of the local market when short periods of years are selected for purposes of comparison. In general use it will most frequently be applied for periods of 5 or 10 years, and then with very satisfactory results. The reckoning itself is simple enough ; but what prophet can foretell exactly the market value of any crop 5 or 10 years hence? So much seems probable, however, judging from the conditions of demand and supply now in operation in those parts of the world whence Britain has hitherto drawn her vast supplies of timber for constructive purposes, that the recent rise in the price of timber, amounting to about 25 per cent in some parts of the country, is not a mere temporary rise, but is much more likely to be an indication of permanent increase in the market value of timber.

Suppose that, in the above example regarding the crop of 4200 cb. ft. likely to increase to 5500 cb. ft. in 10 years' time, the whole monetary increment due to the combination of increase in quantity, rise in technical quality, and appreciation in market value, be summed up in the belief that what is now worth

$$(3600 \times 6d.) + (6{\cdot}00 \times 5s.) = £91,\ 10s. \text{ per acre},$$

will in 10 years' time have a probable value of

$$(4800 \times 8d.) + (7{\cdot}00 \times 6s.) = £162,\ 2s. \text{ per acre};$$

then the *financial increment*, calculated on the mean growing-stock 5 years hence will be

$$= \frac{£162,\ 2s. - £91,\ 10s.}{£162,\ 2s. + £91,\ 10s.} \times \frac{200}{10} = \frac{£70,\ 12s. \times 20}{£253,\ 12s.} = £5,\ 11s.\ 2d. \text{ per cent.}$$

Consequently, if the woods are worked so that the owner expects to get, or has hitherto been receiving, about 4 per cent for his capital, it will obviously be good business to refrain from felling the crop while it is yielding so good a return in current annual increment on the capital value it represents.

(2) **Measurement of Past Increment on Felled Trees and Logs** can easily be made by counting the annual rings (see p. 316). By these means both the growth in height, and that in girth, diameter, or basal area, and consequently also the actual increment, may be determined from year to year or by periods of 5 to 10 years.

(*a*) **Estimating the Past Increment by Analysis or Measurement of Sections.**—If the stem be divided into sections, and the length of each of these be multiplied into the present mean section and into what can be marked off with pencil as being the mean section n years ago, then the total periodic increment for each section during that period will be found by subtracting the former from the present cubic contents; and the average annual increment will be this total divided by n. Similarly, the total periodic and the average annual increment for the whole tree will be found by adding together the contents of all the various sections. So, too, from the number of annual rings shown by each section as compared with those on the basal section of the stem, the height of the tree can be accurately told at different periods of its life-history.

The annual rings are often very interesting records, marking the periods most favourable to the growth of the tree, the traces of successive thinnings being usually discernible in consequence of broader annual rings being formed for some years than formerly, owing to the crown being enabled to expand after the thinning. Then as the canopy closed up again the breadth gradually decreased till a new thinning was made. It is seldom that the past history can be read thus from the stem as from a printed page; but if the details of the crop were known, the results of the treatment, or of accident, could generally be traced by the breadth of the annual rings (see vol. i., Fig. 66, p. 448).

The results of such investigations into the past dimensions of trees can easily be exhibited by Heyer's graphical method, by marking off (on paper divided into squares) the height, diameter, and cubic contents at different ages, and then uniting each of these amounts by a continuous line. Any amount obviously out of the course of the curve must be abnormal, and therefore subject to correction as due to fortuitous circumstances, because in nature the ordinary course of growth in height, girth, and cubic contents is regular and not subject to sudden alterations. Such analysis of the stem is only required for scientific purposes. It is too intricate for practical use.

(*b*) **Estimating the Past Increment from the Mean Diameter of the Stem** at different ages is a more practical method than the former; but even this will seldom be necessary, as the measurements can most conveniently and satisfactorily be made on standing trees, as described below.

If the tree is taken to be a paraboloid, whose contents are found by multiplying height into the area of the middle section, then the cubic contents of the whole tree will be (Fig. 208) equal to $h \times b$, while n years previously it must have been $h_1 \times b_1$. The whole increment during the period has been $(h \times b) - (h_1 \times b_1)$, and the mean annual increment is

$$\frac{(h \times b) - (h_1 \times b_1)}{n}$$

Whenever the precise position of h_1 has been found by making sections, b_1 can also be fixed and the calculation easily made.

Fig. 208.

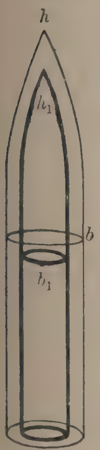
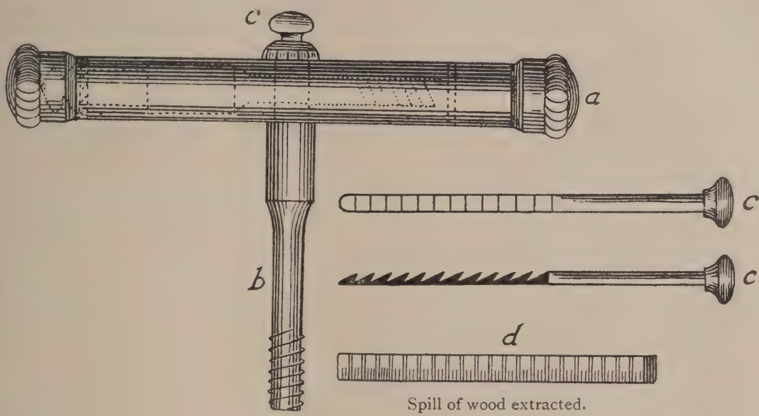


Fig. 209.



Pressler's Borer or Increment Gauge.

(3) **Measurement of Past Increment** and **Estimate of Future Increment on Standing Trees** can be made with greatest convenience at breast-height, $4\frac{1}{4}$ ft. above the ground, and with the aid of a **Pressler's Borer or Increment Gauge** (Fig. 209).[1]

This useful little instrument is made of good steel, in the form of a cylindrical hollow gimlet with a sharp cutting-edge. It consists of three parts—a hollow handle (*a*), the hollow gimlet (*b*), and a long flat pin (*c*), toothed inwards towards the head and marked off in inches and lines on the other side. But measurement of the annual rings on the spill (*d*), extracted from the tree by means of boring, can also more conveniently be made in a little tin trough, also marked off in lines and inches—until this gets lost, as is usually the case, sooner or later, for it is not a necessary part of the instrument.

For portability the toothed pin packs inside the trough, the trough inside the gimlet,

This handy little instrument is invaluable to the forester and the land-agent. By means of it one can easily tell the number of years any sample tree has taken to increase 1 inch in radius (measured at breast-height) or two inches in diameter $= 6\frac{2}{7}$ inches in girth. And the evidence thus given by the spill extracted will best indicate whether the crop is mature, or may be expected to continue growing into money during the next 10 years or so. The latest and best form, Pressler-Neumeister's Borer A, for hard- and soft-woods, is obtainable (price 16s.) from M. Perles, Court Publisher, Seilergasse 4, Stadt, Vienna.

and the gimlet inside the hollow handle, for opening which one of the knobs at the end of the handle unscrews.

The edge of the borer being placed in proper position against the bark of the tree at breast-height, the gimlet is slowly and evenly, but firmly, pressed and turned from left to right with the right hand, care being taken that the instrument is kept truly at right angles to the surface of the tree.

When the gimlet has worked its way well into the stem, both hands can then be used for screwing it home to the depth required. Then the toothed pin is inserted at the back end of the hollow gimlet and shoved home. The instrument is then reversed for a few turns, then given a forward turn again, and the spill is extracted by means of the toothed pin for measurement in the graduated trough, or by means of the gradation on the back of the pin.

It is then easy to count off how many annual rings go to the half-inch or inch, or what the increment of the radius has been within the last 5 or 10 years. As in counting rings on logs and stumps, when they are indistinct they can often be made more distinct by brushing them over lightly with a weak solution of aniline in alcohol.

As in the case of measuring the girth of trees, more accurate results will be obtained by making two borings on any tree at right angles to each other, and taking the mean of these two measurements as the true radius or diameter. But borings should be invariably made on fairly cylindrical stems rather than on such as are elliptical in shape.

The present diameter of the tree being measured, and the rate of growth during the past n years being ascertained from counting the annual rings on the spills obtained by using Pressler's borer, the sectional increment on the basal area of the tree can now easily be found in the difference between the present and the former basal sections. And as this does not alter suddenly (under ordinary circumstances), the past results may be used for estimating the growth during the next few years.

If D be the present diameter, and d that of n years ago, then the respective basal areas are

$$\frac{\pi D^2}{4} \text{ and } \frac{\pi d^2}{4},$$

the periodic increment for the n years is

$$(D^2 - d^2)\frac{\pi}{4} = (D^2 - d^2) \times 0{\cdot}785,$$

and the average annual increment has been

$$\frac{(D^2 - d^2)}{n} \times 0{\cdot}785.$$

As it is somewhat inconvenient to multiply by 0·785, the reckoning can be simplified by multiplying

$(D^2 - d^2)$ or $\left(\frac{D^2 - d^2}{n}\right)$ by 0·8 and subtracting 2 per cent from the total.

The former and the present basal areas being thus known, the increment or growth in cubic contents can also be estimated, but only approximately. In each case the cubic contents are equal to basal area × height × form-factor. For differences of 5 or 10 years on middle-aged or old trees the form-factor may be assumed to be practically the same. This simplifies the matter somewhat, because it reduces the problem to the proportion that the cubic contents now bear to the cubic contents n years ago—*i.e.*, as the product of the present area multiplied into the present height is to the product of the basal area n years ago multiplied into the height n years ago. But this proportion cannot, by actual measurement, be completed so as to enable the cubic contents n years ago to be estimated, because it is impossible to determine on the standing tree the height n years ago. There are different ways, however, in which this difficulty may be circumvented. The increase in height for the last n years may be taken from the mean average rate of growth in height; or it may be estimated from general tables showing the average rate of growth in height for the kind of tree, crop, and land in question; or it may be assumed, with a fair approach to accuracy, that in each case the height is proportional to the basal area. On this latter assumption, consequently, the

Cubic contents now : cubic contents n years ago
= basal area now : basal area n years ago.
= square of present diameter : square of former diameter.

$$\therefore \text{ cubic contents } n \text{ years ago} = \text{cubic contents now} \times \frac{\text{square of diameter } n \text{ years ago}}{\text{square of diameter now.}}$$

Hence the increment during the last n years = cubic contents now − cubic contents n years ago, and the average annual increment has been

$$= \frac{\text{cubic contents now} - \text{cubic contents } n \text{ years ago}}{\text{number of years in the period } n.}$$

It is often convenient to express the current annual increment as a percentage of the actual cubic contents of the tree, and it is therefore of interest to see how the results obtained with Pressler's borer can be used to determine the relation between the increment in diameter (or basal area) and such percentage of increment.

Pressler's Formula.—As we have already seen (p. 323), when p, the percentage of increment, is calculated with reference to any period of n years, it is best to calculate it as regards the mean cubic contents at $\frac{n}{2}$, or half the number of years in the period. As was there shown

$$p = \frac{\text{present cubic contents} - \text{former cubic contents}}{\text{present cubic contents} + \text{former cubic contents}} \times \frac{200}{n}.$$

But the cubic contents are in each case practically proportional to the basal area, or to the square of the diameter, hence

$$p = \frac{\text{square of present diameter} - \text{square of former diameter}}{\text{square of present diameter} + \text{square of former diameter}} \times \frac{200}{n},$$

or, for brevity,
$$= \frac{D^2 - d^2}{D^2 + d^2} \times \frac{200}{n}.$$

Example.—The present diameter of a stem, measured (exclusive of bark) at breast-height, is 15 in. Two spills bored out at right angles to each other respectively show 9 and 11 annual rings make up the last inch of radius. What has been the average annual percentage of increment?

Here the mean of the readings on the spills must be taken, or $\frac{9+11}{2} = 10$ years' rings for 1 in. of radius and 2 in. of diameter.

$$\text{Percentage of increment} = \frac{D^2 - d^2}{D^2 + d^2} \times \frac{200}{n} = \frac{15^2 - 13^2}{15^2 + 13^2} \times \frac{200}{10} = \frac{1120}{394} = 2{\cdot}842 \text{ per cent.}$$

This reckons the percentage of increment for the past; but it can also be estimated for the future by this formula, on the assumption that the breadth of the annual ring will in the future be the same as during the period of investigation. Thus, in the above case, for the next 10 years it would be

$$p = \frac{D^2 - D^2}{D^2 + d^2} \times \frac{200}{n} = \frac{16^2 - 14^2}{16^2 + 14^2} \times \frac{200}{10} = \frac{256 - 196}{256 + 196} \times \frac{200}{10} = \frac{1200}{452} = 2{\cdot}654 \text{ per cent.}$$

Modification of Pressler's Formula.—Without making any really important change in the value of the equation

$$\frac{D^2 - d^2}{D^2 + d^2} \times \frac{200}{n},$$

this may be modified so as to take the form of

$$p = \frac{(D^2 - d^2)}{\frac{1}{2}(D + d)^2} \times \frac{200}{n} = \frac{(D + d)(D - d)}{\frac{1}{2}(D + d)(D + d)} \times \frac{200}{n}.$$

$$= \frac{D - d}{D + d} \times \frac{400}{n}.$$

In the above example this would give as the percentage of *past increment*,

$$p=\frac{15-13}{15+13}\times\frac{400}{10}=\frac{800}{280}=2{\cdot}857 \text{ per cent};$$

and, as the *percentage of future increment*,

$$p=\frac{16-14}{16+14}\times\frac{400}{10}=\frac{800}{300}=2{\cdot}666 \text{ per cent.}$$

The smaller the term of years included in n, the more closely will the estimate given by this formula approximate to the real percentage of increment. If n be taken in its smallest possible dimensions of one year, then obviously $D-d$ must be equal to twice the breadth of the last annual ring, and

$$p=\frac{\text{twice the breadth of last annual ring}}{D+d}\times 400.$$

Now D and d are so very nearly equal, especially in trees of large girth, that $D+d$ may be taken as equal to twice the present diameter, without making any appreciable difference in the reckoning. Hence,

$$p=\frac{\text{breadth of the last annual ring}\times 2}{\text{breadth of the present diameter}\times 2}\times 400$$

$$=\frac{\text{breadth of last annual ring}}{\text{breadth of present diameter}}\times 400.$$

This simple formula may be expressed in words, by saying that "the current annual percentage of increment on any standing tree may be found by dividing the breadth of the last annual ring by the diameter of the stem (exclusive of bark), measured at breast-height, and multiplying the quotient by 400."

This is merely a modification of an older rule, known as **Schneider's Formula** (1849), which put $p=\frac{400}{n\times d}$, where n is the number of annual rings making 1 in. of radius and d the diameter in inches (exclusive of bark); and this may be expressed in words by saying that "*the current annual percentage of increment on any standing tree may be found by multiplying the number of annual rings making* 1 *in. in radius into the number of inches contained by the diameter of the stem* (*exclusive of bark*) *measured at breast-height, and then dividing* 400 *by this product.*[1]

Of these two formulæ Schneider's is the more practically useful for Britain, though the other has been found the more suitable for metric calculations on the Continent. They both yield results approximating very closely with the true percentage of increment. Schneider's formula is indeed mathematically correct, if it be assumed that the increment takes place as to one half inside and the other half outside of the present diameter of the stem. This differentiation is not necessary for practical purposes of forest management; but if such calculations be desired for scientific investigations, they can more conveniently be made by means of **Breymann's Formula** given on p. 329.

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[1] The development of *Schneider's Formula* is as follows: If a basal area $\left(\frac{\pi d^2}{4}\right)$ shows annual rings having a breadth of 1 in. in n years, then the rate of increase of the (1 in.) zone of increment in that time $=\frac{\pi d}{n}$,

$$\text{and } \frac{\pi d^2}{4} : \frac{\pi d}{n}=100 : p$$

$$\therefore \pi d^2 : \frac{4\pi d}{n}=100 : p$$

$$\therefore d : \frac{4}{n}=100 : p$$

$$\therefore p\times d=\frac{4}{n}\times 100$$

$$\therefore p=\frac{400}{n\times d},$$

where n is the number of annual rings in 1 in. of radius, and d is the diameter in inches (under bark).

Example.—An Oak-tree has a diameter (exclusive of bark) of 23 in. measured at breast-height, and spills taken from it there with a Pressler's borer show that it has taken the last 17 years to expand by 1 in. of radius. What is the percentage of the current annual increment? Here the increment

$$=\frac{400}{23\times17}=\frac{400}{391}=1{\cdot}023 \text{ per cent.}$$

Table showing percentage of current annual increment, calculated by means of *Schneider's Formula*, $p=\frac{400}{n\times d}$.

No. of annual rings in last inch of radius.	Diameter in inches (under bark) measured at breast-height.																			
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	16·0	13·3	11·4	10·0	8·8	8·0	7·2	6·6	6·1	5·7	5·3	5·0	4·7	4·4	4·2	4·0	3·8	3·6	3·4	3·3
6	13·3	11·1	9·4	8·3	7·4	6·6	6·0	5·5	5·0	4·7	4·4	4·1	3·9	3·7	3·5	3·3	3·1	3·0	2·9	2·8
7	11·4	9·4	8·1	7·4	6·3	5·7	5·2	4·7	4·4	4·1	3·8	3·5	3·3	3·1	3·0	2·8	2·7	2·6	2·4	2·3
8	10·0	8·3	7·4	6·2	5·5	5·0	4·5	4·1	3·8	3·5	3·3	3·1	2·9	2·8	2·6	2·5	2·3	2·2	2·1	2·0
9	8·8	7·4	6·3	5·5	4·9	4·4	4·0	3·7	3·4	3·1	2·9	2·8	2·6	2·4	2·3	2·2	2·1	2·0	1·9	1·8
10	8·0	6·6	5·7	5·0	4·4	4·0	3·6	3·3	3·0	2·8	2·6	2·5	2·3	2·2	2·1	2·0	1·9	1·8	1·7	1·6
11	7·2	6·0	5·2	4·5	4·0	3·6	3·3	3·0	2·8	2·6	2·4	2·2	2·1	2·0	1·9	1·8	1·7	1·6	1·5	1·4
12	6·6	5·5	4·7	4·1	3·7	3·3	3·0	2·8	2·5	2·3	2·2	2·0	1·9	1·8	1·7	1·6	1·5	1·5	1·4	1·3
13	6·1	5·0	4·4	3·8	3·4	3·0	2·8	2·5	2·3	2·2	2·0	1·9	1·8	1·7	1·6	1·5	1·4	1·4	1·3	1·2
14	5·7	4·7	4·1	3·5	3·1	2·8	2·6	2·3	2·2	2·0	1·9	1·8	1·7	1·6	1·5	1·4	1·3	1·2	1·2	1·1
15	5·3	4·4	3·8	3·3	2·9	2·6	2·4	2·2	2·0	1·9	1·7	1·6	1·5	1·4	1·4	1·3	1·2	1·2	1·1	1·1
16	5·0	4·1	3·5	3·1	2·8	2·5	2·2	2·0	1·9	1·8	1·6	1·5	1·4	1·3	1·2	1·2	1·1	1·1	1·0	1·0
17	4·7	3·9	3·3	2·9	2·6	2·3	2·1	1·9	1·8	1·7	1·5	1·4	1·3	1·3	1·2	1·1	1·1	1·0	1·0	0·9
18	4·4	3·7	8·1	2·8	2·4	2·2	2·0	1·8	1·7	1·6	1·4	1·3	1·3	1·2	1·1	1·1	1·0	1·0	0·9	0·9
19	4·2	3·5	3·0	2·6	2·3	2·1	1·9	1·7	1·6	1·5	1·4	1·2	1·2	1·1	1·1	1·0	1·0	0·9	0·9	0·8
20	4·0	3·3	2·8	2·5	2·2	2·0	1·8	1·6	1·5	1·4	1·3	1·2	1·1	1·1	1·0	1·0	0·9	0·9	0·8	0·8

Another simple method for rough-and-ready use, yet giving good results, is **Breymann's Formula** (1878). If the present diameter, measured free from bark at breast-height, be d, and the last annual increase of the same be a, then the basal area of the stem is $\frac{\pi d^2}{4}$, while the superficial increment of the annual ring, if this be considered as lying half outside and half inside of the present diameter, is $\pi d\times\frac{a}{2}$ (the radial increment being half of d). Hence,

$$\frac{\pi d^2}{4}:\frac{\pi d\times a}{2}=100 : \text{percentage of increment.}$$

$$\therefore \text{percentage of increment}=\frac{100\pi d\times a}{2}\times\frac{4}{\pi d^2}=200\times\frac{a}{d}.$$

In the above shape the formula only gives the current annual percentage during the year of investigation. If it be desired to ascertain the percentage of increment for the last n years, then the mean diameter during the past period of n years $\left(d-\frac{a}{2}\right)$ will have to be taken in place of d; and, similarly, in reckoning the future increment for the next n years $d+\frac{a}{2}$ will have to be substituted for d.

Applying this formula to the example given for Pressler's formula (on p. 327), we should have the percentage of increment during the last 10 years as

$$\text{periodic increment} = 200 \times \frac{2 \text{ in.}}{15 - 1 \text{ in.}} = \frac{400}{14} = 28{\cdot}571 \text{ per cent.}$$

$\therefore$ average annual percentage for the last 10 years $= 2{\cdot}857$ per cent.

For the present it would be (*i.e.*, in this particular case, for the last 5 years and the next 5)

$$\text{periodic increment} = 200 \times \frac{2 \text{ in.}}{15 \text{ in.}} = \frac{400}{15} = 26{\cdot}666 \text{ per cent, and}$$

average annual increment $= 2{\cdot}666$ per cent.

For the coming 10 years it would be

$$\text{periodic increment} = 200 \times \frac{2 \text{ in.}}{15 + 1 \text{ in.}} = \frac{400}{16} = 25{\cdot}00 \text{ per cent, and}$$

average annual increment $= 2{\cdot}50$ per cent.

In *Breymann's formula* the percentage of increment in basal area at breast-height (and also in cubic contents of the tree) $= 200 \times \frac{a}{d}$. Now, the diametral increment is found in the proportion $d : a = 100$: percentage of increment in diameter.

$$\therefore \text{percentage of increment in diameter} = 100 \times \frac{a}{d}.$$

Comparing these two percentages of increment, it therefore becomes evident that *the percentage of increment in basal area of the stem and in cubic contents of the tree is always twice as great as the percentage of increment in the diameter.*

This is just as simple as Schneider's formula, and may perhaps be preferred by some for occasional use in the woods.

Applying this very practical method to the case already frequently solved to show the application of other formulæ, the present percentage of diametral increment (*i.e.*, for the last 5 years and the next 5) is $= 100 \times \frac{2 \text{ in.}}{15 \text{ in.}} = 13{\cdot}33$ per cent for the 10 years, or $1{\cdot}333$ per cent annually. Hence, the periodic percentage of increment on the basal area of the stem and in the cubic contents of the tree is $= 26{\cdot}66$ per cent, and the annual percentage of increment is $= 2{\cdot}666$ per cent.

It should, however, be clearly understood that, even though the particular formula may be mathematically correct, all measurements of past and estimates of present and future increment must necessarily be merely of the nature of approximations, as one can never be certain that the spills obtained by boring or any other annual rings counted really give the true average rate of growth, upon the correctness of which data the results of the formulæ depend.

The use of the above methods of expressing the rate of growth in percentage of the amount of wood in the tree or crop is, however, apt to be rather deceptive. If a tree, containing 30 cb. ft., is adding 1 cb. ft. annually, it has a current percentage of 3·3 per cent; but, if its contents are 50 cb. ft. and its increase is $1\frac{1}{2}$ cb. ft. a-year, this gives the lower percentage of 3 per cent; and this lower percentage, while the actual volume of increase is greater, must be apt to cause confusion.

It is, therefore, best to use the results of the borer in order to ascertain the current rate of growth in girth. Thus, the number of annual rings counted on the last inch of the spill of wood (radius) will show how many years it has taken for the tree to increase by $6\frac{2}{7}$ in. in girth at breast-height (or $2\pi r$, r being here 1 in.); and a similar rate of growth may be accepted as likely to hold good for about the next 5 to 10 years (or, say, an addition of 6 in. in the time it has taken to increase by $6\frac{2}{7}$ in.)—unless the increment can be stimulated by thinning or partial clearance in the case of trees standing thick together and not yet fully mature—because the rate of growth does not usually vary rapidly.

(4) **Estimate of the Past, the Present, and the Future Increment on whole Crops of Wood.**—The method of ascertaining the increment on individual standing trees having been described above, it remains to be seen how and to what extent the knowledge thus gained can be applied to whole crops of wood. Here we at once encounter the difficulty that in single stems all the past increment is incorporated, except as regards dead branches cast off during the course of growth, while in whole crops of wood very appreciable quantities of produce are removed from time to time when *thinning operations* are carried out. Hence it is impossible to make detailed investigations into the past growth of crops as the direct products of basal area × height × form-factor. Leaving this last out of consideration, neither the basal area nor the growth in height can be determined directly from the crop with any approach to accuracy, because the trees forming the wood after each thinning are usually only those that formed the dominant classes before that. The practical outcome of this is that, if average sample stems of the crop be selected and their past increment investigated, the results of these investigations cannot be applied in their entirety to illustrate the past history of the whole crop. The past increment shown by middle-aged and older woods is, owing to thinnings, less than that of the individual average tree.

What it is, however, essential to know are the cubic contents and the age (mean age) of the crop, by means of sample plots, &c., as previously described. A suitable number of sample stems being then selected and examined as to their recent rate of growth in basal area, the results of these investigations may be applied to the whole crop, as explained in the previous section.

If this cannot be done, it is best to go by the height of the crop, as this is, in close and regular crops, in general fairly proportionate to the quality of the soil and the cubic contents of the crop.

For practical purposes of management it is, of course, far more desirable to know the probable future increment than to trace the course of the rate of growth in the past, or even to ascertain it for the present (except in so far as this may indicate the future rate of growth).

As the rate of growth in height, in basal area, and in cubic contents naturally follows a very regular and well-defined course—unless this be terminated by some calamity, like windfall, or interrupted by temporary damage from any other organic or inorganic agency, such as insects, fungous disease, fire, &c.—it is quite safe to assume that the rate of growth for the next 5 or 10 years will be much about the same as during the last similar period. And, in doing so, it is often convenient to express the current annual increment as a percentage of the cubic contents, as has above been described. Otherwise it can, of course, be expressed as so many cubic feet per acre.

In adapting the past and the present increment to the future increment for the next 5 or 10 years, which period cannot safely be exceeded in estimates of this nature, it is, however, necessary to take into consideration the age and condition of the crop. If young and vigorous in growth, the increment of the next 5 or 10 years will very probably exceed that of the period investigated; if the crop is now middle-aged, the increment will continue about the same; and, if the crop is already approaching maturity, the increment will be likely to fall off. Hence some modification of the increment estimated on the sample trees may perhaps be necessary in order to render it suitable for the given circumstances of each case. And it is also best to express the percentage with regard to the cubic contents of the crop as estimated for the middle of the period (see p. 323)—

$$p=\frac{Y-y}{Y+y}\times\frac{200}{n}.$$

For actuarial calculations this is certainly preferable; but otherwise it does not matter whether it be expressed thus or as the percentage of the present actual contents, as

$$p=100\times\frac{\text{mean annual increment}}{\text{present cubic contents.}}$$

As trees, or crops of trees, advance in age the percentage of increment decreases, owing to each year's increment being added to the capital or growing-stock with reference to which the percentage has to be expressed. And when the time comes that the current annual increment has passed its culmination and begun to sink, this decrease in percentage of increment falls very low, even though the tree or crop may still be laying on sufficient wood to make its retention more profitable than its fall. Thus the percentage of increment may be falling while for some years the annual increment is still rising or remains about constant as to actual cubic contents, expressed in cubic feet.

If the cubic contents of the crop be ascertained by means of true average sample trees, the present and the future increment of the crop may be estimated as the mean of the percentages shown by the sample stems. But if the calculation of the cubic contents of the crop has been made by forming a number of diameter-classes, then the mean percentage of increment must be estimated for each of these from the sample stem or stems belonging to that class. From these percentages the cubic contents of the current annual increment can be estimated for each diameter-class, and the sum of the estimates for the various classes will give in cubic feet the increment of the whole crop. This can easily be expressed as a percentage, if desired, because

$$p=100\times\frac{\text{increment}}{\text{total cubic contents.}}$$

Otherwise, general investigations into the past, the present, and the future increment are contained in the Average Yield Tables (see pp. 310, 333, and tables in Appendix III.) But the use of these can only be relied on when the crop is fairly normal in condition—that is to say, of about even age in highwoods, worked by clear-felling and replanting, or of about the mean age of the period in woods regenerated naturally. For such, the amount of the average annual increment from period to period, and from that the current annual increment year by year, can be estimated with considerable accuracy from good statistics of average yield, more especially when the crop consists of regular well-grown poles; and for woods of this sort the yield tables can also be advantageously used for estimating the contents of the growing crop in place of making unnecessary special measurements in crops not yet near their maturity.

The case is different, however, with crops of irregular growth, incomplete density, and more or less interrupted canopy. One might, it is true, make some allowance for this in estimating the growing-stock and the increment, or the increment alone after the cubic contents of the crop have been measured from mean sample stems or plots; but this might be very difficult, and often misleading, as the freer position of the trees stimulates increment on the individual stems, and estimates of this sort would only be introducing a further element of uncertainty into a method already based only on the probability of averages giving reliable results on the whole. The results would be least reliable for woods worked by casual (selection) fellings and for standards in copsewoods, in both of which the deviations from the normal growing-stock and increment may be very considerable.

To give some idea of the current annual increment calculated on the normal growing-stock in the woods (*i.e.*, y, and not $\frac{y+Y}{2}$), Graner has drawn up the following table of percentages, based on the average yield tables for Germany, of Beech (by Baur), Scots Pine (Weise), Spruce (Baur), and Silver Fir (Schuberg); but it must be noted that in Germany the *timber* includes all the wood down to $2\frac{3}{4}$ in. diameter (7 centimeter) measured *over* bark.

Kind of Crop.	Age.	Percentage of current annual increment, calculated on normal growing-stock at the given age—quality of soil and situation.									
		For timber only.					For timber and small branchwood.				
		I.	II.	III.	IV.	V.	I.	II.	III.	IV.	V.
	Years.										
Beech	50	3·2	3·5	4·3	6·0	...	2·5	2·7	2·9	3·1	3·5
	60	1·8	2·2	2·5	3·6	5·8	1·8	2·0	2·3	2·3	2·7
	70	1·4	1·7	1·9	2·6	4·3	1·5	1·6	1·8	1·8	2·0
	80	1·2	1·4	1·5	2·0	2·7	1·2	1·3	1·5	1·5	1·7
	90	1·1	1·15	1·2	1·5	1·5	1·1	1·1	1·25	1·25	1·4
	100	0·95	1·0	1·0	1·3	1·2	0·9	0·95	1·0	1·1	1·25
	110	0·75	0·9	0·85	1·0	0·9	0·7	0·8	0·9	0·9	0·95
Scots Pine	50	1·5	1·6	1·9	2·1	2·5	1·3	1·2	1·3	1·3	1·2
	60	1·1	1·0	1·3	1·2	1·5	0·95	0·85	1·0	0·9	0·85
	70	0·9	0·85	1·1	0·9	1·0	0·8	0·7	0·8	0·7	0·65
	80	0·65	0·6	0·7	0·6	0·75	0·6	0·5	0·65	0·45	0·4
	90	0·6	0·5	0·6	...	...	0·55	0·45	0·55	...	...
	100	0·55	0·45	0·5	...	...	0·45	0·4	0·45	...	...
	110	0·35	0·4	0·4	...	...	0·3	0·35	0·35	...	...
Spruce	50	2·0	3·0	4·5	5·8	...	1·6	2·0	2·3	2·1	...
	60	1·5	2·0	2·6	3·2	...	1·2	1·5	1·7	1·6	...
	70	1·25	1·5	2·0	2·4	...	1·0	1·2	1·3	1·5	...
	80	1·0	1·2	1·5	1·7	...	0·85	0·9	1·0	1·0	...
	90	0·9	0·95	1·2	1·4	...	0·7	0·85	0·85	0·8	...
	100	0·7	0·75	0·9	1·0	...	0·65	0·7	0·7	0·65	...
	110	1·55	0·6	0·6	0·8	...	0·5	0·5	0·5	0·5	...
Silver Fir	50	2·2	3·0	4·0	6·0	...	1·7	2·0	2·5	3·3	4·5
	60	1·5	1·8	2·2	3·1	5·0	1·2	1·4	1·7	2·2	2·8
	70	1·2	1·4	1·6	2·1	2·8	1·0	1·15	1·3	1·6	2·0
	80	0·9	1·0	1·2	1·5	2·0	0·8	0·9	1·0	1·2	1·5
	90	0·75	0·85	1·0	1·2	1·4	0·7	0·75	0·8	1·0	1·25
	100	0·6	0·7	0·8	0·9	1·1	0·6	0·65	0·7	0·8	0·9
	110	0·55	0·6	0·65	0·7	0·75	0·5	0·55	0·6	0·65	0·7

Summarising these for the medium quality of the land, the following table may serve for ready reference :—

Percentage of current annual increment on present growing-stock on land of medium quality.[1]

Age.	Timber only.			Timber and small branchwood.		
	Beech.	Pine.	Spruce and Fir.	Beech.	Pine.	Spruce and Fir.
Years. 50	4·5	2·0	4·0	3·0	1·2	2·4
60	2·5	1·25	2·2	2·2	1·0	1·6
70	2·0	1·0	1·8	1·8	0·8	1·25
80	1·5	0·75	1·25	1·4	0·6	1·0
90	1·25	0·6	1·0	1·2	0·55	0·85
100	1·0	0·5	0·85	1·0	0·45	0·7
110	0·9	0·4	0·65	0·9	0·35	0·55

[1] Here $p = 100 \times \frac{\text{future cubic contents} - \text{present cubic contents}}{\text{present cubic contents of crop}}$.

It will be seen from the above table that the percentages on land of good quality are smaller than on land of poor quality. This paradox is easily explained through the larger cubic contents of wood produced on the better soil and situation, this making the total growing-stock increase in rapid proportion to the annual increment—*i.e.*, the divisor used in expressing the percentage increases more rapidly than the dividend on good as compared with poor land, even though the cubic contents produced are, of course, greater in the former than in the latter case.

In using Average Yield Tables for estimating the present and the future increment of regular crops of wood growing in fairly close cover, it is necessary to ascertain the age of these latter as approximately as possible, and to estimate the cubic contents of the growing-stock per acre.

When these data have been obtained by means of average stems or sample plots, the actual growing-stock per acre may be compared with the normal growing-stock shown in the Average Yield Tables for woods of similar age, in order to classify the land as to quality. If these agree approximately with any of those shown in the table for the given kind of wood, then the land may be taken to be of this particular class, and the probable increment may be estimated according to the average yield shown there as likely to accrue under normal circumstances during the next 5 or 10 years.

If, however, greater accuracy is desired, and if, as will usually be the case, the results shown as the actual growing-stock per acre do not coincide with any of those in the table, one can easily amplify the Average Yield Tables by interpolation so as to get fairly reliable results for half-way halting points between the five different main classes of quality in land, so as to virtually adopt a decimal system of classification. The land can then be taken as of the quality it approximates most closely to, and the estimate of the present and the future increment can take place accordingly. This is not a very scientific method, but it is practical; and it is sufficiently reliable for use in estimating the rate of growth in crops for purposes of management.

The interpolation would take place as follows :—

—	Quality of land.								
Usual classification .	I.		II.		III.		IV.		V.
Equivalent in decimal system . . .	1·0		0·8		0·6		0·4		0·2
Interpolation . .		0·9		0·7		0·5		0·3	
Cubic feet per acre .		...		...		...		...	

A more exact, but a much more complicated, way of doing the same thing is Huber's method (1833), by which the future yield (Y_{a+n}) of a still immature crop may be found by multiplying the present cubic contents (y_a) of the latter into the future or mature yield or fall (Y_{a+n}), shown in the average yield tables as belonging to the class of land nearest in quality to the given crop, and dividing the product by the yield or fall (Y_a) which the table shows for the crop at the age a.

Here the estimate of the cubic contents is made by means of the proportion

$$Y_a : y_a = Y_{a+n} : y_{a+n}$$

$$\therefore y_{a+n} = \frac{y_a \times Y_{a+n}}{Y_a} = y_a \frac{Y_{a+n}}{Y_a}$$

while the increment for the period of n years is equal to $y_{a+n} - y_a$, and the average annual increment $= \frac{y_{a+n} - y_a}{n}$.

This equation will be the more approximately correct the nearer y_a corresponds with Y_a; hence the necessity for selecting the class in the average yield table which corresponds most closely to the actual cubic contents of the crop. The older the crop is, the more likely is Huber's method to give reliable results. But it is too intricate and circumstantial to be of much use in practice.

Example.—A Beech-wood is found to be 60 years old and to have 2500 cb. ft. per acre. Only the following local average yield tables are available :—

Quality of land.	Age of crop in years.							
	30	40	50	60	70	80	90	100
	Cubic contents per acre, in cubic feet.							
I. Good	860	1430	2090	2850	3520	4180	4750	5230
II. Medium . . .	760	1330	1900	2570	3140	3610	4090	4470
III. Poor	670	1140	1710	2280	2760	3230	3520	3800

What will the probable yield of this crop be at 70 years of age? And what may perhaps be expected at 90 years of age?

Here the land of II., or medium quality, corresponds most closely with that of the crop.

Hence $y_{70} = \frac{y_{60} \times Y_{70}}{Y_{60}} = \frac{2500 \times 3140}{2570} = 3054$ at 70 years, or an average annual increment of $\frac{3054 - 2500}{10} = 55{\cdot}4$ cb. ft.

At 90 years, $y_{90} = y_{60} \times \frac{Y_{90}}{Y_{60}} = 2500 \times \frac{4090}{2570} = 3978$ cb. ft., and the total increment is $3978 - 2500 = 1478$, or at the rate of $\frac{1478}{30} = 49{\cdot}26$ cb. ft. per annum.

As has been previously stated (p. 310) failing more specific data, the height is one of the best means of estimating the quality of the land and obtaining the contents of a crop from an Average Yield Table. It is safer than the basal area, or the number of stems per acre, but it is not anything like an absolute factor. Two young crops may show about equal growth in height up to a certain age, and then one, owing to deeper soil, may continue growing upwards more vigorously than the other. But, for young woods, the rough estimation of contents from Yield Tables can quite well be made, whenever considered necessary ; because it is only when the crops are approaching maturity that it becomes really desirable to know the cubic contents and percentage of increment.

That is to say, for young woods the present and the probable future yield can be taken direct from Average Yield Tables, while the present stock and the current rate of growth of older crops should be measured or estimated and compared with the data of the Yield Tables before these can be safely applied for estimating the future yield. In making such future estimates of yield, it is best to calculate the percentage on the cubic contents at the middle of the period $\left(\frac{\text{present amount} + \text{future yield}}{2}\right)$. And, similarly, with regard to crops about to be regenerated naturally, the crop to be harvested and the increment on it during the period of regeneration should be estimated as if coming to the fall at the middle of the period—*e.g.*, $\frac{0 - 10}{2} = 5$, with regeneration extending over 10 years, or $\frac{0 - 20}{2} = 10$, with regeneration and clearance of parent standards extending over 20 years (Beech).

Estimates from actual average yield of similar crops felled on the estate will seldom be obtainable in Britain, as returns of this sort have only in rare cases been kept. But when the crops are so very irregular that Average Yield Tables cannot be used, that is the only way in which estimates can be made ; otherwise measurements of sample areas must be undertaken and the total contents of the crop estimated from them.

CHAPTER III.

THE FORMATION OF WORKING-PLANS, OR THE PRACTICAL APPLICATION OF THE THEORETICAL PRINCIPLES,

WITH SPECIAL REFERENCE TO FIXING THE FALL FOR HIGHWOODS BY MEANS OF PERIODS COMBINING AREA AND YIELD.

1. General Remarks concerning Working-Plans or Schemes of Management.
2. Data and Statistics requisite for the Preparation of a Working-Plan.
3. The Preparation of the Scheme of Management or Working-Plan.
4. The Explanatory Report accompanying the Working-Plan.
5. Control and Revision of the Results of Working.

1. General Remarks concerning Working-Plans.—It is hardly possible for any large tract of woodland to be managed economically, and for the productivity of the soil to be fully utilised, unless the management is regulated according to a Working-Plan. Such a Scheme of Management for the woodlands should deal with all the operations of natural regeneration, sowing, planting, weeding and cleaning, thinning, felling, &c.; and its provisions should be carried out annually, unless these have been interfered with by unforeseen circumstances (windfall, &c.).

The object of the working-plan is, so far as possible, to provide for the continuous yield of annual returns of about equal extent and value, and, so far as is practicable, from about equal areas. Whilst this ruling idea is subordinated to the first fundamental principle of sylviculture—viz., that the form of management must be a truly economic method capable of maintaining the productivity of the soil—yet the details as to kinds of trees forming the crops, method of treatment of crops, and best time and manner of utilising and reproducing them, are all to a very great extent dependent on local circumstances (soil and situation, nature of local markets, &c.). Hence no hard-and-fast rules are applicable to this branch, any more than to the other operations of practical forestry.

Throughout all the State forests of France, Germany, and Austria, the whole of the annual operations are conducted in strict accordance with the provisions of such working-plans; and even in India, fellings within the Reserved Forests are not now allowed before working-plans for their administration have been drawn up and approved by the Conservator of Forests and the Local Government, then formally submitted to the Inspector-General, and finally sanctioned.

This important branch of Forestry has never really received much attention in Britain. When a tour was taken throughout the British woodlands in 1885 by the students of the *École Forestière* from Nancy, the following remarks were made by M. Boppe, who was at the head of the party, and who was asked officially if he would be good enough to submit in writing his views regarding Forestry in Britain (Appendix to *Report of Committee on Forestry*, 1885, p. 48):—

"The productive powers of the soil and of the climate have been made use of by able and intelligent planters, who have thereby enabled Nature herself to accumulate a considerable store of timber; but all this wealth is exposed to the carelessness of some, and to the ignorance of others, until the hand of a forester manages it properly and places it on the only sound economic principle of all agricultural and forest property—a constant annual revenue and a constant improvement in production. It would certainly not be fair to hold Scotch foresters responsible for the present regrettable state of affairs; for though they have for the most part admitted the inefficiency of the present system, they are powerless to effect any improvement so long as the landowners and general public have not learned to appreciate the manifold advantages to be derived from a regular and methodical management. They have to struggle against many adverse interests and hindrances, such as grazing and shooting interests, questions of routine, pecuniary exigencies, and the fancies of sportsmen from all parts of the world. . . . Let the owner of a forest, after having made a careful and detailed inspection of it, divide it off into blocks or compartments, so arranged that they should be uniform as regards conditions of soil and of planting, and then proceed to count and measure all the trees of three feet girth and upwards, classing them in categories according to their diameter. He should then open a debit and credit account for each compartment, placing on the debit side the actual volume of the standing crop, and on the credit side the volume of timber removed at each successive felling. This register should always be consulted before undertaking any forest operation. Whenever the annual fellings fall due, it will show which compartment can best support the withdrawal of timber, and which require to be left untouched. Moreover, the balance-sheet will render an exact account, favourable or otherwise, of the condition of the forest.

"Ten years of such systematic treatment would form in itself the basis of a regular forest working-plan."

2. Data and Statistics requisite for the Preparation of a Working-Plan or Scheme of Management.—To be really serviceable, any Scheme of Management must, in addition to being based upon sound principles, rest upon sure foundations with regard to **area**, **growing-stock**, and **rate of growth**.

Accurate measurement of the woodland area and well-demarcated boundaries are the necessary conditions for the division of the woodlands into convenient blocks and compartments.

As regards estimates of the growing-stock and of the increment of the different crops, these can in actual practice only be made approximately, unless such an amount of time, expense, and circumstantiality were to be expended on the investigations as would be out of proportion to the advantages secured by striving after an almost inattainable accuracy. What is necessary is to determine, as carefully as is practicable under the given circumstances, the cubic contents of the mature crops coming to the fall in the next 10 or 20 years, and to make what may seem a fair estimate of the contents of the younger crops only now beginning to approach maturity.

If it is difficult to determine the cubic contents of growing timber-crops with accuracy, it is still more difficult to estimate their rate of growth correctly; and this is the reason why systems of management based mainly upon the whole growing-stock and the increment throughout the woodlands are so little suited for practical work, despite their theoretical completeness. Equal difficulty is also found in estimating the quality of land and its productivity; and though average yield-tables can very conveniently be applied to estimate roughly the future yield of crops now still immature, yet the use of these for estimating the fall of mature crops must likewise be taken as only a rough approximation. To endeavour to correct such estimates by reducing the areas to a common standard of productivity or quality is not altogether suitable for practical work.

The recommendations made in any Scheme of Management must take the nature of the woodlands, the local conditions, and the desires and objects of the landowner fully into consideration. Even on large woodland estates, however, it is generally preferable to have several small felling-series in different parts of the estate, rather than to concentrate the annual falls merely in one or two places.

The choice of the **method of treatment** and of the **rotation** is partly determined by the nature of the soil and situation, but also to a very great extent by the circumstances of the local market for timber. In trying to accommodate the former to the latter, and to the probable future requirements of this, conditions will almost always be found necessitating some change in the existing state of the woodlands, and the recommendations made should avoid attempting to bring about a normal condition in too short a space of time. Thus the working-plan should try to avoid either bringing immature wood to the fall, or permitting over-mature crops to remain uncut. Difficulties of this sort, arising in connection with maintaining the general direction of the fellings, may best be obviated by making numerous small independent felling-series. The prescriptions of the working-plan should be just as concise and simple as possible. Unless the proprietor specially desires this to be done, it is a mistake to go into detail, such as making special recommendations for carrying out the falls for natural regeneration, or whether reproduction should be by sowing or planting, or how and at what distances these cultural operations should take place, &c., because the carrying out of such details sometimes depends to a great extent on future circumstances (*e.g.*, a good beech-mast year). A simple, clear working-plan is easier to understand and to follow than any scheme loaded with detail; and when details cannot be carried out, the forester and those who have to perform the work in the woods easily become sceptical of the benefits of the plan, and are apt to deride its recommendations and to take little interest in carrying them through so as to yield the best results.

In the tabular statement which forms the plan itself, unnecessary details of any sort should be scrupulously avoided. The description of each compartment should be as terse as possible. In the report which accompanies the working-plan conciseness should also be aimed at, while not neglecting special mention of such matters as the reasons for making the specific choice of methods of treatment, fixing the rotation, &c.

In estimating the fall for the next 10 or 20 years, care should be taken to avoid making too sanguine an estimate. The current annual increment should be measured as carefully as is practicable, and used as the basis of calculation only for short periods of 5 or 10 years. Comparisons of such estimates with the actual yield of similar crops that have recently been felled should be made wherever feasible; and in some cases these latter results can be used directly for estimating the fall of the standing crops. Any sort of differentiation of the material, or classification into anything beyond *timber* and *branchwood* at most, is more apt to be misleading than productive of any real advantage. So, too, is it a mistake to attempt to specify in detail the yield of thinnings, which may vary considerably from crop to crop. It is much better merely to indicate the areas to be thinned from time to time, and to summarise the results generally in the working-plan.

(1) **Reliable Maps** are essential as a basis for any sound scheme of management. In Britain, the Ordnance Survey maps are excellently adapted for this purpose, and particularly those on the scale of 6 inches to the mile (1 : 10,560), which have the great additional advantage of contour-lines that can easily be used in projecting roads, marking off compartment boundaries, and the like. For very large estates, a reduced map on the scale of 3 or 4 inches to the mile will be found most convenient for use in the woods.

(2) **Subdivision into Compartments.**—In many cases, particularly when dealing with estates having only a small woodland area, the different blocks or patches of wood will be so scattered about here and there as to render any further subdivision into compartments unnecessary. Where this is not so, however, subdivision must take place in the manner indicated in Chap. I., section 7. The **Kind of tree, method of treatment,** and **configuration of the ground** are the main points to be taken into account in subdividing the woodlands into compartments; but the **age of the crop** and **its condition** can also be of importance when temporary sub-compartments appear desirable. **Blank spaces,** if of any considerable size, should be measured and tabulated, so that recommendations may be made as to planting them.

The whole of the crops may be conveniently tabulated thus, in order to have a complete list of them (but the most convenient form of classification can of course only suggest itself when the particular circumstances of the woods are known):—

A. . . . . ESTATE BLOCK.					
I. Working Circle: **Ornamental Woods** (excluded from commercial treatment, and to be worked by Casual [Sporadic or Selection] Fellings).					
Compartment No.	**Name of wood.**	**Present crop.**	**Age. Years.**	**Area. Acres.**	**Remarks.**
1	Pegwell Brake.	Oak Copse.	1-10 ; Standards 40-100	11·2	
2	Basin Cover.	Beech.	60-90	12·8	
II. Working Circle: **Copse Woods,** to be worked with a rotation of 20 years.					
1					
2					
III. Working Circle: **Conifer Highwoods,** to be worked with a rotation of 80 years.					
1					
2					
B. . . . . ESTATE BLOCK.					

Internal divisions inside compartments should not be made unless there seems some real advantage to be obtained thereby, because it is far better to have the falls proceed regularly in the proper direction against wind than to render management more difficult by anything like mere petty crop-distinctions within compartments. The size of these may conveniently vary from about 10 to 25, or up to 50 acres, according to the given circumstances; yet whenever there is any doubt about any particular area being formed into one or into two compartments, it is best to make two, as it is much easier to group two compartments together in a felling-series than to split up a compartment into two later on. But the kind of crop must here be taken into consideration. For Pine, larger compartments may be made than for Spruce; while for Beech, they should be such that natural regeneration can be accomplished during the course of one period of 20 years.

Where the boundaries of compartments are marked by natural features, such as different kinds of crops, distinct difference in age, roads, drives, rides, brooks, dells, &c., no special demarcation is necessary beyond the ordinary numeration of the compartments; otherwise they should be demarcated as already recommended (see p. 254).

For subdividing large compact areas into compartments, maps with contour lines are of great assistance, as well as for laying out a suitable network of roads and green lanes.

Simultaneously with the subdivision of the woodlands into compartments, the various crops must be allocated to **Working-circles** and **Felling-series**. That is to say, working-circles and felling-series are so mutually dependent on each other that, although the subdivision into compartments actually takes place first of all, the boundaries of the various felling-series must be selected so as to coincide with the boundaries of working-circles, where more than one circle is being dealt with. Thus, at any rate, general conclusions must already have been arrived at regarding the kind of crop, method of treatment, and rotation, before the subdivision into compartments can be proceeded with; and any alterations in, or additions to, the existing roads for timber transport should also be decided on before the compartments, *the permanent framework of the future management*, are definitely formed.

(3) **Allocation of the various Felling-Series.**—Although the definite allocation of the various independent felling-series can only be made after the **Stock-map** has been coloured so as to exhibit the different kinds of crops and their ages, yet the formation of the permanent felling-series should at any rate go hand-in-hand with the subdivision into compartments, so that each series may consist of 1, or 2, or more compartments.

The longest felling-series can be made in **coppices** and **copse-woods**, because here the effects of wind, insects, &c., are not such as to cause anxiety when fall annually follows fall upon adjacent areas. But in **highwoods**, especially of Conifers, sylvicultural requirements and the danger from weevils make it desirable that the neighbouring falls of any one felling-series should not occur more frequently than at intervals of 5 years, though it is preferable (if matters can be so arranged) to have an interval of 10 years between them. And this, of course, means making numerous short felling-series, in place of merely a few long series. But it also usually means making several **Protective Fellings** or **Severances** (see p. 265), so that suitable initial points may be provided where these short felling-series will have to begin some 10, 20, or 30 years from now: *because these contingencies can be foreseen, and should be provided for.*

(4) **The Formation of the Working-Circles** must, where there is more than one circle, be made after the compartments of the felling-series have been arranged, by these being distributed to the different working-circles. A **working-circle** comprises within one series of age-classes all the woodland areas subject to the same treatment; hence the local conditions must determine whether the whole of the woods can be worked as one circle, or if two or more working-circles are necessary owing to differences in crop, method of treatment, or rotation.

The conclusions to be arrived at on these important points hinge mainly on considerations regarding the land and the local market for the woodland produce. Proximity of woods to a mansion-house, special reservation of copses as cover for pheasants, and similar considerations of various sorts may necessitate the exclusion of certain woodlands from any one or more of the working-circles; and if one or more of such tracts occur they can easily form a separate working-circle to be treated merely by casual fellings (so-called "selection" system). Different methods of treatment (**highwoods, copse,** and **coppice**) require to form separate working-circles. In highwoods on large woodland estates it would often be advisable, or even necessary, to separate the different kinds of tree-crops into independent working-circles; but this may easily be avoided when the woods consist of mixed crops, either of broad-leaved or of coniferous trees, or of both.

It is always desirable to try and keep the number of working-circles as small as possible in order to simplify work, because all investigations into and estimates of growing-stock and annual fall, and all accounts regarding actual yield, have to be kept separately for each circle. The different working-circles can best be distinguished by Roman figures—*e.g.* I. **Excluded woods** (casual fellings), II. **Copse-woods** (rotation 20 years), III. **Beech-woods** (rotation 120 years), IV. **Conifer highwoods** (rotation 80 years).

(5) **Estimating the Quality of the Land.**—As the productivity of the land depends upon the soil and the situation, including all the climatic factors comprised within this latter term, investigations have to be made into these before any sound scheme of management can be framed, because the most profitable kind of tree-crop, the proper method of treatment, and the best rotation depend on the given soil and situation considered in connection with the present and the probable future local market for timber.

Apart from the general local climate, as to drought, frost, rainfall, &c., which requires special mention in the report accompanying the Scheme of Management (see p. 366), the quality of the land in each compartment should be noted with regard to its **aspect** and **situation**, its **configuration**, its **elevation** above sea-level, and its **slope**.[1]

The **aspect** alone (N., S.E., S.W., &c.) gives no complete information as to the situation of the land, because this depends greatly on its configuration and the surroundings, the trend of valleys, the hills lying to windward, &c. Thus the situation may either be *exposed* or *sheltered*, no matter to what point of the compass the aspect may face.

As the geological formation is referred to in the general report, the **soil** of the different compartments need only be described as *sand*, *loam*, *clay*, *lime*, *marl*, &c., but its *depth*, *porosity*, *relation to moisture*, *and humosity* should be specially mentioned, as also whether it is stony or gravelly, and of what nature the **subsoil** underlying any shallow soil may be. It is also often useful to note what the **soil-covering** is, whether chiefly of dead leaves, grasses, whortleberry, heather, or moss, &c., as the vegetation on the ground conveys useful information for sylvicultural purposes. Indeed, the specific nature of the soil-covering often determines important points with regard to treatment of crops, cultural operations, and even the choice of the crop to be grown.

These various factors regarding soil and situation determine the quality or fertility of the land for the purpose of producing crops of wood; and this quality or productive capacity can best be expressed by means of comparing the cubic contents of each crop with the known general results of Average Yield Tables (see Appendix III.). Here the current annual increment, or the average increment, or the total cubic contents per acre, may be ascertained for any given crop and compared with the average yield for other crops of the same age and kind of tree; and the general quality of the land may be assessed as about equal to that to which this approximates most closely. Where other means of comparison are wanting, a fair general idea of the quality of the land can be obtained by means of the age and height (see Table, p. 315); and this is the best means of estimating it in the case of young crops.

The classification adopted for experimental investigations in Germany consists of five qualities, but these may easily be modified and increased by interpolation so as to give a wider margin for classification.

I.		II.		III.		IV.		V.
Very good.		Good.		Medium.		Inferior.		Poor.
1·0		0·8		0·6		0·4		0·2
	0·9		0·7		0·5		0·3	

It should be noted that the classification is merely relative for each different kind of tree, and not absolute as to the quality of the land. Thus what might be *inferior* for growing Oak may perhaps be *good* for Pine.

[1] The usual classification of slope is—
level up to 5°, *gentle* 5-10°; *moderate* 11-20°, *steep* 21-30°; *abrupt* 31-45°, *precipitous* over 45°.

Some method of classification is necessary. But to limit it to three classes—which would practically mean I. *good*, II. *medium*, III. *inferior*—is somewhat too inelastic; while the decimal system is far too complicated, as it is more difficult to estimate correctly as 0·5 or 0·4, than to decide in a general manner if it be, on the whole, classifiable as *medium* or merely *inferior* for any given kind of crop. The best system is perhaps as follows:—

I. **Very Good.** II. **Good.** III. **Medium.** IV. **Inferior.** V. **Poor.**	This classification only, however, applies to the particular kinds of crop that are being specially considered.

To obviate uncertainty regarding classification as to the general quality of *soil and situation* in different parts of Germany, the Committee in charge of the various Forestry experiments in 1888 adopted the following scale of assessment:—

Quality of soil and situation.	Cubic feet per acre (*true cubic-contents* without root-wood) yielded by crops of 100 years in age.		
	Beech.	Scots Pine.	Spruce and Silver Fir.
I.	10,440	10,150	15,950
II.	8,410	7,975	13,050
III.	6,670	6,090	10,440
IV.	5,075	4,350	7,975
V.	3,625	2,900	5,800

Classification by means of decimals has the advantage that the several crops in a working-circle may very easily, if desired, be reduced to a mean average quality of land. Thus, if 45 acres had the quality of 0·8, 63 acres of 0·7, and 71 acres of 0·6, then their reduced area as of quality 1·0 would be 36·0, 44·1, and 42·6 acres respectively; and the whole 179 acres would be equal to 122·7 acres of I. class land, while the mean quality would be $\frac{122{\cdot}7}{179}=0{\cdot}68$. Although plausible, this idea of reduction is not of much use for highwoods, because the factors of reduction are seldom quite reliable, the variations in the quality of land being usually gradual and without sharp, definite distinctions. It is therefore more convenient to allocate the annual falls in such manner that a smaller area of good land is brought to the fall, or a larger area of less productive land, as the case may be. Hence the above method of reduction is not of much practical use, as the quality of the land is only one factor in determining the yield at the time of the fall, the treatment meanwhile being often of equal or even greater importance; for it is in many cases the latter which mainly influences some of the factors determining the former. Thus the estimate of the quality of the land can never be depended on for regulating the treatment and estimating the yield of woodland crops. It must always be more or less of a rough approximation, and hence the necessity for making special investigations into the cubic contents and rate of growth of the different crops.

(6) The **Field-Book** containing the **Description of the Crops or Growing-Stock** should note the *area*, *kind of wood*, *method of treatment*, *age*, *density and cover*, *general condition*, and the *cubic contents and rate of growth* of each crop. But the degree of accuracy to which the investigations into these matters should extend depends on the local conditions and the objects of the management. It is best to make them neither very superficial, nor too detailed.

As regards the **Kind of Tree** forming the crop of the particular compartment or wood under description, the crop may be either pure or mixed.

In mixed woods, the mixture may be either in individual stems, or in patches or groups of smaller or larger size; and in either case the approximate area occupied by each different kind of tree may be conveniently expressed either by such proportions as $\frac{1}{2}$ *Larch*, $\frac{3}{8}$ *Scots Pine*, $\frac{1}{8}$ *Birch*, or 0·5 *Beech*, 0·2 *Larch*, 0·2 *Oak*, 0·1 *Ash*, the chief kind of tree being mentioned first of all. When less than about 0·1 of the area is occupied by any tree or trees, reference can be made to them as "*a few Pine, Birch, Sycamore, Willows*," &c. It is sometimes well to indicate whether the mixture is intended to be permanent or temporary, and whether any particular tree is forming part of the main crop, or is merely retained to preserve the soil against deterioration.

(*a*) The **Method of Treatment** should be briefly noted as *coppice*, *copse*, or *highwood*. And in the latter case it should be specially mentioned whether the woods are worked in annual falls with artificial reproduction (Conifers), or in periodic falls with natural regeneration (Beech-woods and most broad-leaved trees), or merely by casual fellings (in excluded woods, extending over the whole area or portions thereof).

(*b*) The **Age of each Crop** is of special importance for *highwoods*, because it is necessary to know this for estimating the quality of the crop and the best time for harvesting it. It is also essential for the purpose of classifying the crops in order to ascertain if, and to what extent, the present distribution of the various age-classes varies from the normal proportion required for the given rotation, as well as for estimating from Average Yield Tables the probable yield per acre when the woods are mature and come to the fall. If the age of each crop cannot be ascertained from the estate records, then suitable sample stems must be selected and felled, and the age determined from the number of annual rings found, except in the case of young crops of Conifers whose whorls can still be counted. The more regular the growth of the crop, the safer it is to estimate the age by felling and counting the annual rings on stems corresponding in girth to the mean average of the sum of the basal areas of the stems.

If the differences in age are considerable, their limits should be noted, and the crop should be classed as belonging to that age-class indicated by the bulk of the crop. In highwoods being regenerated naturally, the age both of the standards and of the young crop should be noted. In *coppices and copse-woods* it is easy to fix the date when the last fall took place, and if the standards on the hags have been worked in regular rotation it would also be easy to fix their age; but this will not usually be found to have been the case in Britain.

If a copse be worked regularly with a rotation of 20 years and four classes of standards, then these would of course be from 20-40, 40-60, 60-80, and 80-100 years old, while the underwood varies from 0-20 years of age. The area occupied by each of the age-classes of the standards would depend on the number of standards of each class and the individual growing-space each then requires on the average.

While the age can be accurately determined for coppice and copse, it is often difficult to be equally precise with regard to highwoods that have already advanced beyond middle age. Hence it is most convenient to classify such older crops merely as of 50-60, 70-80, 90-100, &c., years of age. By this arrangement they fall naturally into the periodic age-class to which they really belong, and the classification is subsequently suitable when the crop has attained maturity and comes to the fall.

Sometimes it happens that it is more convenient to classify a young crop in an age-class lower than that to which it really belongs. Thus, a plantation that has been seriously retarded in growth through being browsed on by deer, or a young Beech-crop that has suffered from the parent standards being retained long in order to profit by the rapid increment on isolated trees, may advantageously be classed as of, say, 10-20 years of age, although it may really be 20-30 years old.

A sort of natural classification of highwood crops can also be made for general descriptive purposes, though it is of no use for the practical purposes of the working-plan, where crops must be ranged definitely in periods according to age in years and not merely as to development. Thus, there follow in succession the *seedling crop* or *young plantation*, the *thicket*, the *pole-wood*, and the *tree-crop*—the latter distinguishable again as a crop of young, middle-aged, or old trees, according to their girth. If convenient, it may be noted how the crop was raised, whether by natural regeneration, coppicing, sowing, or planting; while the original distance of the plants and the course, and especially the extent, of the thinnings also convey useful information.

(*c*) The **Density of the Crop** may be characterised in highwoods of regular growth as *crowded*, *close cover*, *light canopy*, and *open* or *broken canopy*. Where there is not intended to be anything like close cover—as in Beech-woods undergoing natural regeneration, Oak- or Ash-groves treated by partial clearance and underplanting, or standards in copse—the distribution of the trees may be referred to as being *regular* or *irregular*, or as standing *thickly* or *thinly*. Where the canopy of highwoods or the crop of copse or coppice is interrupted to any considerable degree, these open spaces are *blanks*.

The density of the crop, or the degree to which canopy is formed, is expressed in decimals, 1·0 representing a normally complete canopy for a crop of the given kind of tree and age. The average number of trees per acre in Scots Pine, Spruce, and Beech-woods in Germany is shown (according to different estimates) on pages 223 and 407. It will be seen from these that normal density is far greater on the Continent than in Britain.

A very simple way of estimating the **number of trees per acre**, and ascertaining their average individual growing-space, is to measure the distance from centre of stem to stem in about 12 or 15 trees, take the mean average of the measurements, square this (thus ascertaining the average individual growing-space), and divide it into the 43,560 sq. ft. contained in 1 acre. For example, if measurements from centre to centre of 12 adjoining trees are 8½, 7, 8, 8¼, 7¾, 9, 10, 7¼, 8½, 7¼, 7, and 7½ ft. (=96), then the average distance apart is 8 ft., the average individual growing-space is $8 \times 8 = 64$ sq. ft., and the number of stems per acre is $\frac{43560}{64} = 680$.

(*d*) With regard to the **Condition of the Crop**, it should be noted whether it is *vigorous* or *backward* in growth. Any particular appearance giving indication in this direction should be mentioned—*e.g.*, tendency to form short boles and large crowns, to flushing adventitious shoots, to becoming stag-headed and dry in the top, to get overgrown with moss and lichens, &c.—as these notes often convey useful information.

(*e*) An **Estimate of the Cubic Contents of the Crop and its Current Increment** is necessary, because, next to the acreage, a knowledge of these factors is of more importance than anything else for framing the scheme of management. Hence the crop-description should at any rate state the *cubic contents* and the *current increment;* and it would characterise the crop better if the *basal area of the stems* per acre, their *number*, *mean height*, and *the cubic contents of the true average stems* were also mentioned.

If the cubic contents and increment be estimated for all crops forming the working-circle, this would enable an estimate to be formed of the whole actual growing-stock and increment, and a comparison of these data to be made with the annual fall which may be fixed.

The estimate of the cubic contents and the current increment of old crops which are likely to come to the fall within the next 10 to 20 years, is best made either by measuring the diameter of all the stems or by taking large sample-plots; and the more irregular the crop is, the larger and the more numerous will these sample-plots have to be before approximately correct results can be obtained for the whole crop. The contents and the rate of growth of pole-woods and middle-aged tree-crops can either be estimated by sample areas or by means of Average Yield Tables (see Appendix III.), while the latter is the best way of estimating them for thickets and younger crops.

The current increment will have to be measured with the assistance of a Pressler's borer (see p. 325) on all crops considered characteristic for furnishing "*the indicating percentage*"—*i.e.,* for determining the financial rotation generally, and for indicating the maturity or immaturity of crops that, if still growing at a profitable rate, need not, so far as purely protective or sylvicultural reasons are concerned, be brought to the fall within the next 10 or 20 years.

The cubic contents of the various crops must in any case be estimated in order to be able to decide the quality of the crop for its age. In young crops the necessary indication is given in the general vigour of growth, and particularly in the height; but in older crops more exact measurements can hardly be obviated, even although the length of the bole here also gives a certain amount of information as to the quality of the crop. And it is very necessary indeed that the contents and rate of growth of the crops coming to the fall within the next 20 years should be carefully determined.

Neumeister recommends (*Die Forsteinrichtung der Zukunft*, 1900, p. 31) that the cubic contents should be added to the description of all crops over 40 years of age, while it should be left to the person drawing up the working-plan to determine whether the assessment can best be made by measuring the whole of the stems, by felling sample stems, or by ocular estimate only; and he adds that, where the previous yield of similar crops is known from past fellings, results have proved the estimates of those who have had some experience of framing schemes of management to be sufficiently accurate for practical purposes.

The estimates of cubic contents and current increment should be in cubic feet per acre. If the woods are in a locality where the small branch-wood has little or no practical value, it may be most convenient to express the yield of timber only, *and this must be reduced by* $21\frac{1}{2}$ *per cent below the actual cubic contents in order to be in accordance with the British "square-of-quarter-girth" method of measuring timber, while a further reduction of* 16 *per cent of the true cubic contents* (*or of the square-of-quarter-girth measurement*) *is only too often customary as bark allowance in most parts of England* (see p. 291). If the whole of the wood above ground be estimated, it is perhaps most convenient to estimate the timber in customary British measurement and the branch-wood in actual contents. The current increment must, however, in either case be estimated in actual contents, and then reduced to square-of-quarter-girth measurement.

In estimating the cubic contents of mixed woods it is usual to differentiate merely between broad-leaved trees and Conifers on the Continent; but in Britain it will generally be necessary, or at any rate desirable owing to great variations in value per cubic foot, to make greater distinctions between the component parts of the crop.

All of the above-mentioned circumstances must be considered in subdividing the crops and making their description. The ordinary course of this work will be first of all to mark and map the boundaries of the different crops and to estimate their areas, and so on from compartment to compartment, the portions (*i.e.*, the temporary sub-compartments) falling within each compartment being noted in small letters after the number of the compartment (1*a*, 1*b*, &c.), after which the special crop-description is made for each compartment.

When the description of the crops is being made, notes should also be taken as to the sylvicultural and other measures required for the future treatment of the woods. Such notes are very useful when framing the scheme of management and determining in what periods the different crops ought to come to the fall. The main points to be kept in view have reference to (1) the time at which the crop will be mature, or can apparently best be harvested; (2) whether it should be regenerated naturally or reproduced artificially, or replaced by some other kind of crop; and (3) what fellings are necessary before this, and particularly what thinnings or partial clearances, if any, should be made in order to increase the rate of increment and make the mature crop more profitable.

No hard-and-fast statement can be given as to the age at which any specific crops of trees arrive at maturity, for all depends on the nature of the soil and situation in which they grow, and on the treatment they may have hitherto received. Birch, Aspen, Poplar, and Willow often yield their best returns when cut out from among other trees at 30 to 50 years of age. Ash, Sycamore, and Maple will usually be quite mature between 50 and 70 years of age; while Oak should often still be growing in value at 120 to 140 years. And when trees grow on light soil, or are drawn up by crowding, or have been over-thinned, they culminate in productivity at an earlier age than when growing on loam, or when the thinnings have been light. Larch grown on a wet, uncongenial soil sometimes matures under 30 years of age, and then turns rotten in the heart; while on dry, well-drained land it may grow healthily till 70 or 80 years of age, or more. In the Scottish highlands, the Scots Pine matures between 60 and 120 years, according to the individual nature of the crops; whereas in England and Ireland it is often, especially when thinned freely and frequently, fully mature by 35 to 40 years of age. Spruce, also, matures in Britain far earlier than on the Continent—often at 35 to 40 years.

Even after the average annual total increment may have culminated, however, the timber crops may be still advancing steadily and profitably with regard to **qualitative increment**, in respect to the dimensions of the wood at the top-end of the bole; and as this qualitative increment determines the adaptability of the timber for technical purposes, it of course affects the marketable value to a very considerable extent.

So far as the net returns derivable from any given soil, situation, and crop are concerned, they may be calculated by the formula

$$\frac{Fc + Ta + Tb + \ldots\ldots Tq - (c + fv)}{f}$$

Where

Fc = the value of the yield of timber obtained at the **final clearance.**

T(a, b, . . . q) = the value of **thinnings** carried out in the years a, b, . . . q, calculated at compound interest up to the date of the final clearance.

c = the outlay for **cultural costs**, calculated at compound interest.

v = the **various annual outlays**, *e.g.*, protection, rates, &c., calculated at compound interest.

f = the number of years included in the **fall or period of rotation of the crop.**

Whatever calculations (made from actual data taken from the estate books, or from Average Yield Tables) by the above formula exhibit the largest net result, will at the same time indicate the best age to clear the timber crop. But when the most profitable time for the fall is being thus calculated, the rate of interest at which the problem is worked out is of enormous influence on the result (see pp. 384, 388).

Special attention is also sometimes required in regard to such matters as the improvement of existing roads, or the opening out of new tracks for extracting timber, drainage, and the planting up of blank spaces or land not now under a crop of wood.

Recommendations made concerning the time of felling a crop, and the future crop to be raised, can of course only have any value when it has been clearly settled beforehand what are the most profitable crop and rotation.

In addition to being thus briefly noted along with the crop-descriptions, these matters relating to general principles and objects of management, choice of kind of tree, rotation, fellings, thinnings, cultural operations, road-making, protection, &c., are all referred to more particularly and at somewhat greater length in the report accompanying the working-plan.

These brief notes relative to the harvesting, tending, and regeneration of crops, as well to improvements in the way of transport, drainage, &c., have reference to contingencies which appear probable, although any definite decision about each of the particular points can only be arrived at when the actual working-plan is being framed.

The notes regarding **felling** naturally extend to the whole series of crops, with the maturity and yield of which they concern themselves. Although the allocation of the falls can only be made after all the crops are coloured according to age-classes and shown on the Stock-Map, yet the local conditions of soil and situation convey much useful information as to where a felling-series can begin, and how the falls can proceed. With these points in view, particular attention should be paid to those crops in which protective fellings or severances have to be made in order to obtain a good succession of falls or the establishment of various independent felling-series.

As regards **tending the woods**, it should be specially mentioned where thinnings, cleanings and weedings, partial clearances, pruning of lower branches, &c., should be carried out over the whole or portions of the area during the next 10 to 20 years.

The notes on **regeneration** should include both the areas to be felled during the first period, and also the sowing or planting of unstocked land and of blanks in young crops. Here it is useful to mention the most suitable kind of tree, and the method of sowing or planting. When young crops require to be improved, it is best to state roughly the percentage of the area thus to be dealt with, and to suggest the most suitable tree to be sown or planted.

These crop-descriptions can most conveniently be made first of all in a note-book, and then arranged more concisely in tabular form (as the **Field-Book**), so as to have a better outlook over the whole of the crops, and to see at a glance details which it is impossible to show on the Stock-Map. A very convenient arrangement of the manual, suitable for ruled sermon or essay paper about 8 × 10 inches in size, is as follows (compare with Working-Plan on p. 276, and Felling-Plan on p. 357).

1. *Name of Block or Estate:* Rosemount.
2. *No. and Name of Compartment:* 1. Briar Hill.
3. *Area:* 37 acres.
4. *Situation:* Gentle NE. slope, protected.
5. *Soil:* Clay of medium depth, somewhat stony, but fresh and fertile.
6. *Quality of Land:* III. to II., mostly II.
7. *No. of Sub-compartment:* [1]

7a. *Area:* 16 acres.

7b. *Quality of Land:* II. for Conifers.

8. *Description of Crop* (kind of tree, age, &c.): Mixture of Scots Pine, 0·5; Spruce, 0·3; Larch, 0·2, with a few Birch; 85 years old (planted in 1815); fairly well stocked, though rather open in places where there is no Spruce. Pine and Larch well grown; Spruce generally outgrown. Soil-covering mostly of grass, with patches of whortleberry here and there, where the crop stands thin.

9. *Height; Density and Canopy:* About 75 ft. on average; fair.

10. *General Quality of Crop:* I. for Pine.

11. *Rate of Growth:* Good; present yield 8200, and current increment 85 cub. ft. per acre (true cubic contents).

12. *Treatment:* Should be brought to the fall during I[1]. (*i.e.*, in the first 10 years of the I. period), and replanted with Larch and Douglas Fir at about 4 × 4 ft.

When all the various compartments have thus been gone through, the results of the crop-descriptions can be briefly tabulated as follows:—

Woodland area.				Growing stock in 1900.					
Number and description of compartment.		Area.	Quality of land.	Age.	Height.	Density of canopy.	Quality of crop.	Description of crop.
		Acres.		Years.	Feet.			
1. *Briar Hill* = 37 acres.	*a*	16	II.	85	75	Fair.	II. to I.	S.P. 0·5, Sp. 0·3, L. 0·2 in good growth.
Situation: gentle N.E. slope, protected.	*b*	12	III.	74	60	Medium.	II.	do.
Soil: clay of medium depth, somewhat stony, but fresh and fertile.	*c*	9	II.	62	60	Good.	I.	do.

[1] Where no subdivision into sub-compartments is necessary, the description under 8 to 12 can be at once made for the whole compartment.

This table is continued on opposite page of note-book as follows :—

Growing stock in 1900.		Preliminary recommendations as to treatment.		
Present yield.	Current increment.	Fall to be made in the period.	Felling and reproduction.	Remarks.
Cubic feet per acre.				
8200	85	I^1.	Clear-felling and replanting should begin at once.	Replant with Larch and Douglas Fir at 4 ft.
6800	80	I^1. or I^2.	...	Replant with Larch and Scots Pine.
6400	130	I^2.	The fall can be shifted to II. if necessary.	Should soon be lightly thinned.

(7) **Statistics relative to Past Yield, Returns from Timber, Cost of Planting, &c.**, can only be depended on when a detailed account of the debit and credit of the woods has been regularly kept; and this has rarely been the case on British estates.

Reliable figures, furnishing trustworthy bases for future estimates, will seldom in Britain be obtainable regarding the yield, in material and money, of past falls of mature wood (timber, branch-wood, and bark) and of thinnings and intermediate yield of any other nature. Where available, the most useful returns for the purposes of future management are those of the last ten years regarding timber and branch-wood, which may conveniently be summarised in some such form as the following table, or in any other way thought more suitable :—

TABLE OF YIELD DURING EACH OF THE LAST TEN YEARS.

Year.	Mature fall.									Thinnings, &c.									Total yield.									Remarks.
	Timber.			Branch-wood.			Total.			Timber.			Branch-wood.			Total.			Timber.			Branch-wood.			Total.			
	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	Broad-leaved trees.	Conifers.	Total.	
	Cubic ft.			Cubic ft.			Cubic ft.			Cubic ft.			Cubic ft.			Cubic ft.			Cubic ft.			Cubic ft.			Cubic ft.			
1890 to 1899																												
Annual average																												

Wherever most of the crops are only broad-leaved trees, or only Conifers, it may often be more useful to arrange the table according to the different kinds of trees (Beech, Oak, Ash, &c.; Pine, Larch, Spruce, &c.), seeing that the local price of each usually varies considerably, and the information thus conveyed is useful. It is only when reliable statistics of this sort are available, that proper actuarial calculations can be made.

3. The Preparation of the Scheme of Management or Working-Plan.—As the principle on which the method of fixing the annual or periodic fall by combination of area and yield is based consists in dividing the whole woodland area into working-circles whenever necessary, and in determining the most suitable treatment and rotation for each of these, the next work to be taken in hand after subdividing the whole area into compartments and making the above investigations into the crops and their rate of growth is—

(1) To ascertain the present distribution of the different **age-classes** in each working-circle;

(2) To prepare a preliminary sketch for the **Felling-Plan,** *according to area;*

(3) To estimate and regulate the **Annual Fall;**

(4) To elaborate the definite Scheme of Management or **Working-Plan,** and to prepare the Explanatory Report and Stock-Map which should accompany it.

(1) **The Present Distribution of the Different Age-Classes** is found by tabulating the crops in each working-circle according to their age. No matter what particular method of management be adopted, it is only by doing this and by making a Stock-Map that a clear idea can be formed as to how far the actual growing-stock differs from the ideal or normal condition with regard to a regular succession of crops of different ages. The necessity for such a table, when highwoods are being dealt with, will be apparent when it is considered how essential the normal distribution of age-classes and the regulation of the general felling direction are for the normal condition of the growing-stock, and how differences between the actual and the normal distribution must be taken into account in modifying the normal fall as to area during the near future, in order to try and bring the woods ultimately into the normal condition.

For copse-woods and young plantations the summary may be less detailed, as in the following case (the Earl of Selborne's woods in Hampshire, in 1899):—

SUMMARY OF COPSEWOODS AND OF PLANTATIONS IN 1899.

(*Note.*—The Block Numbers refer to recognised divisions of the whole estate.)

I.—*Copsewoods.*

Block of estate.	Compt.	Name of Copse.	Area.	Coppice.		Standards.	
				Last fall.	Present age.	Girth.	Estimated age.
			Acres.		Years.	Feet.	Years.
IV.	A	Blackmoor Wood .	31	1889, 1890, 1892, 1893, 1894, 1896, 1897, 1898	1, 2, 3, 5, 6, 7, 9, and 10	2 to 6	30-40 to 70-80
	B	Hazel Copse . .	3	1894	5	,,	up to 70-80
	C	Lower Ridges Copse	1½	1894	5	,,	,,
	D	Upper Ridges Copse	¾	1894	5	,,	,,
	E	Highfield Copse .	2½	1894	5	4 to 6	50 to 80
		Total area in Block	38¾				
VII.	A	Squiresfield Hanger .	2½	1890	9	3 to 4	30 to 50
	B	Homefield Hanger .	1	1896	3	,,	,,
	C	Lane Hanger . .	2½	1893	6	,,	,,
	D	The Alder Bed .	2	1897	2	up to 5	up to 50-60
		Total area of Block	8				
VIII.	A	Snapwood . .	33½	1889, 1891, 1893, 1894, 1895, 1898	1, 4, 5, 6, 8, and 10	...	30 to 40
	C	Cornbrooks Hanger .	5	1888, 1893	6 and 11	6 to 7	90 to 120
	D	Bradshott Wood .	15	1892, 1894, 1896, 1898	1, 3, 5, and 7	up to 4	up to 50-60
	F	Bushy Copse . .	5	1896	3	...	35 to 40
	G	Island Copse . .	1½	1896	3	...	50 to 60
		Total area in Block	60				
IX.	C	Temple Hanger .	16½	1888, 1889, 1893, 1894	5, 6, 10, and 11	...	Oak, 50 to 80 Ash, 40 to 50
	E	Plainbarn Copse .	21	1890, 1894, 1895, 1896, 1897	2, 3, 4, 5, and 9	3 to 4	50 to 60
	F	Iron Paddock Copse	17	1892, 1893, 1894	5, 6, and 7	3 to 4	50 to 60
	G	Sothrington Lane Side	4	1893	6	up to 8	up to about 120-150
		Total area in Block	58½				
XI.	A	Oakhanger Pond .	2¼	1881, 1882	17, 18	4 to 6	40 to 60
		Total area of Block	2¼				
XII.	A	Claypit Copse . .	3	1891	8	up to 2¼	20 to 30
	B	Oakwood Row .	½	1896	3	up to 7	80 to 100
		Total area of Block	3½				
		Total area under Copse	171	Acres.			

II.—*Plantations* (consisting mostly of Pine and Larch).

Block of estate.	Compt.	Name of Plantation.	Area.	Species of crop.	Age of plantations.
			Acres.		Years.
I.	A	Eveley Corner . . .	16	Scots Pine . . .	25-35
	B	Eveley Allotment . .	2	,, . . .	25-35
	C	Eveley Birchwood . .	2	Birch . . .	32
		Total area in Block	20		
II.	A	Church Plantation . .	39	Scots Pine . . .	33
	B	Lemon's Firs . . .	4	Scots Pine, Oak .	29
	C	Eveley Field Larches .	5	Larch . . .	14
	D	,, ,, . .	3	Pine and Larch . .	12
		Total area in Block	51		
III.	A	Vicarage Plantation . .	14	Scots Pine, Larch .	33
	B	Rhododendron Plantation (Total area 12 acres; under wood, 9 acres only)	9	Scots Pine, Larch, Corsican Pine, Birch	29 ; 17-19
		Total area in Block	23		
IV.	F	Wolmer Plantation . . .	10¼	Scots Pine, Larch, Chestnut, Birch	30
		Total area in Block	10¼		
VIII.	B	Cornbrooks Plantation .	7	Larch, Corsican Pine, Douglas Fir, Ash, Sycamore, Oak	4
	E	Bradshott Plantation .	1	,, ,,	4
		Total area in Block	8		
IX.	A	Rhode Plantation . . .	10	Pines, Firs, Larch, Ash, Sycamore	4
	B	Temple Larches . . .	5	Larch, Ash, Chestnut.	13
	D	Temple Hop-Garden Plantation	2	Pines, Larch, Ash, Sycamore	3
		Total area in Block	17		
XI.	B	Sandy Lane Plantation .	½	Scots Pine . . .	29
		Total area in Block	½		
Total area under Plantations[1] .			129¾	Acres.	

The Total area under Woods is therefore—

Copse	171	Acres.
Plantations	129¾	,,
Total .	300¾	Acres.

[1] Abstract of Conifer Woods—

	Acres.
Plantations under 5 years of age	20
,, from 5 to 15 years of age	13
,, ,, 15 to 25 ,, ...	4
,, ,, 25 to 35 ,, ...	92¾
Total	129¾

The classification of the crops in the table is made according to the notes jotted down in the crop-descriptions. The number of classes, usually divided by periods of 20 years, will depend on the kind of crop and the rotation. For Conifers in Britain, III. or IV. usually, or at most V., will suffice, while V. or VI. will usually be required for Beech-woods and other broad-leaved trees grown along with Beech. The periods are numbered, so as to include in I. crops intended to be felled during the next 20 years, in II. those probably coming to the fall between 21 and 40 years hence, and so on.

With data like those referred to on page 350, such a table would be as shown on the left-hand side of page 357—where (for the sake of completeness) it is given in combination with the preliminary Felling-Plan made out according to area—because it is much the most practical and convenient method to have these two tabular statements combined in one form.

Where the land has deteriorated so much under old broad-leaved crops that it is evidently best to clear them and make the area part of a Conifer working-circle, it is perhaps most convenient to regard those particular crops as part of the latter, in order to simplify the management and make the working-plan clearer. This is all the more permissible as such crops will almost invariably be among those coming to the fall within the first 10, or at most 20 years.

Where areas are in course of natural regeneration, as in Beech-woods, those allotable to the oldest and the youngest periods can be assessed according to the estimate of the cubic contents in the parent standard trees.

Example.—Suppose the contents of the old standard trees of 120-140 years of age are found to amount to 3200 cub. ft. per acre on land from which a yield of about 8000 cub. ft. per acre might be expected (judging from the look of the trees) at 130 years of age, then the area occupied by that portion of the crop belonging to the I. period will be $\frac{3200}{8000} = 0{\cdot}4$ of the whole area, while the remainder, $1{\cdot}0 - 0{\cdot}4 = 0{\cdot}6$ of the area, will be classified as stocked with a crop belonging to the youngest period (VI. or VII., according as the rotation is fixed at 120 or 140 years). If the whole area were 30 acres, then the old crop would be $30 \times 0{\cdot}4 = 12$ acres, and the young crop $30 \times 0{\cdot}6 = 18$ acres.

In addition to this tabular statement of the age-classes, it will be found very useful at this stage to make the **Stock-Map** showing the whole woodland area, its subdivision into compartments, and the nature and age of the crops in the different working-circles. It need not be on a larger scale than 3 inches to 1 mile (1 : 21,120), though the 6-inch scale Ordnance Survey Map is also very suitable. As the object of the Stock-Map is to distinguish plainly between the different working-circles, and between the various age-classes in each of these, it is desirable, in the case of highwoods, to use a separate colour for each working-circle, and to indicate the different age-classes by the depth of the tint. The crops of 1-20 years receive a light wash of the colour used for the particular working-circle, those of 21-40 a deeper wash, those of 41-60 still deeper, 61-80 yet darker, and 81-100 either pure colour, or else, if that has already been applied for 61-80, a wash over with gum arabic or white of egg to deepen the tint, and to make it glossy and easily distinguishable.

When woods are being regenerated naturally, the stage of the regeneration (*e.g.*, preparatory fellings, seed-fellings, or gradual clearances in Beech-woods) can easily be shown by wide cross-hatching with dotted lines of different colours.

It is immaterial what colours are selected for the different working-circles, but preference may well be given to those which can be most easily washed on with the hair-pencil; and the colour will lie all the better if the paper be first of all sponged or washed with a weak solution of alum.

For Conifer highwoods washes of *Indian ink* of different depth can be recommended, for Beech-woods *lake*, for mixed woods of broad-leaved trees *green*, and so on; but the choice of colours can best be made according to the actual circumstances of the work in hand.

It is of course different in the case of very large estates like State forests, where it is desirable to have uniformity prescribed in such matters.

It is only when some such Stock-Map has been prepared that it is possible to see clearly where the various felling-series can be located, how they can proceed, and where it is necessary to make protective falls or severances in order to provide starting-points for felling-series, 10 to 20 or more years ahead, without then incurring considerable danger of windfall. Such a map is, in any case, required to accompany the felling-plan in illustration of the Scheme of Management; so it is better, in the case of highwoods, to lay in the groundwork of it now, and to add the further necessary details to it later on when the final details of management have been fixed and the falls of the next 20 years determined. For woodlands consisting only of copse and coppice, however, such preliminary preparation of the Stock-Map is unnecessary. Here the falls can be arranged so much more easily that it is best to wait till this is settled, and then to colour the Stock-Map for the next 10, 15, or 20 years of rotation in whatever manner seems clearest and most convenient.

(2) **A Felling-Plan according to Area** must next be sketched in a preliminary and tentative manner. The object of this is to determine the areas forming the fall in each period, to allocate the different crops to their proper periods for felling, to arrange convenient felling-series, and to see where it may be necessary to make severances now in order to prevent windfall later on.

With the aid of the notes made in the crop-descriptions the areas of the various woods are first of all entered according to their age, in what seems the most suitable distribution with regard to the falls from period to period. The entries thus made are then considered more critically, to see that they can furnish a fairly even yield from year to year—*i.e.*, for each of the first two periods, and for each of the two sub-periods of period I. And in addition to this, careful consideration should also be given to the way in which the felling-series must run. It is only after the preliminary sketch has been made, as shown on opposite page, that closer criticism can be applied to see if the arrangement of the different felling-series, which are of a *permanent* nature, is that which is most suitable, and if the periodic falls are properly distributed over the first two sub-periods and periods (I^1., I^2., II.). The areas are altered by shifting part from period to period, or sub-period to sub-period, and the yield is calculated for various arrangements, until what appears the most suitable has been determined. When these matters have been thoroughly considered, the felling-plan can be definitely fixed and used for the framing of the Working-Plan (see p. 276).

Tabular Statement showing present distribution of Age-Classes. | Preliminary Sketch for the Felling-Plan, according to Area.

Working-Circle for Conifers, on the Frampton Estate (Rotation, 80 years).

Woodland area: Compartment.		Area. Acres.	Quality of land.	Age. Years.	Growing-stock in 1900: Age-Classes, in Acres: I. (over 60 years).	II. (41-60)	III. (21-40)	IV. (1-20)	Falls for re-planting.	Blanks and land for new plantations.	Felling-Plan for mixed Conifer Highwoods: Fall, in Acres: I. Period (1901-1920). 1. Sub-period (1901-1910).	2. Sub-period (1911-1920).	II. Period (1921-1940)	III. Period (1941-1960)	IV. Period (1961-1980)
1. Briar Hill =37 acres.	a	16	II.	85	16						16				
	b	12	III.	74	12							12			
	c	9	II.	62	9							9			
2. Greenwood =36 acres.	a	21	II.	59		21					Thin	Thin	21		
	b	15	I.	55		15					do.	do.	15		
3. Round Hill =47 acres.	a	18	III.	33			18				Thin	Thin	Thin	18	
	b	16	III.	30			16				do.	do.	do.	16	
	c	5	II.	20				5			do.	do.	do.	Thin	5
	d	8	II.	17				8			do.	do.	do.	do.	8
4. Gorse Cover =24 acres.		24	I.	78	24						15	9			
5. Oakwood =33 acres.	a	10	III.	54		10					Thin	Thin	10		
	b	16	III.	45		16					do.	do.	11	5	
	c	7	III.	31			7				do.	do.	Thin	7	
6. Rushton Brake =31 acres.	a	13	II.	19				13			Thin	Thin	Thin	13	
	b	18	II.	18				18			do.[1]	do.	do.	Thin	18
7. Frampton Hill =32 acres.	a	27	II.	12				27			Thin	Thin	Thin	Thin	27
	b	5	II.	just felled.					5		(5)	do.	do.	do.	5
Total . .		240	II.		61	63	41	71	5		31[2]	30	57	59	63
Actual distribution of periodic age-classes					61	62	41	76							
Normal do. do.					60	60	60	60							
Nature and degree of variation from the normal distribution: excess					+1	+2	...	+16							
deficit					...	...	−19	...							

Remarks as to Treatment.

1st Felling-Series; compartments 1*a*, *b*, *c*; 2*a*, *b*; 3*a*, *b*, *c*, *d*. The falls in this series should precede those in the 2nd series.

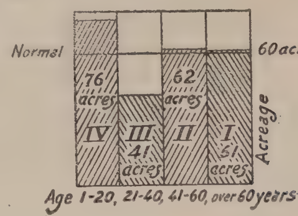
The annual falls being small (only 1½ acres), there will be merely very slight danger from weevils if planting is done after one year's fallow. If the stumps can be grubbed profitably, replanting can at once be done after the fall; otherwise the areas should be burned before planting.

2nd Felling-Series; compartments 4; 5*a*, *b*, *c*; 6*a*, *b*; 7*a*, *b*.

[1] There are a good many sporadic softwoods, which should be cut out whenever interfering with the Conifers.

[2] Areas to be planted during the next 10 years are underlined (16, 15, 5, 31).

The distribution of the age-classes may also be shown graphically, thus:—



For example, in the case here given it might perhaps be better to harvest crop compartment 1*b* before compartment 4, but the necessity of having two felling-series points to advantage in allocating compartment 4 in I¹., and 1*b* in I². If this were not done, then the annual falls throughout I¹. and I². would be made year after year in immediate proximity to each other (in compartment 1*a* and *b*), and with the inevitable result that the most favourable conditions—fresh root-stumps and young plantations, side by side—would be deliberately given for encouraging the breeding of weevils, that might prove very destructive to the young plantations. In broad-leaved woods regenerated naturally, there being no danger of this sort, the periodic falls can be fixed more simply according to the age and the rate of growth of the crops already mature or approaching maturity.

This preliminary felling-plan according to area can be dispensed with for small woods in which the allocation of the annual falls (in copse or coppice) or the periodic falls (in highwoods) can be at once fixed and entered in the Working-Plan.

The chief attention is to be paid in the preliminary felling-plan to the allocation of the falls during periods I. and II., and more particularly for the two sub-periods of I. In the remaining periods the areas merely represent the sort of probable allocation of the falls among the crops then maturing, unless accident of any sort may perhaps require them to be harvested earlier. Although it is impossible that allotting such areas to far distant periods can be of any really practical use in fixing the fall for the comparatively near future, yet the arrangement is of advantage in showing where severances will have to be made for beginning felling-series later on, where somewhat heavier thinnings than ordinary are advisable to force on the crops to early maturity by making the stems thicken rapidly in girth when once their main growth in height has been accomplished, or where it may perhaps be best to remove old trees at a comparatively early date on account of natural regeneration having to be delayed so as to make the crop fit in properly with the regular succession of the falls. Unquestionably, too, the extension of the outlook over the whole rotation of each crop enables one to form a better idea of the thinnings that will probably be necessary, and to estimate more correctly what these are likely to yield.

(3) **The Assessment and the Regulation of the Annual Fall** differ according to the nature of the working-circle and the treatment followed.

In **coppice** and **copse**, as already stated more than once, the most practical way is to assess the yield from past results and to regulate the annual fall by area in such a manner that a somewhat larger acreage is cut over if the land is below the average in quality.

In **copse** any attempt to assess the yield in overwood in a more methodical manner is at once met with the practical difficulty that it will be a matter of extremely rare occurrence to find copses in Britain where the standards have been habitually retained and utilised according to any fixed plan for anything like so long a period as one full rotation of the overwood.

The stock can be measured on sample-plots and then estimated for the whole of the woods, but the standards are so seldom regularly distributed as to number and age that such data may indeed often prove very misleading. It is much easier to forecast what the yield in overwood ought to be when once the provisions of the Scheme of Management have been sufficiently long in operation to produce a fairly normal distribution of age-classes among the standards; and such estimates will mainly depend on the quality of the land.

Each time that the underwood is felled, the fall also removes the following from the overwood (see also vol. i. Part III., *Sylviculture*, p. 343).

I. All the mature standards (trees to be felled in I. Period).
II. An equal number of those in the next age-class (trees to be felled in II. Period).
III. Twice as many ,, ,, ,, ,, ,, III. ,,
IV. Four times as many ,, ,, ,, ,, ,, IV. ,,

So, too, if there were five age-classes, then eight times as many of the youngest class would be removed; but if a rotation of 20 years be adopted, as may frequently prove advisable, four classes will usually be all that will be required in Britain.

The number of standards which may be left, while giving the underwood any chance of forming a profitable crop, depends on the quality of the land. For very good soil and a favourable situation, as many as about 75 standards per acre may perhaps be retained with profit. This gives an individual growing-space of $\frac{43560}{75}=580$ sq. ft. per standard, and the average distance at which these would stand from each other will be $=\sqrt{580}$, or about 24 ft.; while the respective age-classes (with a 20 years' rotation) would consist of the following number of standards forming the overwood:—

Just after each fall.	Just before each fall.	Cut at each fall.
IV.—40 young stores, of 20 years.	IV.—40 young stores, of 40 years.	IV.—20
III.—20 double stores, of 40 ,,	III.—20 double stores, of 60 ,,	III.—10
II.—10 young trees, of 60 ,,	II.—10 young trees, of 80 ,,	II.— 5
I.— 5 old trees, of 80 ,,	I.— 5 old trees, of 100 ,,	I.— 5
Total, 75 standards.	Total, 75 standards.	Total, 40

The standards belonging to each age-class should be distributed as equally as possible over the whole area, though this is—like the "normal condition" generally—a thing to be aimed at rather than really attainable.

If the quality of the land be such that the stems should not be closer than about 27 ft. apart, which would represent a soil and situation of fair medium quality, then there could only be about 60 standards per acre $\left(\frac{43560}{60}=726\right.$ ft., and $\sqrt{726}=$ about 27 ft. apart), and these would be distributed in the proportion of I., 4; II., 8; III., 16; IV., 32=60 in all.

If it seems advisable not to have them closer than 30 ft. apart on the average as on land of rather inferior quality, then there would only be about 48 stems left per acre ($30\times30=900$ sq. ft., and $\frac{43560}{900}=48$ standards), and these would be in the proportion of I., 3; II., 6; III., 12; IV., 24=45 in all.

And in much the same manner, the distances at which the individual trees of each class should stand, on the average, can also be estimated. If there are four old trees of Class I., or one to every ¼ acre, then their average distance will be $\sqrt{\frac{43560}{4}}=104$ ft., or 34 yards apart, and so on. But, of course, mathematical accuracy of this sort is quite unattainable in practice, seeing that the selection of stores and standards must adapt itself to the crop as found at each time of felling over the area, and that the number of standards left is also influenced by the amount of shade they cast on the underwood.

Where the land is decidedly poor in quality, the question may well arise whether it would not be more profitable to work it as simple coppice merely, or to clear it gradually and replant with a crop of Conifers, or to interplant it with Larch or Douglas Fir at about 6 or 8 to 10 ft. apart (on suitable soil only).

In **highwoods**, as also already stated, the degree of accuracy with which it is necessary to estimate the mature yield varies with the age of the crop. The contents of such crops as are likely to be cut during the I. period should be assessed carefully by one or other of the methods described in Chap. II. for the determination of the cubic contents and of the current increment per acre—the increment being calculated for each crop to the **middle** of the period or sub-period in which the crop is to come to the fall. It is unnecessary to go to the trouble of making actual measurements of the rate of growth of old, over-mature crops, which evidently should be cut as soon as convenient.

If any crop comes to the fall partly in one sub-period (or period) and partly in that following, then it is best to regard it as practically representing two crops having the same yield and increment per acre, and to calculate the latter separately from each of these to the middle of the sub-period (or period) in which the clearance is to be made.

Sample-plots will probably usually prove most convenient for practical purposes in Britain; and it will be of advantage (in order to collect data on the subject) to compare the results thus attained with the figures given for similar land in the Average Yield Tables for Germany (Appendix III.). The crop and its increment will have to be estimated first of all in actual cubic contents, and then reduced by $21\frac{1}{2}$ per cent for so much of it as is classifiable as timber to reduce this to British (square-of-quarter-girth) measurement and also by 16 per cent for bark allowance (see p. 291).

The regulation of the annual fall varies, however, according as the woods are clear-felled and then reproduced by sowing or planting, or are regenerated naturally while the parent crop is being gradually removed to make way for the seedling growth. In either case the fall is fixed for the whole period, or for each of the two sub-periods of the I. period; but there is this difference, that when the woods are clear-felled the annual fall is respectively $\frac{1}{20}$ or $\frac{1}{10}$ of the whole fall fixed for the period or sub-period, whereas in the woods to be regenerated naturally the annual falls must be grouped together, and the fellings, after a good seed-year has come, extend annually over the whole of such periodic area to the full extent required to make up the cubic contents of the fall for one year.

Seeing that Forestry in Britain has generally been carried on in rather a haphazard manner during the past century, it will seldom be found practicable to make annual falls approximately of the normal size $\left(\frac{\text{total area of working-circle}}{\text{years in rotation}}\right.$ for broad-leaved crops, and $\left.\frac{\text{total area of working-circle}}{\text{years in rotation}+\text{years of fallow}}\right.$ for Conifer crops), and to group these into regular sub-periodic and periodic falls by multiplying the quotient respectively by 10 and 20. This can only be possible when the actual distribution of the age-classes does not vary in any very marked degree from the normal condition. But even then, the rotation fixed is rather a sort of useful guide than anything in the nature of a hard-and-fast rule.

If the bulk of the crops are merely middle-aged and younger, then it is best to ascertain the extent of the crops already mature or approaching maturity, to estimate their cubic contents and increment, and to arrange for these being brought to the fall in about equal annual quantities till the time comes when the middle-aged crops attain their maturity. Where, on the other hand, the bulk of the crops are either mature or will soon become so, it seems best—unless ready money is required by the landowner for some special object—to bring no more than the normal area annually to the fall, and to utilise first of all those crops which show the least profitable rate of growth, or which require to be cleared for other sylvicultural or for protective reasons. With the present indications of a rising market for good timber in the near future, it will probably pay better to hold over crops still in vigorous growth than to clear them off simply because they represent an excess of capital in the growing-stock required for a working-circle of the given area and rotation. Otherwise, should it for any reason—say, to utilise an exceptionally favourable market, or to be sure of natural regeneration, &c.—be desirable to clear off this surplus within the next period, then somewhat more than the normal fall will have to be cut annually till the excess has been utilised.

In either case, if the deviation from the normal fall be not great, the annual fall can either be reduced or increased by being fixed as

$$= \frac{\text{total area of working-circle}}{\text{years in rotation}} \times \frac{\text{actual average age of all the crops}}{\text{normal average age of all the crops}},$$

a formula recommended for practical use by Prof. Stoetzer of Eisenach (*Die Forsteinrichtung*, 1898, p. 245).

When once the extent of the falls has been definitely fixed for the I. period, it must next be decided which crops will be brought to the fall. These should include, in the first instance, over-mature crops of poor growth, or badly stocked old crops, and severances required for the commencement of future felling-series, then also such crops as are shown by the "indicating percentage" (see p. 247) to have reached, or to be on the point of attaining, their financial maturity. Of these latter only so many need be included as are required to make up the periodic fall, while the remaining portions may be entered as part of the fall in the following period.

When the fall has been determined for the I. period, it is divided into those for the two sub-periods I^1. and I^2., so as to indicate plainly which crops ought to be cleared first of all, and which subsequently. And in doing this, as has been already explained, it is of great importance to form convenient, safe, small felling-series, and to arrange for the falls succeeding each other in the proper direction, against wind. To attain this, an old mature crop must sometimes be allowed to stand longer than would otherwise be the case, till the falls reach it in regular succession; while, on the other hand, a younger crop may perhaps have to be cleared sooner than its increment and the "indicating percentage" show to be desirable. But the advantages derivable from maintaining the proper felling direction are worth making some such little sacrifices for.

For convenience of calculation, the estimate of the annual fall should always be rounded off in tens of cubic feet, so that the periodic fall will be shown in hundreds and thousands.

For calculating the yield of the falls and arranging them so as to give about equal returns during periods I. and II., and during the two sub-periods I^1. and I^2., the following tabular form may be found useful. Its use will be clear from a comparison of the Felling-Plan on page 357 and the Working-Plan on page 276.

ESTIMATE OF YIELD PER ACRE, AND MATURE FALL OF I. AND II. PERIODS.

No. of Compartment.		Area. Acres.	Yield and Increment per Acre.	I. Period (1901-1920).						II. Period (1921-1940).		
				I^1. (1901-1910).			I^2. (1911-1920).					
				Area. Acres.	Yield. Per Acre.	Yield. Total.	Area. Acres.	Yield. Per Acre.	Yield. Total.	Area. Acres.	Yield. Per Acre.	Yield. Total.
1. Briar Hill =37 acres.	*a*	16	8,200 +85	16	8,625	138,000						
	b	12	6,800 +80				12	8,000	96,000			
	c	9	6,400 +130				9	8,350	75,150			
2. Greenwood =36 acres.	*a*	21	6,200 +132							21	10,160	213,360
	b	15	4,000 +125							15	7,750	116,250

The details of the I. period being completely arranged, with the intention of working up to them as closely as may be possible, the fall can now be entered as to area and yield for the II. period, and in area only for the remaining periods. The yield and the increment for the crops maturing only in the II. period can be estimated from Average Yield Tables, without making unnecessarily elaborate measurements in the meantime. So, too, may the probable yield of more distant periods be estimated, where this seems desirable for the purpose of making actuarial calculations. By taking the average age of the crops from period to period, and the average quality of the land, an estimate can easily be made of the total growing-stock throughout the whole working-circle. These data as to area and yield can only, however, be regarded as nothing more than indicating the general scheme of management recommended, because it is impossible to foretell with anything like absolute accuracy what the actual yield of crops will be from 20 to 40 years hence.

It is this necessity for looking ahead, and for aiming at *introducing* regularity in management, that seems to me to make the system of combining area and yield better suited for Britain than the otherwise excellent Saxon system of fixing the falls for the next 10 years only.

"In order to have such a regularly sustained annual yield as the given circumstances allow, it is necessary to fix the fall according to the normal area to be cleared annually, the distribution of the different age-classes (with comparison of the actual and the normal), and the past yield, by utilising these factors so as to regulate the fall in the crops now mature or nearly so. The more accurate the data about past yield and distribution of the age-classes, the longer that regular management has been carried out in the woods, and the larger the number of revisions of the past working that have already taken place, the more advantageous it is only to fix the felling-plan for a short period. Where a scheme of management is being drawn up for the first time, when such data are wanting, it must naturally be of benefit to regulate the working-plan for the near future by also looking further ahead. As the normal distribution of the age-classes according to area and position is one of the first principles to be kept in view, it is advisable to forecast the proportions of the age-classes for several periods of 10 years, taking the proposed area of the annual fall as a basis. If the distribution thus attained be satisfactory, then the mature crops should be harvested as soon as convenient, due care being taken to ensure that the yield should be about equal from year to year, and the fellings made in the proper direction against wind" (Neumeister, *Die Forsteinrichtung der Zukunft*, 1900, p. 56).

In Germany, it is usual to make separate estimates of the *final yield* and the *intermediate yield or thinnings.* Everything that is cut on the areas allotted to the fall during the I. period must be classed as belonging to the "final yield" and forming part of the annual fall, while thinnings made in crops allotted to the II. or any younger period are dealt with separately as the "intermediate yield." It is different, however, in the case of exceptionally heavy thinnings made, after the crop has completed its main growth in height, with the object of stimulating the increment and making the trees grow rapidly in girth. These are in reality *partial clearances*, and as such they should of course be taken into account as forming part of the final yield of the crop. The proper thinnings are the slight fellings made for the express purpose of preventing overcrowding till the crops have passed through the pole-wood and the middle-age stages of growth, and which may be necessary at intervals varying from 5 to about 10 years, according to kind of tree, age, general condition, and rate of growth of the crop.

The obvious reason for this differentiation of thinnings is that the final yield is estimated on more or less accurate data, to secure which time and trouble have been spent, whereas the yield of thinnings in crops of different age and of various conditions of growth can only be assessed very roughly. It is therefore best merely to note in the felling-plan the crops to be thinned, then to add these together and see what is likely to be the area that will have to be thinned annually. Whether the thinnings should be made about once every 5 years, or only once every 10 years or so, will of course depend on the given conditions of the working-circle; but, in any case, the yield from thinnings and their value can only be satisfactorily estimated from knowledge of past results on the estate. The yield from roots and stumps varies too much to be even roughly estimated. The special reference to thinnings in the working-plan is made rather for the purpose of ensuring their being carried out at least once every 10 years than with any view of recommending whether the crops should be thinned heavily, moderately, or slightly. This is a matter that must usually be left to the judgment of the wood-manager with regard to the requirements of each individual crop.

In calculating the annual fall of broad-leaved crops it is usual to estimate the yield in timber and in branchwood, as all of it is generally marketable, while for Conifer crops it is best to estimate merely for the timber, unless the tops and branches can be regularly disposed of locally. As previously remarked (p. 348), although it will always be most convenient to make the calculations as to growing-stock and increment in actual cubic contents, yet it is desirable to convert these into customary British measurement for all the wood classifiable as *timber*, *i.e.*, down to 6 inches (hardwoods) or 3 inches (Conifers) in top-diameter, or whatever may be the local custom, and to express the annual fall as being of so many cubic feet of timber (square-of-quarter-girth measurement) and so many cubic feet of small branchwood (actual contents, or else cord or stack measurement). And the same may be done with regard to thinnings, though here classification into hop-poles, pea-sticks, &c., will also often be desirable.

It is convenient to note at the end of the Working-Plan what particular crops, giving their acreage, have to be thinned during the next 10 years, so as to see the extent of the work to be done and to be able to estimate roughly what the yield may perhaps amount to each year on the average. The following is a convenient form for this purpose, as it separates the *thinnings* (which are profitable) from the *weedings and cleanings* of seedling crops and young plantations (usually necessary once every five years, and in which the material cut does not cover the cost of removal) :—

Plan of Thinnings, &c., 1901-1910.			
Compartment.		Thinning. Acres.	Cleaning and weeding. Acres.

The yield in thinnings varies so much locally that it is best to go by local results, or, if necessary, to thin out sample plots and classify and measure the material.

The case will sometimes occur in Britain that it may be desirable to convert copses, or highwoods treated by the casual (selection) system of felling, into regular highwoods worked in periodic falls without changing the present kind of crop. Here the first thing to do is to determine the rotation within which the transformation is to be accomplished, to divide this into three or four periods of, say, 20 years each, and then to arrange the falls systematically throughout this time.

Say, for example, that mixed crops of broad-leaved trees, hitherto worked entirely by the casual (selection) system of felling, are to be converted gradually within the next 40 years into crops worked by regular periodic falls, and that they can be conveniently arranged into four series for treatment, then these latter might be as follows :—

During Periods of 10 years each.	Method of Treatment of the Crops during next 40 years.			
	Series 1.	Series 2.	Series 3.	Series 4.
I.	**Natural regeneration and planting of Conifers.**	Preparatory felling.	Modified Copse treatment.	Modified Copse treatment.
II.	Cleaning and weeding.	**Natural regeneration.**	Preparatory felling.	Modified Copse treatment.
III.	Thinning.	Cleaning and weeding.	**Natural regeneration.**	Preparatory felling.
IV.	Further thinning.	Thinning.	Cleaning and weeding.	**Natural regeneration.**

The crops forming series 1 would be those of so poor a character, with deteriorated soil, as to make it advisable to clear the existing crop and plant with Conifers. It would also comprise the areas having a good stock of underwood or young growth, which would be allowed to grow up as a highwood while the old trees or standards are gradually removed during the I. period.

The second series would comprise the crops having a good supply of standards or old trees, but little underwood. The third series would consist of crops with fewer large trees but plenty of poles, which would prove seed-bearers 20 years hence. The fourth series would consist of crops not specially falling under any of these categories, and any vacant land that can at once be planted or interplanted with Conifers that might become marketable at about 35 years old.

The periodic falls will of course need to be equalised so far as possible, and an endeavour should be made to arrange the crops so as to fit in conveniently with the local felling-direction. By the time the crops forming series 4 are regenerated, the Conifer crops in series 1 will be fit for felling.

It is a simpler matter when copse or poor broad-leaved highwoods are to be transformed straight off into Conifers. Here the conversion can take place in any way that the landowner desires, either during the course of, say, the next 10, 20, 30, or 40 years, as the proprietor may decide after consideration of the very plain, self-evident arguments for and against speedy or gradual conversion.

This question will often arise wherever the woodland portions of estates are to be treated commercially in Britain. Personally, I am inclined to advise that in such cases it will be best to carry out the transformation of poor copse or highwood of broad-leaved trees, under which the soil has been allowed to deteriorate, within the next 10 or 20 years, one-tenth or one-twentieth of the area being cleared annually and replanted with whatever mixture of Conifers appears best suited to the given conditions of soil, situation, and local market for wood.

It is practically certain that there will be an excellent future market for well-grown Conifer timber in Britain, and the clearance of the whole of the copse or highwood trees should furnish, besides the annual fall, a surplus more than sufficient to pay for the planting of the area with Conifers. That this is a deliberate, though only a temporary, withdrawal of *capital* from the normal growing-stock of the woods must not be overlooked, nor the fact that, owing to such temporary withdrawal of capital, there will probably—unless the local market for small produce from early thinnings is exceptionally good—be a falling off in the annual returns for some years after the conversion of the old woods has taken place and before the new Conifer crops attain their maturity.

If good Conifer crops will probably pay better than indifferent copse or broad-leaved highwoods, it seems better to effect the conversion as speedily as convenient than to extend it over any long period, merely in order that mature Conifer crops may then be ready for the fall as soon as the last of the deteriorated copse or high-woods are cleared from the ground, so as to have a regularly sustained annual yield in accordance with one of the fundamental principles of economic Forestry. The fact that, at the end of the period of conversion, the Conifer crops would not be more than 10, 20, or 30 years of age must of course mean a reduction of income from the particular areas here dealt with ; but this is merely the temporary result of having previously and deliberately made an inroad into the capital when clearing off the old crop, and it will in course of time be made up for by larger returns than hitherto. Later on, the management can easily carry out such arrangements as will obviate any practical difficulty about such crops being all too much of one age—*e.g.*, by bringing the older half of them to somewhat early maturity by means of heavy thinning and other sylvicultural measures. But until these operations can be taken in hand after the young crops have reached the desired length of stem, the only income that can be expected from them is what is yielded on the average by thinnings carried out every few years in the ordinary course of tending the woods.

The conversion of simple coppice into copse, or of copse into regular broad-leaved highwoods, can only be made gradually by storing well-grown young trees—of seedling growth, for preference—at each rotation of the fall. The period within which the transformation can be accomplished depends, of course, on the rotation and the number of age-classes among the standards.

With a rotation of 20 years and four age-classes, it would be 60 years after the next fall before all the different age-classes would be formed throughout the crop, and 80 years before the fall would harvest wood of all dimensions (old trees, young trees, double stores, stores) along with the underwood.

Conversion from copse into coppice is even simpler, by merely felling all of the standards and working the whole area as coppice. Here the complete transformation can take place within one rotation of the underwood—*i.e.*, within 10, 15, or 20 years, as the case may be.

4. **The Explanatory Report accompanying the Working-Plan.**—The Scheme of Management consists of a Working-Plan made in the form of a tabular statement, such as previously shown on page 276. As it is accompanied by an **Explanatory Report**, having as Appendices the detailed description of the various crops and a **Stock-Map**, it seems most convenient to deal with all of these in the form in which they should be submitted to the landowner to whose woods they refer.

Regarding all of these as forming the *Scheme of Management*, this may then be said to consist of three different portions, namely—

Part I.—Summary of Facts upon which the proposed Working-Plan is based.
Part II.—The Working-Plan proposed for the Future Management, with the detailed Description of Crops and the Stock-Map appended.
Part III.—Directions as to the mode of carrying out the Fellings and other Operations recommended.

Part I.—**Summary of Facts upon which the proposed Working-Plan is based.**—A general description of the whole of the local circumstances connected with the woodlands on any estate is not only of interest to the landowner, as perhaps placing certain matters connected with Forestry before him in a new light, but it is often of considerable practical use to the agent, factor, or lawyer who manages the estate, and to the forester or steward charged with the care and working of the woodlands. Besides this, it is in any case essential that all the matters herein about to be referred to should be investigated before any sound scheme of management can be drawn up and recommended; and this being so, it is desirable to commit the results of the investigations to paper in as concise a manner as is possible, while giving a general view of the estate and of the past and present management of the woodlands.

As the headings of the various sections into which this Part is subdivided are self-explanatory, notes regarding them need only be made here and there when considered of special advantage. These sections[1] are—

1. *Situation, Area, and Description of the Estates.*
2. *Configuration of the Ground, and Elevation above Sea-level.*
3. *Geological Formation: Soil and Subsoil.*
4. *Climate and Rainfall.*
5. *Area, Composition, and Condition of the Woods.*—Under this heading suggestions may perhaps be made regarding the rounding off of the woods by planting vacant land, or otherwise.
6. *General Quality and State of the Soil.*
7. *Park, Field, and Hedgerow Timber.*
8. *Estimated Value of Present Woodland Crops.*
9. *Fences and Boundaries:* condition, &c.
10. *Legal Position of the Estate.*—This should be particularly inquired into and noted, because of the limitations in the case of entailed estates in England, and of the legal distinctions drawn between timber and *sylva cædua* in consequence thereof (see vol. i. p. 58).
11. *Dangers to which the Woods are Exposed.*—This should make special mention

[1] The arrangement here followed is based on the instructions of the Indian Forest Code with regard to Working-Plans for the State (Reserved) Forests, but it is modified as I have found most suitable for the usual circumstances of woodland estates in Britain.

of the prevailing dangerous wind, and of risk from fires, insects, farm-stock, ground and other game, fungous diseases, &c., cases of heavy damage being noted in detail.

12. *Present Rate of Growth.*

13. *Past Yield of the Woods, and Income from them; Rating and Assessment.*

14. *Cost of Reproduction (Natural Regeneration: Sowing or Planting).*

15. *Marketable Products and Markets; Prices obtainable for Produce.*—The probable tendency of the local market in the future should here also be noted.

16. *Administrative and Executive Staff.*

Part II.—**The Working-Plan proposed for the Future Management.**[1]—This can very conveniently be made in a tabular form, as shown on page 276. It should be kept as brief and concise as possible, because the details concerning each crop can be looked up, whenever necessary, in the Field-Book containing the Description of Crops, which, together with the Stock-Map, is appended to the Working-Plan. This is introduced by a short general sketch, also kept as brief and concise as seems consistent with clearness, of the principles kept in view when drawing up the Working-Plan.

1. **Objects of Management.**—When various courses of treatment seem open, these should be discussed with the landowner or his responsible agent. They should also be noted in the report, and the objects of management specially desired by the owner distinctly stated, *as the Working-Plan is intended to show how these objects can be attained in the most economical manner and in the shortest period of time.*

2. **Choice of Kinds of Crops and Methods of Treatment; Formation of Working-Circles.**—The general results of the crop-descriptions contained in the Field-Book can here be briefly summarised, and a concise statement made as to the deductions drawn with regard to future management. This should state definitely what kinds of crops, and mixtures of trees, are likely to be most profitable, and how these conditions can best be attained.

3. **Fixing the Rotation of each Working-Circle.**—The reasons for recommending any change from existing rotations should be given, and supported by actuarial calculations, if necessary.[2]

4. **Statement of the Principles upon which the Annual Fall is fixed.**—This need not go into matters the knowledge of which may be taken as granted, or which should be left to be dealt with by the manager or forester as seems best to him at the given moment; but the reasons for or against periodic falls with natural regeneration, or clear-felling in annual falls with artificial reproduction (and in the latter case for or against sowing and planting), may with advantage be noted for each of the working-circles, as also the specific manner in which such natural regeneration or artificial reproduction should be carried out.

5. **The Working-Plan**, in tabular form.—A typical specimen of a simple Working-Plan for Conifers has already been given on page 276. But sometimes for highwoods it may be even much simpler, as in the following case of woodlands on an estate in the North of Scotland:—

[1] For the benefit of the student it may be noted that the following Working-Plan Reports (with maps) for British woodlands have up to date been published, and may easily be referred to:—1. For the Forest of Dean and the Highmeadow Woods (Crown Woodlands), by H. C. Hill (H.M. Stationery Office, 1897); see also *Trans. Roy. Scot. Arbor. Socy.*, 1898, pp. 292–300); 2. Plan for the Pit-Wood Working-Circle, Raith Estate, Fifeshire, by Col. F. Bailey (*Trans. Roy. Scot. Arbor. Socy*, 1898, pp. 223-278); 3. Working-Plan for the Novar Woods, Ross-shire, by Col. F. Bailey (*Trans. Roy. Arbor. Socy.*, 1899, pp. 25-95); 4. Working-Plan for the Earl of Selborne's Blackmoor, Bradshott, and Temple Woods, Hampshire, by J. Nisbet (*Trans. Surveyors' Institution*, 1900, and *Trans. Roy. Scot. Arbor. Socy.*, 1900, pp. 193-240).

[2] If the timber-crops are for pitwood only, a rotation of about 40 years (35 to 45) will probably pay best (see vol. i. p. 98).

The **Working-Plan.**—Felling and Replanting may best take place as follows:—

I. **Conifers**: *Clear-Felling and Replanting with mixed Conifers* (Pine, with Larch and Douglas Fir).

Year.	Name of wood.	Number of compartment.	Present crop.	Area, exclusive of roads, &c.	Total fall for year.	Remarks as to treatment.
				Acres.	Acres.	
1900-01	North Wood	1	80-90-year mixed Conifers and hardwoods, chiefly Pine and Oak.	27	54	If cut in autumn, fell from E. to W.; if in spring, from W. to E., to minimise danger of windfall. Burn area to clear it of rubbish and reduce danger from weevils, then plant with mixed Conifers (Scots Pine, Larch, and Douglas Fir, with Spruce in damp patches) during following autumn.
	do.	2	80-90-year mixed Conifers, mostly Scots Pine.	27		
1901-02	Dennie Hill	12	Mostly old Beech (140-160 years) and other hardwoods in lower part, with Pine (100-120 years) and mixed Conifers (about 60-70 years).	24	59	Do. do. do. Should be planted with pure Scots Pine on the poorest and most exposed parts.
	do.	13		35		
1902-03	Pond Wood	3	Chiefly Scots Pine (80-90 years), mixed with Spruce and a few Larch.	15	32	Fell from E. to W. Burn and replant as above. E. part requires drainage and planting mostly with Sycamore, Ash, Birch, and Spruce.
	do.	6		17		
1903-04	High Hill	16	Mixture of old Beech and other 90-year-old hardwoods and Conifers, mostly in patches.	40	40	Do. do. do. Opening out of old drains would be advantageous before replanting.
1904-05	Pond Wood	4	Much the same as compartments 3 and 6.	28	48	Do. do. do. Old curling-pond should be thoroughly drained and planted with Sycamore, Ash, Birch, and Spruce.
	do.	5		20		
1905-06	Binn Hill	14	Partly hardwoods, partly Conifers, mixed in patches, mostly about 90 years of age, with some old Beech and Scots Pine.	23	23	Fell from E. to W. in autumn, or W. to E. in spring; then replant as in 1 and 2.
1906-07	Dennie Hill	7	60 to 70-year-old Scots Pine with a sprinkling of Larch.	32	59	Fell from E. to W., and replant as in 1 and 2. E. portion requires drainage, and should be planted chiefly with Sycamore, Ash, Spruce, and Birch. Exposed parts of 8 to be planted with pure Scots Pine.
	do.	8		27		

1907-08	High Hill	17	Much the same as in compartment 16, but situation drier.	42	53	Do. do. do. Parts of 17 may require a little drainage.
	West Cliff (upper part only)	18	90-year-old mixed woods, chiefly Conifers.	11		
1908-09	Dennie Hill	9	Mostly 80 to 90-year-old Pine and Larch, with pure Pine (100-120 years) along exposed S. face, and Spruce and Pine (50 years) in moist patches.	25	57	Do. do. do. 50-year-old Spruce and Pine cannot be protected from wind, and should be cleared with rest of crop. Plant Pine pure on the poorest and most exposed knoll and the S. side of hill. Small young plantations should be filled up to 4 × 4 ft. with Scots Pine on dry parts, and Sycamore, Ash, and Birch on moist patches.
	do.	11		32		
1909-10	Dennie Hill	10	Partly mixed hardwoods (mostly old Oak, a very thin crop) and partly mixed Conifers (90 years).	31	44	Do. do. do.
	West Cliff (the upper portion of each compartment)	19, 20	Mixed woods, mainly Conifers in patches.	5, 8		
					Total, 469	

II. **Hardwoods**: *to be naturally regenerated and interspersed with Conifers.*

					Total fall during whole period of ten years.	
					Acres.	
1900-01 to 1909-10	Binn Hill	15	......	23	71	Careful thinning of existing crop, and natural regeneration of hardwoods, with subsequent filling up with Larch, Douglas Fir, and Pine. Sycamore and Ash should be favoured in the natural regeneration, being likely to form the most profitable crop. Soil-preparation should take place by hoeing parallel strips, or raking with heavy rakes, horizontally along the hill sides, and sowing them with Sycamore and Ash wherever seed trees do not stand near at hand. The present trees to be then gradually removed according to the necessity of the young seedling crop, and Larch, Douglas Fir, and Pine planted wherever desirable to fill up and complete the crop.
	West Cliff (the lower portion of each compartment)	18, 19, 20	......	22, 14, 12		
					Total, 71	
			Add area of Conifer crops,		469	
			Grand Total,		540	

Statement of the Principles upon which the Annual Fall is fixed.—As the crops in the various compartments are, almost without exception, fully mature, the main principle upon which the allocation of the falls during the next ten years—the period of complete utilisation and reproduction—has above been made is to ensure their protection against danger from windfall, and the avoidance of damage to young plantations by beetles. Danger from windfall can only be minimised, but not altogether obviated. No assistance can be obtained in the way of severance-cuttings, owing to the advanced age of the woods.

And for copse-woods, as also for coppice, the Working-Plan may of course be much more simple, extending merely to area, as in the following Plan of Fellings for the Earl of Selborne's woods (Copse-wood Working-Circle) in Hampshire:—

A.—Tabular Statement of Fellings in Copses for the First 10 Years (1899-1900 to 1908-1909), being a Short Provisional Rotation for the Special Improvement of both the Overwood and the Underwood.

Year.	Block of estate.	Compt.	Name of copse.	Portion for fall.	Approximate area of fall.	Total fall of the year.
					Acres.	Acres.
1899-1900	IX.	C	Temple Hanger . .	Whole	16½	21½
	VIII.	C	Cornbrooks Hanger .	,,	5	
1900-1901	VIII.	A	Snapwood . . .	E. part	17½	17½
1901-1902	IV.	A	Blackmoor Wood . .	S.E. and S.W. parts	15	17¼
	XI.	A	Oakhanger Pond . . .	Whole	2¼	
1902-1903	IX.	F	Iron Paddock Copse .	Whole	17	17
1903-1904	VIII.	A	Snapwood . . .	W. part	16	16
1904-1905	VII.	A	Squiresfield Hanger .	Whole	2½	12½
	VII.	C	Lane Hanger . .	,,	2½	
	IX.	G	Sothrington Lane Side .	,,	4	
	XII.	A	Claypit Copse . .	,,	3	
	XII.	B	Oakwood Row . .	,,	½	
1905-1906	IX.	E	Plainbarn Copse . .	N.W. part	10	18
	VIII.	D	Bradshott Wood . .	S. part	8	
1906-1907	IV.	B	Hazel Copse . .	Whole	3	17¼
	IV.	C	Lower Ridges Copse .	,,	1½	
	IV.	D	Upper Ridges Copse .	,,	¾	
	IV.	E	Highfield Copse . .	,,	2½	
	VIII.	F	Bushy Copse . .	,,	5	
	VIII.	G	Island Copse . .	,,	1½	
	VII.	B	Homefield Hanger .	,,	1	
	VII.	D	The Alder Bed . .	,,	2	
1907-1908	IX.	E	Plainbarn Copse . .	S.E. part	11	18
	VIII.	D	Bradshott Wood . .	N. part	7	
1908-1909	IV.	A	Blackmoor Wood .	N.W. part	16	16
				Total Acres .		171

Average Area of Annual Fall, 17 *Acres.*

B.—Tabular Statement of the Regular Fellings, with Normal Rotation for the following 20 Years (1909-1910 to 1928-1929).

Year.	Block of estate.	Compt.	Name of copse.	Portion for fall.	Approximate area of fall.	Total fall of the year.
					Acres.	Acres.
1909-1910	IX.	C	Temple Hanger . .	N.E. part	6½	6½ *
1910-1911	IX.	C	Temple Hanger .	S.W. and N.W. parts	10	10
1911-1912	VIII. XI.	C A	Cornbrooks Hanger . Oakhanger Pond . .	Whole ,,	5 2¼	7¼
1912-1913	VIII.	A	Snapwood . . .	E. part	9	9
1913-1914	VIII.	A	Snapwood . . .	E. of centre	8½	8½
1914-1915	IV.	A	Blackmoor Wood . .	S.E. part	7½	7½
1915-1916	IV.		Blackmoor Wood . .	S.W. part	7½	7½
1916-1917	IX.	F	Iron Paddock Copse .	N.E. part	8½	8½
1917-1918	IX.	F	Iron Paddock Copse .	S.W. part	8½	8½
1918-1919	VIII.	A	Snapwood . . .	W. of centre	8	8
1919-1920	VIII.	A	Snapwood . . .	W. part	8	8
1920-1921	VII. VII. IX.	A C G	Squiresfield Hanger . Lane Hanger . . Sothrington Lane Side	Whole ,, ,,	2½ 2½ 4	9
1921-1922	IX.	E	Plainbarn Copse . .	N.W. part	10	10
1922-1923	VIII. XI. XII.	D A B	Bradshott Wood . . Claypit Copse . . Oakwood Row . .	S. part Whole ,,	8 3 ½	11½
1923-1924	IV. IV. IV. IV. VII.	B C D E B	Hazel Copse . . Lower Ridges Copse . Upper Ridges Copse . Highfield Copse . . Homefield Hanger .	Whole ,, ,, ,, ,,	3 1½ ¾ 2½ 1	8¾
1924-1925	VIII. VIII. VII.	F G D	Bushy Copse . . Island Copse . . The Alder Bed . .	Whole ,, ,,	5 1½ 2	8½
1925-1926	IX.	E	Plainbarn Copse . .	S.E. part	11	11
1926-1927	VIII.	D	Bradshott Wood . .	N. part	7	7
1927-1928	IV.	A	Blackmoor Wood . .	N.E. part	8	8
1928-1929	IV.	A	Blackmoor Wood . .	N.W. part	8	8
				Total Acres .		171

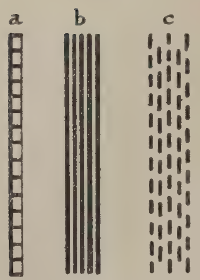
Average Area of Annual Fall, 8½ *Acres.*

* The lower, sheltered, and more productive portion.

With regard to the Stock-Map, which should be appended to the Working-Plan Report, it may be remarked that the falls in highwoods are usually indicated by the sub-periodic and periodic numbers (I^1., I^2., II., &c.). In the excellent Saxon Stock-Maps, however, the places where the falls of the next ten years are to be made are definitely indicated, instead of being left to the discretion of the wood-manager.

"After the felling-plan has been fixed for the next ten years, the felling-places are indicated (Fig. 210) on the map in Chinese white.[1] For clear-fellings straight lines *b*, and for natural regeneration dotted lines *c* are drawn in parallels at about one-tenth of an inch apart. The direction of these lines should correspond with that of the falls, while protective fellings or severances are marked by ladder-like cross-lines *a*. If any crop is to be treated for natural regeneration and then finally cleared as to the old trees during the ten years, this may be shown by making dotted lines alternate with straight lines. Conversions from copse or coppice into highwoods can be indicated by straight white lines as for clear-felling in highwoods, while transformations of highwoods into copse can be marked by small white arrows. In copse and coppice the distinctive letter of the crop (or sub-compartment) should be underlined with white. . . . To protect the map against rain when in use in the woods, it should be given a coating of colourless varnish" (Neumeister, *op. cit.*, p. 53). In Fig. 210 the various kinds of fellings are simply shown in black to suit the engraving used for representation.

Fig. 210.



(a) *Protective Falls or Severances.*
(b) *Clear-fellings, for replanting.*
(c) *Falls for natural regeneration and casual (selection) fellings in ornamental (excluded) woodlands.*

Part III.—**Mode of Carrying out the Fellings and other Operations recommended.**—The directions in this Part should likewise be as concise as seems consistent with clearness, and should extend to the following matters:—

1. *The General Felling-Direction, and the various Felling-Series.*—The latter are only necessary when the annual falls are cleared and reproduced artificially, as is usual with Conifer crops. Here the best size and shape, and particularly the maximum breadth permissible, should be mentioned, the number of felling-series stated (thus also giving the number of years in which two successive falls will be made in each crop), and the compartments and crops specified which should form each independent felling-series. Special mention must here also be made of the protective falls or severances which should now be made in order to provide starting-points for future felling-series, and to protect crops that will later on be exposed when falls are made in the next crop lying to windward. Here, too, the special measures to be taken with regard to gradual transformations from one kind of crop or method of treatment to another ought to be adverted to. In copses special mention should be made with regard to the standards and to the coppice-woods, and also with reference to areas to be gradually converted into highwoods or cleared for replantation.

2. *Cleaning or Weeding, and Thinning.*—Attention should be called to the steps taken in the working-plan to have these carried out regularly and in proper

[1] These white lines on the Saxon maps do not represent the actual falls as to length and breadth. They merely indicate the localities in which the fellings are to take place.

order; and it may often be necessary to indicate what changes should be made in the way of carrying out thinnings in the future, as compared with the past.

3. *Sowing and Planting: Natural Regeneration.*—As this has been partly dealt with under II. 4, it will here only be necessary to indicate the crops in which sowing, and those in which planting, seems preferable, and to make specific recommendations as to method, distance, and quantity of seed for sowing, size of plants to be used, and distance and manner of planting. It should also be stated whether a nursery should be kept up in order to supply the young plants required, or if it will probably be cheaper to obtain them from nurserymen. Similarly, when natural regeneration is intended, any specific recommendations regarding kinds of trees to be favoured and the most profitable way of filling up blanks should be mentioned.

4. *Shelter-belts and Wind-mantles.*—Indications should be given as to where and how such can advantageously be formed or renewed in order to provide shelter for land or live-stock, and to preserve the woodland soil from deterioration.

5. *Maintenance of Roads, Rides, Fences, &c. (including boundaries of Compartments.*—Any new roads, the formation of which would probably lead to easier extraction of timber, should be mentioned, as good communications of this sort are usually necessary to obtain the full market-value of the produce.

6. *Protection of the Woods.*—Suggestions can be given with regard to the chief dangers, and mention made as to the specific measures that might be adopted to secure immunity from damage by wind, insects, game, &c.

7. *Financial Results of proposed Scheme of Management.*—A forecast of these as compared with past results should be made, so far as the given circumstances permit of this, in tabular form. Otherwise, the advantages obtainable by following the recommendations made should be clearly stated with regard to the improvement to be expected in the value of the woodland capital, *i.e.*, land *plus* growing-stock, and in the income to be derived when the effects of regular management have time to become manifest.

8. *Control Books* (see below).

9. *Executive Staff.*—Any suggestions thought desirable should here be made as to improving the manner in which woodland operations are conducted—*e.g.*, training of wood-reeves and woodmen, time of different operations, &c.

5. Control and Revision of the Results of Working.—On large woodland estates where it may have been necessary to employ a specialist in Forestry to draw up the Scheme of Management,—a branch of professional business in which the great majority of British land-agents and factors have not had the advantage of thorough technical and practical training, for the very simple reason that no such education in Forestry has hitherto been provided in Britain,—it may probably be desirable that his services should be retained for annual inspection and report, at any rate for a few years, until the wood-reeves and woodmen have been trained to carry out woodland operations more systematically and thoroughly than has been customary in Britain. And in any case, a thorough examination of past results, with a revision or an extension of the details of the Working-Plan, will be necessary about once every ten years.

To enable this to be done, **Control Books** must be kept to show the results of working from year to year. It is of course desirable to avoid increasing work in the estate office; but at the same time it is necessary, for purposes of control and revision, to have a clear view of the incomings and outgoings, and of the exact position of the woods with reference to the proposals made in the Working-Plan, if approved and brought into operation.

The precise form in which this information can be tabulated with least increase of clerical work must depend on the particular manner in which the estate accounts are kept. Some such form as the following should usually suffice if kept for each Working-Circle, in addition to the general cash account:—

Year of fall.	Working-Circle, Block and Compartment.	Name of wood.	Work done.	Area of fall.	Yield of Fall. Cubic feet.													Receipts.	Expenditure.	Net income.
				Acres.														£ s. d.	£ s. d.	£ s. d.
I.	*For Copsewoods and Coppices*				Timber	Posts	Large poles	Small poles	Pit-wood	Bean-sticks	Fishing-rods	Hurdles	Firewood stacks	Faggots	Bark					
II.	*For Highwoods*				Pine	Larch	Spruce	Silver Fir		Oak	Beech	Ash	Elm	Sycamore						

Changes in the woodland area, by reason of purchase, sale, &c., must also be recorded as directly necessitating modifications in the Working-Plan, at any rate so far as concerns the annual fall; and these must be duly taken into account at the time of revision.

It is always very much easier to revise and amend a Working-Plan, or to draw up a new Plan for the next ten or twenty years, than to frame a Scheme of Management for the first time, because there will always be more definite data as regards yield and working during the period just concluded than were obtainable when the Plan was first framed. This fact should always be borne in mind when any one is criticising a Working-Plan drawn up under difficult circumstances, without the assistance of accurate information regarding the details of past income and expenditure, yield, rate of growth, and the various other factors which, in most cases, can only at present be estimated somewhat roughly.

CHAPTER IV.

BOOK-KEEPING ON WOODLAND ESTATES.

In addition to some convenient form of Control Book, as referred to on the opposite page, it is necessary for the forester to keep other books dealing with his cash accounts. At least five books are necessary—viz., 1. **Cash Book**; 2. **Daily-Labour and Piece-Work Book**; 3. **Sales-Book of Timber**, &c.; 4. **Ledger**; and 5. **Timber, &c., Stock-Book.** But others may also with advantage be kept, though of course it is always desirable to restrict office-work to the minimum consistent with maintaining proper business-like records. Thus, where there is a home-nursery, there should be a **Nursery Stock-Book**, and where a saw-mill is worked in connection with the woods, special **Mill Accounts** will also be necessary. These books should be of convenient size to suit the transactions on the estate, and should be large enough to contain the entries for several years.

1. **Cash Book**.—This should be written up daily, and receipted vouchers taken for all payments made. A clear and simple form is as follows:—

Dr. **Cr.**

Date.	No. of item.	Details.	Received from estate office. £	s.	d.	Receipts in cash. £	s.	d.	Date.	No. of item.	No of voucher.	Details.	Remitted to estate office. £	s.	d.	Payments in cash. £	s.	d.
1904. May 1	1	To *Cash from Estate Office* .	30	0	0	...	...	...	1904. May 1	1	1	By Daily Labour for week ending 30th April	...	...	...	7	10	0
,, 4	2	,, J. Gordon, Milltown, balance due on 1500 cub. ft. Oak, at 2s. per ft., purchased in February 1904	...	...	...	50	0	0	,, 1	2	2	,, Piece-work in April . . .	...	...	...	9	10	0
									,, 4	3	3	,, *Remittance to Estate Office* .	50	0	0	...	...	...
									,, 5	4	4	,, J. Hunter, Forester, Salary for April . .	...	...	...	10	0	0
												(Balance in hand, £3.)						

By using *red ink* for entering the sums above italicised, as showing that they have been received from (or remitted to) the estate office, and by having these entries in special columns, the clearness of the cash book is greater, and it is much easier to detect any error that may have crept into the accounts of any month.

There should be loose folios (as well as a bound cash book), which can very conveniently be used in submitting the monthly accounts (along with the necessary vouchers) to the estate office.

2. The **Daily Labour and Piece-Work Book** is simply the monthly abstract of the weekly pay-sheet of workmen employed in the woods, and of the payments for piece-work. The receipted weekly pay-sheets themselves, as also the receipts for the piece-work done, are of course used as vouchers in support of the items as they are entered in the cash book. Such weekly pay-sheets may be in the form of that on the opposite page, or any other convenient form.

Month by month an abstract of these, and of the piece-work completed and paid for, should be entered in the daily-labour book, the expenditure being allotted to the different heads in some such form as the following :—

Woodland.		Details of work.	Daily labour.				Piece-work.				Total amount paid.		
Block.	Compt.		Days.	Amount.			Rate.	Amount.					
				£	s.	d.		£	s.	d.	£	s.	d.
Adams Wood	3	Felling, logging, and lotting Oak timber	47	5	17	6	...	...	...	...	5	17	6
Bankhead	6	Thinning Oak plantation .	14½	1	16	3	...	...	...	...	1	16	3
Nursery	...	Cleaning and weeding . .	12	1	10	0	...	...	...	...	1	10	0
Braidwood	7	Opening drains, 2000 yards	...	...	...	...	2d.	16	13	4	16	13	4

In any case, some such abstract is necessary in order to know the cost of work with regard to the estimates and the annual accounts, and it is far easier and more satisfactory to maintain the record from month to month than to try and compile it from the cash book at the end of the year.

Before entering into any important contract for **piece-work** a detailed specification should be drawn up, and a formal agreement signed by the contracting parties on stamped paper, setting forth the general conditions of the bargain. This should provide that payment is to be made monthly for such part of the work as may be finished to entire satisfaction by the end of each month, and that the signing of the receipt for any such portion as shall be paid for at the end of any month shall be held as a sufficient receipt for such sums as may have been paid and received on the work progressively ; and in the cash book these sums can be entered as advances on account of work partly completed. It will usually, however, be most convenient to have an additional receipt in full made out and signed in the usual account form as a voucher on the completion of the whole work.

3. The **Sales-Book of Timber, &c.**—When large sales of timber are made by public auction, this is usually (at any rate in England) placed in the hands of an auctioneer, who lots, values, advertises, and sells the timber, then collects the money due from purchasers (less the usual discount of 2½ per cent for cash down, or 10 per cent cash and balance paid after three months) and remits it to the estate office (p. 481). There is, however, nothing to prevent the forester obtaining an auctioneer's license and holding the auction himself, if the owner or agent thinks this preferable to paying the auctioneer's fees (usually 10 per cent). In this latter case an account must be kept of each **Timber Sale by Public Auction**, in some such form as that on page 378.

When an auctioneer is employed to sell the timber, the only timber sales-book required to be kept by the forester is that for **Sales by Tender or by Private Contract**, which may be kept in some such form as that on page 378, or else in any other particular form as may perhaps seem more convenient for the given circumstances; for example, as on page 379.

4. The **Ledger** is only necessary to be kept for accounts which extend for some time, as with J. Gordon, T. Grant, and G. Brown in the two above sales-books, and for large piece-work contracts when part-payments are made from month to month before the work is completed. Like the cash book, the ledger accounts are kept

WEEKLY PAY-SHEET FOR DAILY-LABOUR EMPLOYED from 1st to 7th May 1905.

Name.	Monday. 1st May.	Days.	Tuesday. 2nd.	Days.	Wednesday. 3rd.	Days.	Thursday. 4th.	Days.	Friday. 5th.	Days.	Saturday. 6th.	Days.	Total.	Rate.	Wages due.	Receipt.
														s. d.	£ s. d.	
A. Gregor .	Felling, logging, and lotting Oak, Adams Wood.	1	Felling, logging, and lotting Oak, Adams Wood.	1	Felling, logging, and lotting Oak, Adams Wood.	1	Felling, logging, and lotting Oak, Adams Wood,	1	Felling, logging, and lotting Oak, Adams Wood.	½	Thinning Oak, Bankhead.	1	5½	2 6	0 13 9	(Signed) A. Gregor.
J. Grant. .	,,	1	,,	1	,,	1	,,	1	,,	½	,,	1	5½	,,	0 13 9	J. Grant.
D. Fraser .	,,	1	,,	1	,,	1	,,	1	...	...	,,	1	5	,,	0 12 6	D. Fraser.
J. Donald .	,,	1	,,	1	,,	1	,,	1	...	...	,,	1	5	,,	0 12 6	J. Donald.
W. Scott .	,,	½	,,	1	,,	1	,,	1	...	..	,,	1	4½	,,	0 11 3	W. Scott.
D. Ross . .	,,	½	...	...	,,	1	,,	1	...	...	,,	1	3½	,,	0 8 9	D. Ross.
W. Calder .	,,	½	...	...	,,	1	Weeding Nursery.	1	...	...	,,	1	3½	,,	0 8 9	W. Calder.
A. Roberts .	,,	½	,,	1	,,	1	,,	1	...	...	,,	1	4½	,,	0 11 3	A. Roberts.
J. Watson .	,,	1	,,	1	,,	1	,,	1	...	...	,,	1	5	,,	0 12 6	J. Watson.
J. Cook . .	,,	1	,,	1	,,	½	,,	1	...	...	,,	1	4½	,,	0 11 3	J. Cook.
H. Cameron	,,	½	,,	1	,,	1	,,	½	...	...	,,	1	4	,,	0 10 0	H. Cameron.
TOTAL .	Adams Wood,	8½	Adams Wood,	9	Adams Wood,	10½	Adams Wood, Nursery, . .	6 4½	Adams Wood,	1	Bankhead,	11	50½		6 6 3	

SALE OF TIMBER BY PUBLIC AUCTION on 4th May 1905.

No. of Lot.	Sold from		Description of Lot.				Purchaser.		Sold for	How paid for on day of sale.				Remarks.
										Paid in full.				
	Wood.	Com-partment.	Kind of timber.	Trees.	Logs.	Cub. ft.	Name.	Residence.		Less discount ($2\frac{1}{2}$ per cent).	Cash.	Deposit (10 per cent).	Bill at three months (due 4th August 1904).	
									£	£ s. d.	£ s. d.	£ s. d.	£ s. d.	
1	Lait	9	Larch	370	...	4310	J. Gordon	Milltown	210	...	..	21 0 0	189 0 0	
2	,,	,,	,,	280	...	3820	R. Tulloch	Baldric	195	4 17 6	191 2 6	...	...	
3	,,	,,	Oak	...	116	2560	T. Brash	Milltown	236	5 18 0	230 2 0	...	...	
			Total .	650	116	10,690		Total .	641	10 15 6	421 4 6	21 0 0	189 0 0	
4	Lait	10	Scots Pine	456	...	6340	J. Gordon	Milltown	160	...	...	16 0 0	144 0 0	
5	,,	10	,,	316	...	4160	T. Grant	Eden	105	...	...	10 10 0	94 10 0	
			Total .	772	...	10,500		Total .	265	...	...	26 10 0	238 10 0	
6	Clury	5	(and so	on as	above)									

At public auctions, as each lot is knocked down the purchaser should be made to sign the sale-book in acknowledgment of his having been the purchaser; this prevents subsequent misunderstandings.

Sales by Tender, or by Private Contract.

Date.	Purchaser.	Residence.	Sold from: Wood.	Sold from: Compt.	Kind of timber, &c.	Quantity sold: Poles: Small.	Quantity sold: Poles: Large.	Quantity sold: Trees (or Logs): No.	Quantity sold: Trees (or Logs): Tons weight.	Quantity sold: Trees (or Logs): Cubic feet.	Selling rate.	Amount. £ s. d.	How paid for at time of sale: Paid in full: Less discount (2½ per cent). £ s. d.	How paid for at time of sale: Paid in full: Cash. £ s. d.	How paid for at time of sale: Deposit (10 per cent). £ s. d.	How paid for at time of sale: Bill at three months. £ s. d.	Remarks.
1904. May 7	J. Ross .	Laggan	Clury	5	Scots Pine .	700	...	...	...	...	£5 per 100	35 0 0		35 0 0			
,, 10	T. Grant	Eden .	Bankhead .	6	Larch . .	...	108	...	...	...	18s. per doz.	8 2 0		8 2 0			
,, 13	J. Gordon	Milltown	Adams Wood	3	Oak . .	...	...	5	...	240	2s. per cb. ft.	24 0 0			2 8 0	21 12 0	
,, 15	G. Brown	Milltown	Burnside .	4	Birch (powder wood)	...	...	80	76	...	20s. per ton	76 0 0			7 12 0	68 8 0	
,, 21	R. Tulloch	Baldric	Clury . .	5	Larch (paling rails)	...	1740	...	...	...	3s. per doz.	21 15 0	0 11 0	21 4 0			
,, 27	W. Scott	Airlie .	Strawn . .	8	Ash . .	...	...	2	...	75	2s. per cb. ft.	7 10 0		7 10 0			
					Total .	700	1848	87	76	315	Total .	172 7 0	0 11 0	71 16 0	10 0 0	90 0 0	

in folio form, all sales of timber, &c. (or part-payments recovered from piece-work contractors), being entered on the left-hand page, and the payments (or entries regarding piece-work measured and paid for) on the right-hand page. To facilitate reference to the accounts, there should always be a lettered index at the beginning of the ledger, in which the names of those with whom accounts are kept should be entered alpabetically. The following is a specimen of a ledger account :—

Folio 1. **Dr.** John Gordon, Milltown. **Cr.** *Folio* 1.

Date.	Particulars.	Amount. £ s. d.	Date.	Particulars.	Amount. £ s. d.
May 4	*To* Lot 1, Public Auction, 4th May 1904, 370 Larch .	210 0 0	May 4	*By* Deposit of 10 per cent, as *per contra*	21 0 0
,, 4	,, Lot 4, Public Auction, 4th May 1904, 456 Scots Pine . . .	160 0 0	,, 4	,, Deposit of 10 per cent, as *per contra*	16 0 0
,, 13	,, purchase of 5 Oak, 240 cub. ft., at 2s., from Adams Wood	24 0 0	,, 13	,, Deposit of 10 per cent, as *per contra*	2 8 0
			,, 31	,, Balance due .	254 12 0
		394 0 0			394 0 0

5. The **Timber, &c., Stock-Book** is a necessary record, showing the total number of poles and trees felled, how they have been disposed of, and what balance still remains on hand. This, again, must vary in special form according to circumstances. The following is suggested as a simple form :—

Timber Stock-Book for month of May 1905.

	Scots Pine.		Larch.		Oak.		Ash.					
	Poles.	Logs.	Poles.	Logs.	Poles.	Logs.	Poles.	Logs.				
Balance on hand, 30th April . .	13,500	22,875	1,908	13,820	120	5	—	2				
Felled during May	2,760	—	5,462	—	—	—	—	—				
Total . .	16,260	22,875	7,370	13,820	120	5	—	2				
Sold during May	700	21,712	4,860	10,800	—	5	—	2				
Balance on hand, 31st May . .	15,560	1,163	2,510	3,020	120	—	—	—				

Of course this return must be kept in a much more elaborate form if it is intended to utilise it as a record of fellings made in the different woods and compartments. But it will usually be necessary to keep a separate record of the out-turn from all such thinnings and falls of timber.

It is also necessary to have each year a complete **Estimate of Receipts and Expenditure** for the coming year. It should be as concise and clear as possible, and should be made out for whatever term corresponds with the customary year in the estate office. When the estimate has been formally approved, it constitutes the forester's authority for the work he has to do during the year.

Estimate of Receipts and Expenditure for the Year from 1st July 1904 to 30th June 1905.

Income.

	Amount.	Total.
1. Sales of Timber:	£	£
Briar Hill: 10,000 Larch, 100,000 cub. ft. at 1s.	5000	
Clury: 12,000 Scots Pine, 108,000 cub. ft. at 6d.	2700	
Adams Wood: 4000 cub. ft. Oak at 2s. 6d.	500	
2. Sales of Thinnings:		8200
Pine and Larch from Burnside, Clury, and Lait, 56,000 poles at 3d.	700	
Oak from Rettie and Eden, 8000 poles at 1s.	400	
Mixed Hardwoods from Strawn, 6000 poles at 8d. . . .	200	
3. Sales of Oak-bark:		1300
50 tons bark from Oak in Adams Wood, at £4	200	
50 tons bark from thinnings in Rettie and Eden, at £5 per ton	250	
4. Rents:		450
Saw-mill, £80; 2 Lodges, £15	95	
		95
Total		£10,045

Expenditure.

	Amount.	Total.
1. Felling and Preparing Timber for Sale:	£	£
10,000 Larch (Briar Hill), 12,000 Scots Pine (Clury), } at 10s. per 100	110	
100 Oak (Adams Wood), at 4s.	20	
Thinnings, 70,000 poles, at average of 2s. per 100 . . .	70	
Oak-bark, 100 tons at 50s.	250	
2. Pruning:		450
Oak in Rymore plantation	5	
3. Fencing:		5
Braidwood, 6000 yards, and Corrie, 4000 yards, wire-fencing at 6d.	250	
Maintenance of fences, hedges, and gates	50	
4. Draining, Preparing, and Planting:		300
Braidwood, 118 acres, and Corrie, 61 acres, with mixed Conifers at 4 × 4 ft., at an average of £5 per acre	895	
5. Roads, Rides, and Walks:		895
New road, Milltown to Clury, 2400 yards, at 1s. 6d. . .	180	
Maintenance of roads, rides, and walks	60	
6. Repairs:		240
Lodges	20	
Water-runs	15	
Saw-mill dams	10	
7. Nursery:		45
500,000 seedlings for bedding, at an average of 10s. per 1000 .	250	
Labour, at an average of 20s. per week	52	
8. Establishment:		302
Forester	120	
2 woodmen at 15s. a week	78	
Cartman at 13s. 6d. a week	35	
9. Sundries:		233
Travelling expenses	15	
Carpentry and smithy work	20	
Tools	10	
Keep of cart-horse	26	
Repairs to harness	3	
Stationery and petty sundries (postage, &c.)	6	80
Total		£2550

This statement should be docketed outside as follows:—

Estimates for 1904-1905.	
Receipts	£10,045
Expenditure	2,550
Net Income .	£7,495

A concise **Annual Abstract of the Accounts** should be submitted, as soon as possible after the close of each year, in some form enabling it to be easily compared with the estimates framed over a year previously, *e.g.* :—

Annual Abstract of Accounts, Lynmore Woodlands, from 1st July 1904 to 30th June 1905.

Dr. Receipts.

		Actuals.	Estimate.	Difference.
		£	£	£
1. **Sales of Timber**:				
(*a*) *By Public Auction* (4th May 1905):				
9806 Larch, Briar Hill	£4805			
13,215 Scots Pine, 163 Spruce } Clury . . .	2903			
	7708			
Less Auctioneer's fees and sale-expenses	102			
Net amount paid to credit in estate office =	7606			
(*b*) *By Private Contract*:				
93 Oak, Adams Wood, 3960 cub. ft. at 2s. 4d.	462			
		8068	8,200	−132
2. **Sales of Thinnings**:				
(*a*) Burnside, Clury, and Lait:				
22,680 Larch poles, at 6d.	£567			
31,600 Scots Pine and 320 Spruce, at 2d.	266			
(*b*) Rettie and Eden:				
4640 Oak poles, at 1s.	232			
1260 ,, ,, 9d.	47			
(*c*) Strawn:				
7200 mixed hardwood poles, at 6d. .	180			
		1292	1,300	−8
3. **Sales of Oak-bark**:				
54 tons thick bark, at 84s.	£227			
47 tons thin bark, at 105s.	247			
		474	450	+24
4. **Rents**:				
Saw-mill	£80			
Two lodges	15			
		95	95	...
Total .		9929	10,045	−116

EXPENDITURE.				Cr.
		Actuals.	Estimate.	Difference.
		£	£	£
1. **Felling and Preparing for Sale:**				
9806 Larch, 13,215 Scots Pine, and 163 Spruce, at 10s. per 100	£116			
93 Oak, at 4s.	19			
Thinning 67,700 poles, at 2s. per 100	68			
Oak-bark, 54 tons at 47s. 6d.	128			
,, 47 ,, ,, 52s. 6d.	123			
2. **Pruning:**	——	454	450	+4
Oak, Rymore plantation		4	5	−1
3. **Fencing:**				
Braidwood, 5820 yards, and Corrie, 3940 yards, at 6d.	£244			
Maintenance of fences, hedges, and gates	63			
4. **Draining, Preparing, and Planting:**	——	307	300	+7
Braidwood, 118 acres	£579			
Corrie, 61 acres	313			
5. **Roads, Rides, and Walks:**	——	892	895	−3
New road, Milltown to Clury, 2260 yds., at 1s. 8d.	£188			
Maintenance of roads, rides, and walks	57			
6. **Repairs:**	——	245	240	+5
Lodges	£32			
Water-runs	12			
Saw-mill dams	13			
7. **Nursery:**	——	57	45	+12
500,000 seedlings, averaging 10s. 6d. per 1000	£263			
Labour	48			
8. **Establishment:**	——	311	302	+9
Forester	£120			
Two woodmen	78			
Cartman	35			
9. **Sundries:**	——	233	233	..
Travelling expenses	£11			
Carpentry and smithy work	17			
Tools	7			
Keep of cart-horse	31			
Repairing harness	2			
Stationery, postage, and petty sundries	8			
	——	76	80	−4
Total		2579	2550	+29
Net income		£7350	7495	−145

This return should also be docketed as follows:—

ABSTRACT OF ANNUAL ACCOUNTS.

Year, 1904-1905.	Actuals.	Estimate.	Difference. +	Difference. −
	£	£	£	£
Receipts	9929	10,045	...	116
Expenditure	2579	2,550	29	...
Net Income	7350	7,495	...	145

In the case of very large woodland estates, like State forests, the financial statements annually submitted are divided into three sections—

(1) Actuals for past year.	(2) Revised estimate for present year.	(3) Budget estimate for coming year.
1903-1904	1904-1905	1905-1906

All items of revenue and expenditure are then shown side by side under their numbered headings; and where any considerable difference exists between columns 1 and 2, or 2 and 3, the causes of variation should be explained. This system is advantageous on large estates, for the management can then see well ahead, and better arrangements can be made for carrying out the work. It is also more satisfactory, because it shows at a glance whether the net income or revenue is increasing or decreasing.

When such a record as this last has been kept for several years, it will then be easy to compile from it at any time (with the assistance of the estate office, from which alone will be obtainable the necessary details as to the proportionate sums debitable to the woodlands for *General Administration and Agency*, *Rates and Taxes*, and *Legal and Miscellaneous Charges*) a statement showing the **Average Receipts** from, and **Average Expenditure** on, the woods. And if it should happen (as will very seldom be the case in Britain) that the woodlands are in such a fairly normal condition as to permit of the crops being gradually cleared by a succession of falls producing about equal returns year by year, then the **Average Net Income** can fairly be used to estimate the **Capital Value** of the woodlands (*i.e.*, land *plus* timber-crops) by the formula $C = \frac{r}{0 \cdot 0\,p}$. It will then only remain to fix the rate of interest, p, in order to be able to solve the otherwise very simple equation. But it may be pointed out that if the woods are thought to be doing so well as an investment that, say, 3¼ per cent may be taken as p, then this will make them appear as having a far lower capital value than if they are only calculated to be yielding, say, 2¾ per cent—which is absurd (see pp. 388 and 391).

CHAPTER V.

THE VALUATION OF WOODLANDS.

1. Formulæ for Calculating Present and Future Value of Capital and Rental.—One of the most striking features of British Forestry is the disregard hitherto usually shown as to financial considerations. So long as agriculture was flourishing, it was then of less consequence than now that the woodland portions of large estates should be treated on purely commercial principles; but now matters have changed. The shrinkage in income from arable and pasture land renders it desirable that the woods should be made profitable, and the general fall in the value of bark and coppice-wood invites attention to the best means of growing profitable woodland crops. And whenever points of this nature are being considered, actuarial methods have to be applied, even though perhaps only in a very simple form. Although often formidable in appearance when expressed algebraically and extending over a series of eight or ten thinnings, yet the formulæ required for actuarial calculations in Forestry are not in reality so abstruse or intricate as they at first glance appear to be, because they are merely the common formulæ for the solution of the ordinary problems occurring in other business matters regarding interest, discount, annuities, permutations, and equation of payments, as treated in school and college text-books, and as actually employed in ordinary business. They are perhaps nowhere better explained than in Todhunter's *Algebra*.

The whole of the financial questions occurring in Forestry may be solved by means of one or other of the following XIV. formulæ dealing with prolongation, discount, and permutation of annual or periodic returns or rentals into capital sums. They are necessarily those dealing with compound interest, because all money—whether consisting of capital only, or of interest only, or partly of capital and partly of interest—is of equal value to the owner, and must be treated as a capital sum capable of bearing interest. To treat money otherwise, as in calculating by means of simple interest, would be contrary to its true nature, and would sometimes give absurd results.

(1) Summarising or Calculating the Future Value, C_n, of a capital, C, invested for n years at a rate of interest of p per cent.

$$C_n = C \times 1{\cdot}0\,p^n \qquad \text{(I.)}$$

Example.—What is the value 50 years hence of an investment now made with £1000 at 3 per cent?

$$C_n = 1000 \times 1{\cdot}03^{50} = £4383,\ 18s.$$

(2) Discounting or Calculating the Present Value, C, of a future sum, C_n, obtainable only once at the end of n years, interest being reckoned at p per cent.

$$C = \frac{C_n}{1{\cdot}0p^n} \qquad \text{(II.)}$$

Example.—What is the present value of a crop of Larch and Pine, now 40 years old, which is likely to be worth £120 an acre at 70 years of age, interest being reckoned at 3 per cent?

$$C = 120 \div 1{\cdot}03^{30} = £49,\ 8s.\ 9\tfrac{1}{2}d. \text{ an acre.}$$

(3) Summarising or Calculating the Future Value of Rentals or Monetary Returns:[1]—

(*a*) *Periodic Rentals or Returns.*—A periodic rental or return, R, obtainable for the first time after m years, and then again for n times after intervals of m years, attains up to the end of $m \times n$ years the summarised value C_n,

$$C_n = \frac{R\,(1{\cdot}0\,p^{mn} - 1)}{1{\cdot}0\,p^m - 1} \qquad \text{(III.)}$$

Example.—Thinnings to be carried out every 5 years in a wood are expected to realise a net return of £5 an acre, and to be continued for the next 20 years; what will be their summarised value at the end of that time, interest being reckoned at 3 per cent?

$$C_n = \frac{5(1{\cdot}03^{20} - 1)}{1{\cdot}03^5 - 1} = \frac{5(1{\cdot}8061 - 1)}{1{\cdot}1593 - 1} = \frac{5 \times 0{\cdot}8061}{0{\cdot}1593} = £25,\ 6s. \text{ an acre.}$$

(*b*) *Annual Rental or Return.*—An annual rental or return, r, obtainable regularly each year, and for n times in all, attains at the end of n years the summarised value C_n,

$$C_n = \frac{r(1{\cdot}0\,p^n - 1)}{1{\cdot}0\,p - 1} = \frac{r(1{\cdot}0\,p^n - 1)}{0{\cdot}0\,p} \qquad \text{(IV.)}$$

This formula is only a modification of III., because here $m = 1$.

Example.—Grazing in a Larch-wood is now worth 5s. an acre, and can be let annually at that rate till the wood is brought to the fall 10 years hence; what will its summarised value then be, interest being 3 per cent?

$$C_n = \frac{5(1{\cdot}03^{10} - 1)}{0{\cdot}03} = \frac{5(1{\cdot}3439 - 1)}{0{\cdot}03} = 57s.\ 3\tfrac{3}{4}d. \text{ an acre.}$$

(4) Discounting or Calculating the Present Value of Rentals or Monetary Returns:—

(*a*) *Terminable Rentals or Returns*—

(*α*) *Periodic Rentals or Returns.*—The capitalised present value, C, of a periodic rental or return, R, obtainable for the first time after a years, and then regularly, at intervals of m years, for n times altogether is (at the commencement of a)

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[1] These calculations are all based on the general formula for summarising a geometrical progression—

$$S = a + aq + aq^2 + \ldots + aq^{n-1} = a\frac{q^n - 1}{q - 1} \text{ or } = a\frac{1 - q^n}{1 - q}.$$

$$C=\frac{R(1{\cdot}0p^{mn}-1)1{\cdot}0p^{m-a}}{(1{\cdot}0p^{m}-1)1{\cdot}0p^{mn}} \qquad \text{(V.)}$$

When it is obtainable at regular intervals of m years ($m=a$) and for n times in all, then its present value is

$$C=\frac{R(1{\cdot}0p^{mn}-1)}{(1{\cdot}0p^{m}-1)1{\cdot}0p^{mn}} \qquad \text{(VI.)}^{1}$$

Examples.—1. What is the present value of thinnings, in a 12-year-old plantation, which may be begun at 15 years of age and repeated every 10 years, giving a net return of £10 an acre each time, till the wood be cleared when 70 years old, interest being at 3 per cent?

$$C=\frac{10(1{\cdot}03^{10\times6}-1)1{\cdot}03^{3}}{(1{\cdot}03^{10}-1)(1{\cdot}03^{10\times6})}=\frac{10(5{\cdot}8916-1)1{\cdot}0927}{(1{\cdot}3439-1)5{\cdot}8916}=\frac{48{\cdot}916\times1{\cdot}0927}{0{\cdot}3439\times5{\cdot}8916}$$

$$=\frac{53{\cdot}450}{2{\cdot}026}=£26,\ 7s.\ 7d.\ \text{an acre.}$$

2. What would their present value be if the plantation were now only 5 years of age in place of 12 years old?

$$C=\frac{10(1{\cdot}03^{10\times6}-1)}{(1{\cdot}03^{10}-1)1{\cdot}03^{10\times6}}=\frac{10(5{\cdot}8916-1)}{(1{\cdot}3439-1)5{\cdot}8916}=\frac{48{\cdot}916}{0{\cdot}3439\times5{\cdot}8916}=\frac{48{\cdot}916}{2{\cdot}026}=£24,\ 2s.\ 9d.\ \text{an acre.}$$

(β) *Annual Rental or Return.*—When the rental or return, r, is obtainable annually ($m=a=1$) for n years in all, its present value, C, is

$$C=\frac{r(1{\cdot}0p^{n}-1)}{1{\cdot}0p^{n}\times0{\cdot}0p} \qquad \text{(VII.)}^{1}$$

Example.—Grazing in a Larch-wood is now worth 5s. an acre, and can be let annually at that rate till the wood is brought to the fall 10 years hence; what is its present value from now till then, interest being at 3 per cent?

$$C=\frac{5(1{\cdot}03^{10}-1)}{1{\cdot}03^{10}\times0{\cdot}03}=\frac{5(1{\cdot}3439-1)}{1{\cdot}3439\times0{\cdot}03}=42s.\ 7\tfrac{3}{4}d.$$

(Compare this result with the summarised prolonged value in the example under IV.)

(*b*) *Continuous, Interminable, or Perpetual Rentals or Returns*—

(α) *Periodic Rentals or Returns.*—The discounted capitalised present value, C, of a rental or return, R, obtainable for the first time after m years, continuously thereafter at intervals of n years, is

$$C=\frac{R(1{\cdot}0p^{n-m})}{1{\cdot}0p^{n}-1} \qquad \text{(VIII.)}$$

When it is obtainable immediately, and regularly every n years after that, then

$$C=\frac{R(1{\cdot}0p^{n})}{1{\cdot}0p^{n}-1} \qquad \text{(IX.)}$$

When it is obtainable for the first time after n years ($m=n$), and thereafter at intervals of n years, then

$$C=\frac{R}{1{\cdot}0p^{n}-1} \qquad \text{(X.)}$$

Examples.—1. A coppice area, maturing 5 years hence, is capable of being felled then and every 10 years thereafter. It may be estimated to yield a net return of £15 an acre at each fall; what is the present capitalised value of its crops of wood, interest being at 3 per cent? (VIII.)

$$C=\frac{15(1{\cdot}03^{5})}{1{\cdot}03^{10}-1}=\frac{15\times1{\cdot}1593}{1{\cdot}3439-1}=\frac{17{\cdot}3895}{0{\cdot}3439}=£50,\ 11s.\ 3d.\ \text{per acre.}$$

[1] Formulæ VI. and VII. are only modifications of V., as in the one case $m=a$, and in the other $m=a=1$.

2. If the crop were now mature and just about to be cut and realised, what would the present capitalised value of that and all future crops then amount to? (IX.)

$$C=\frac{15(1{\cdot}03^{10})}{1{\cdot}03^{10}-1}=\frac{15\times1{\cdot}3439}{1{\cdot}3439-1}=\frac{20{\cdot}1585}{0{\cdot}3439}=£58, \text{ 12s. 4d. per acre}$$

(or, by Table III. p. 419, $=20{\cdot}158\times2{\cdot}9077=£58$, 12s. 2d. per acre).

3. If the crop had just been cleared, what would the respective future crops now be worth? (X.)

$$C=\frac{15}{1{\cdot}03^{10}-1}=15\times2{\cdot}9077=£43, \text{ 12s. 4d.}$$

(β) *Annual Rental or Return.*—When the rental or return, r, is obtainable annually *in perpetuo*, then (as here $m=n=1$, in equation VII.)

$$C=\frac{r}{0{\cdot}0p} \qquad \text{(XI.)}$$

Example.—The woodlands on an estate bring in a net annual income of £1000 a year; what is their capital value, on the assumption that they are yielding 3 per cent?

$$C=\frac{1000}{0{\cdot}03}=£33,333, \text{ 6s. 8d.}$$

And what would their capital value be, if they are supposed to yield only 2½ per cent?

$$C=\frac{1000}{0{\cdot}025}=£40,000. \quad \text{(See pp. 384 and 391.)}$$

(5) **Permutation or Conversion of a Periodic into an Annual Rental or Return :—**

(a) If the periodic rental or return, R, is obtainable every n years from now, the equivalent annual rental or return, r, is

$$r=\frac{R}{1{\cdot}0p^n-1}\times0{\cdot}0p \qquad \text{(XII.)}$$

(b) If the periodic rental or return, R, is first obtainable only after m years, and regularly every n years thereafter, then the equivalent annual rental or return, r, is

$$r=\frac{R\times1{\cdot}0p^{n-m}}{1{\cdot}0p^n-1}\times0{\cdot}0p \qquad \text{(XIII.)}$$

(c) If the periodic rental or return, R, is obtainable immediately, and thereafter at intervals of n years, then the equivalent annual rental or return, r, is

$$r=\frac{R\times1{\cdot}0p^n}{1{\cdot}0p^n-1}\times0{\cdot}0p \qquad \text{(XIV.)}$$

Examples.—In the examples given to illustrate the use of formulæ VIII., IX., and X., what would the amounts respectively be if converted into annual rentals or returns?

(1) $r=\frac{15}{1{\cdot}03^{10}-1}\times0{\cdot}03=15\times0{\cdot}03\times2{\cdot}9077=£1$, 6s. 2d. an acre. (XII.)

(2) $r=\frac{15\times1{\cdot}03^5}{1{\cdot}03^{10}-1}\times0{\cdot}03=15\times1{\cdot}1593\times0{\cdot}03\times2{\cdot}9077=£1$, 10s. 4d. an acre. (XIII.)

(3) $r=\frac{15\times1{\cdot}03^{10}}{1{\cdot}03^{10}-1}\times0{\cdot}03=15\times1{\cdot}3439\times0{\cdot}03\times2{\cdot}9077=£1$, 15s. 2d. an acre. (XIV.)

These results may be noted for comparison with the arithmetical mean. According to the common custom, it is usually said in such cases that the average annual income would be £15÷10=30s. an acre; but this is not correct, owing to the necessity for reckoning by means of compound interest.

These various formulæ may be conveniently tabulated in the following abstract :—

Basis of calculation in addition to p = the rate of interest per cent.	Object of calculation.	No.	Formula.	See Appendix IV., Table No.
A. Capital.	**Capitalisation :—**			
1. **Present Capital, C.**	Summarised Future Value.	I.	$C_n = C \times 1{\cdot}0p^n$	I.
2. **Future Capital Sum, C_n.**	Discounted Present Value.	II.	$C = \frac{C_n}{1{\cdot}0p^n}$	II.
B. Terminable Returns (after n times in all).	**Capitalisation :—**			
1. **Periodic, R.**				
(*a*) First obtainable after m years.	Summarised Future Value.	III.	$C_n = \frac{R(1{\cdot}0p^{mn} - 1)}{1{\cdot}0p^m - 1}$	
(*b*) First obtainable in a years, and then after every m years.	Discounted Present Value.	V.	$C = \frac{R(1{\cdot}0p^{mn} - 1)1{\cdot}0p^{m-a}}{(1{\cdot}0p^m - 1)1{\cdot}0p^{mn}}$	
(*c*) Obtainable at once, and then every m years (here $m = a$).	Do.	VI.	$C = \frac{R(1{\cdot}0p^{mn} - 1)}{(1{\cdot}0p^m - 1)1{\cdot}0p^{mn}}$	
2. **Annual, r.**	Summarised Future Value.	IV.	$C_n = \frac{r(1{\cdot}0p^n - 1)}{0{\cdot}0p}$	IV.
	Discounted Present Value.	VII.	$C = \frac{r(1{\cdot}0p^n - 1)}{1{\cdot}0p^n \times 0{\cdot}0p}$	V.
C. Perpetual Returns.	**Capitalisation :—**			
1. **Periodic, R.**				
(*a*) First obtainable after m years, and then every n years.	Discounted Present Value.	VIII.	$C = \frac{R(1{\cdot}0p^{n-m})}{1{\cdot}0p^n - 1}$	
(*b*) Obtainable at once, and then every n years.	Do.	IX.	$C = \frac{R(1{\cdot}0p^n)}{1{\cdot}0p^n - 1}$	
(*c*) First obtainable after n years ($m = n$), and then every n years afterwards.	Do.	X.	$C = \frac{R}{1{\cdot}0p^n - 1}$	III.
2. **Annual, r.**	Do.	XI.	$C = \frac{r}{0{\cdot}0p}$	
D. Periodic Returns.	**Permutation or Conversion of a Periodic Return, R, into an Equivalent Annual Return, r :—**			
(1) R obtainable every n years from now.	Converted value, r.	XII.	$r = \frac{R}{1{\cdot}0p^n - 1} \times 0{\cdot}0p$	
(2) R first obtainable after m years, and then every n years.	Do.	XIII.	$r = \frac{R \times 1{\cdot}0p^{n-m}}{1{\cdot}0p^n - 1} \times 0{\cdot}0p$	
(3) R now obtainable, and then every n years.	Do.	XIV.	$r = \frac{R \times 1{\cdot}0p^n}{1{\cdot}0p^n - 1} \times 0{\cdot}0p$	

Calculations by means of the above formulæ are facilitated by using Tables I. to V. of Appendix IV., which at once give the values of the above formulæ I., II., X., IV., and VII. (see p. 416).

2. **Points to be considered in making Calculations concerning Forestry.**—The **capital** required in Forestry consists of the **land** and the **growing-stock of wood.** Together these form the **woodlands**, from which returns in timber or other produce are obtained, either periodically, or else regularly year by year. A woodland may be valued according to—

1. **Its Productivity or Prospective Value**—that is to say, the net value of all prospective future returns, freed from cost of production or of harvesting, discounted to the present time.
2. **The Cost of its Production**, or actual expenditure that has been incurred, or would be necessary, in order to produce it.
3. **Its Market Value**—that is to say, the sum it would fetch if sold, or the amount usually obtained for similar properties.
4. **The Capitalised Value of the Annual Income it produces**, as expressed by formula XI., where C is the capital required to produce the annual rental, r, at the given percentage, p. Here $C : r = 100 : p$, and $C = \frac{100r}{p}$, or $= \frac{r}{0 \cdot 0p}$.

On consideration, it will be seen that only the first method is the common-sense one to apply to woodlands (though merely when they are being managed on purely commercial principles), because it is this productivity or prospective value which, so far as commercial principles are followed, practically determines the market value of estates and the capitalised value of the annual income they produce. This purely commercial standard is, however, seldom, if ever, applicable, owing partly to the special amenities derivable from forests (shooting, fishing, &c.), and partly because woodlands, like landed property in general, are not capable of being increased to an indefinite extent, but must belong to the few on whom, *cœteris paribus*, they confer a certain amount of local prestige and social status.

The cost of production of woodlands is in Britain a method of calculation liable to very considerable errors at present—and mainly on account of *rabbits*. Wherever ground game is preserved, or is liable to commit damage through being preserved on adjoining estates, the cost of production of plantations is increased greatly. In such cases it would be obviously incorrect to charge against timber production the extra cost incurred solely on account of ground game. Moreover, except in very young plantations, the cost of production has nothing to do with the prospective returns derivable from them, because these depend mainly on factors (local market, soil and situation, suitability of crop, distance of plants, treatment as to thinning, &c.) not necessarily in any manner determined by the amount of money spent in forming the plantations.

So far as actuarial investigations connected with Forestry in Britain are concerned, the prospective value therefore forms by far the surest basis of calculation, whenever satisfactory data are available for estimating that.

In all these four ways of valuing woodlands the net monetary return from the timber-crops, clear of the cost of production or regeneration and of harvesting, is, and must necessarily be, the essential factor in making the calculation. Even where the intention is to ascertain the value of the land, this can only be done through estimating its productivity by means of the net monetary returns yielded by the timber-crop it has produced, or is considered to be capable of producing.

The **Rate of Interest** reckoned in making actuarial calculations regarding Forestry is a matter of great importance. If either a very low or a very high rate of interest be used, the results worked out are often palpably absurd and contrary to common-sense. Yet it is a very difficult matter to strike anything like a true average for general use; and even such average rate would of course be subject to fluctuation locally and from time to time. Apart from the relation between supply and demand as regards capital, the rate of interest is generally dependent on the degree of safety of the investment, and on the regularity and convenience with which the returns are obtainable. Now, in Forestry the rate of interest may be taken below the current rate, because, in addition to the social and other amenities connected with the ownership of woodlands, forests (even taking loss from windfall, and damage through fire, insects, fungous diseases, &c., into account), give better guarantee for the security of the capital than ordinary investments, and because trade statistics prove very clearly that the value of timber has been steadily increasing (besides being very likely to increase much more rapidly in the near future), whilst the exchange-value or purchasing-power of money has been gradually sinking.

As an aid to fixing the rate of interest in **forestry**, it is natural that a comparison should be made with **agriculture**, although there are important essential differences between these two methods of utilising land.

In comparison with agriculture, the following **advantages** on the side of forestry tend to raise the rate of interest:—

1. Woodlands require less labour and supervision than agricultural operations involving the same amount of capital.
2. Woodlands can be managed so as to produce about equal monetary returns annually, whereas agricultural harvests often vary to a very considerable extent.
3. A favourable market can be utilised by making heavy falls of timber, while fellings can be kept short if prices are temporarily low.

On the other hand, the following **disadvantages** tend to reduce the rate of interest to be expected—

1. Plantations and other young woodlands do not begin to yield valuable returns till a long time after their formation; and the capital is meanwhile completely locked up.
2. It is more difficult to determine the average annual returns from woodlands than from field-crops.
3. Danger of damage from wind, snow, fire, insects, &c., extends over a much longer time in the case of woodland crops—though the total amount of damage throughout a long term of years is not on this account greater in forestry than in agriculture.
4. Woodlands cannot, without great risk to the owner, be let like farms; nor can loans of money be raised on them so easily.

Other points of difference might also be noted. Thus, the rental value of farms depends on the demand for them, while the upward tendency in the price of timber is due to foreign and colonial supplies to Britain diminishing through the competition of Germany and the United States of America. As a matter of practical experience, however, good land yields a better rental if utilised agriculturally, while poor soil gives a better return as woodland.

Taking the general rate of interest for business loans at about 4 per cent, and the agricultural rate at about 3 to 3½ per cent, that of forestry may fairly be assessed at about $2\frac{1}{2}$ to 3 per cent in the case of hardwood timber-crops requiring long to mature and not exposed to many dangers, and about 3 to $3\frac{1}{2}$ per cent for coniferous crops more liable to damage from wind, snow, insects, fire, and fungous diseases. *Everything being considered, 3 per cent may perhaps be taken as a fair rate of interest for general use in making actuarial calculations regarding forestry in Britain.*

This also corresponds with the rate of interest ordered under the Succession Duty Act, 1853, according to which the average value of the returns from timber is to be taken at 3 per cent per annum on the estimated capital value of the woodland produce, a rate which also regulates the amounts payable under the Finance Act, 1894. By the Finance Act, 1896, the land-tax is redeemable at 30 years' purchase (equal to just below $3\frac{1}{3}$ per cent).

In calculating the value of woodlands, all marketable minor produce, shooting, and fishing must of course be taken into account as well as timber; while due allowance must be made for covering the annual cost of management, sowing and planting, maintaining boundaries and roadways, and payment of rates and any other assessments on the land.

3. **The Valuation of Forest Land.**—In Scots law, under the Valuation of Lands Act, 1854, sec. 6, in valuing lands that consist of woods, copse, or underwood, the yearly value shall be taken to be the rent at which they might in their natural state be reasonably expected to let from year to year as pasture or grazing lands. Under English law, the standard prescribed is practically much the same, being based on the agricultural value of land in its "natural and unimproved" state.[1]

Under the Finance Act, 1894, the annual value of the woodland, the actual land itself, is estimated at what it is according to its value in the natural and unimproved state, while the timber growing upon it is subject to separate valuation. While the Act declares the *principal value* of any

[1] *Rating of Plantations, Woods, &c.*—By section 14 of the Rating Act, 1874 (37 & 38 Vict. c. 54), so much of the Poor Relief Act, 1601 (43 Eliz. c. 2), as related to the taxation of an occupier of saleable underwoods was repealed, and by section 3 of the Act, the statute of Elizabeth, and the Acts amending the same, were extended to land used for a plantation or a wood or for the growth of saleable underwood, and not subject to any right of common.

Under this enactment it is the land, and not the timber, underwood, or other produce of the land, which is made the subject of assessment; and it would seem that if land used as a plantation or a wood, or for the growth of saleable underwood, is subject to common rights, it is exempt from the poor rate and other local rates.

Mode of Valuing Woodlands.—The method of estimating the gross estimated rental and rateable value of such woodlands is prescribed by section 4 of the Act, and is as follows:—

"(*a*) If the land is used only for a plantation or a wood, the value shall be estimated as if the land instead of being a plantation or a wood were let and occupied in its natural and unimproved state.

"(*b*) If the land is used for the growth of saleable underwood, the value shall be estimated as if the land were let for that purpose.

"(*c*) If the land is used both for a plantation or a wood and for the growth of saleable underwood, the value shall be estimated either as if the land were used only for a plantation or a wood, or as if the land were used only for the growth of the saleable underwood growing thereon as the assessment committee" (or where there is no assessment committee the persons making the poor rate) "may determine."—(*Forestry Committee Report*, 1903, Appendix xix. p. 206.)

property to be what it would sell for in the open market, yet special provision is made for estimating the principal value of agricultural property, including woodland, at an amount not exceeding twenty-five times the annual value as assessed for income-tax on lands, after making certain deductions for repairs, rates, management, &c.

Except in the rather unusual case of land being bought for the express purpose of planting, it is difficult to fix its actual market value. Where land has been thrown out of arable cultivation or pasturage, its rental value may be assessed as below its previous agricultural value, and the capital value may then be estimated as

$$C = \frac{r}{0{\cdot}0\,p}.$$

Thus, pasture land thrown out of occupation at 7s. 6d. an acre might be fairly assessed at about 5s. an acre for planting, and its capital value would then be $5 \div 0{\cdot}03 =$ £8, 6s. 8d. an acre.

This same formula $\left(C = \frac{r}{0{\cdot}0\,p}\right)$ can also at once be used to determine in a rough-and-ready practical manner the capital value of woodlands—*i.e.*, land and growing-stock of wood—if the woods are in "normal condition" as to distribution of age-classes, and the management on the basis of a regularly sustained annual yield has been of long enough duration to enable the true average net annual income to be estimated with something like accuracy.

Ordinarily, however, the value of woodlands can only be estimated by their productivity—*i.e.*, the amount of net income obtainable from the timber, &c., they are capable of producing. This, the only sound practical standard of valuation, can be assessed by discounting to the present all the future net monetary returns which may be expected, and deducting therefrom the present discounted value of all expenses necessary to obtain these returns. This mode of valuation concerns itself with all the capital invested in Forestry—that is to say, both with the land primarily, and also with the growing-stock; but this combination is unavoidable, as neither the soil nor the plants put into it can of themselves produce timber or any other marketable produce; and to ascertain the value of either one of these, the other must also be taken into careful consideration. The items here coming into calculation in order to determine the productivity of the land, are the following data regarding timber and other produce:—

Receipts.	*Expenditure.*
(1) The fall of mature timber.	(1) Cost of formation of crop (sowing and planting, &c.).
(2) Thinnings at various times.	(2) General Annual charges (rates, management, protection, &c.).
(3) Minor produce obtainable.	

The **Receipts** are net returns, free from the cost of harvesting the crop and collecting the money.

(1) The present value of all the future falls (F) of mature timber at n years of age, F_n is $= \frac{F_n}{1{\cdot}0\,p^n - 1}$. (Formula X.)

(2) The present value of all the future thinnings, T, at a, b, and . . . q years of age, if prolonged to n years of age, and treated as a perpetual rental occurring first at a years and then every n years,

is $$= \frac{(T_a \times 1{\cdot}0\,p^{n-a})}{1{\cdot}0\,p^n - 1} + \frac{(T_b \times 1{\cdot}0\,p^{n-b})}{1{\cdot}0\,p^n - 1} + \ldots + \frac{(T_q \times 1{\cdot}0\,p^{n-q})}{1{\cdot}0\,p^n - 1}$$

$$= \frac{(T_a \times 1{\cdot}0\,p^{n-a}) + (T_b \times 1{\cdot}0\,p^{n-b}) + \ldots + (T_q \times 1{\cdot}0\,p^{n-q})}{1{\cdot}0\,p^n - 1}. \quad \text{(Formula VIII.)}$$

(3) The present value of minor produce is calculable by the same formula as for thinnings, except as regards a fixed annual return like shooting, which has a present value of $\frac{r}{0{\cdot}0\,p}$ (Formula XI.); or as regards a return obtained regularly for some years, like grazings. The latter may be prolonged to the year at which it ceases, and then treated as a perpetual recurring periodic return $\frac{R(1{\cdot}0\,p^{n-m})}{1{\cdot}0\,p^n - 1}$ (Formula VIII.), the present capital value of which can be added to the capitalised value of the land and the growing-stock.

The **Expenditure.**—(1) Assuming that an outlay, c, for sowing and planting, &c., will be necessary at each time of regenerating or reproducing the crop, then the capital sum now required to defray this is $= \frac{c \times 1{\cdot}0\,p^n}{1{\cdot}0\,p^n - 1}$ (Formula IX.). For newly formed copse and coppice, where the first outlay is greater than subsequent reproductions, this formula has to be modified to $c \times \frac{c}{1{\cdot}0\,p^n - 1}$, but for all practical purposes the simpler general reckoning is preferable.

(2) The general charges, g, for management, protection, rates, &c., being of annual recurrence, have a present capitalised value of $= \frac{g}{0{\cdot}0\,p}$. (Formula XI.)

Summarising these credit and debit capitalised present values to estimate the productivity, we therefore arrive at the following formula, known as Faustmann's, which has previously been referred to on p. 239 :—

The **Productivity** or Present Capital Value of Land (as estimated by the real value of the timber, &c.) is

$$= \frac{F_n + (T_a \times 1{\cdot}0\,p^{n-a}) + (T_b \times 1{\cdot}0\,p^{n-b}) + \ldots + (T_q \times 1{\cdot}0\,p^{n-q}) - (c \times 1{\cdot}0\,p^n)}{1{\cdot}0\,p^n - 1} - \frac{g}{0{\cdot}0\,p}.$$

Examples of the use of this formula, for determining the present value of returns from woodlands of 80 and 100 years in order to ascertain the more profitable rotation, will be found on page 241.

If misused, the formula leads to apparently absurd results. Thus the land and the growing-stock could be shown as having a negative value, if the rotations for which the calculations are made are so low that the produce is unmarketable and fails to counterbalance the amount of expenditure incurred in formation and maintenance. And the same happens if the rate of interest be unduly high.

Theoretically, the above method is quite correct; but in practice it has certain weak points, such as are, however, common to other methods dealing with the future as well as the actual present returns available. It is exceedingly difficult to estimate returns quantitatively far ahead, and impossible to assess their monetary value one or two generations hence. Then, again, the result varies essentially with the rate of interest, which forms one of the main bases of reckoning. Notwithstanding these drawbacks, however, Faustmann's formula is of great practical use in calculating, by means of the returns of average yield tables, what kind of timber-crop is likely to pay best on land of any given quality, and what is likely to prove the most remunerative rotation. Continental results worked out by it correspond with those of practical experience in showing that Conifers are usually the most profitable kinds of timber-crops, especially on land of only medium or inferior quality, and that the most remunerative rotation for these varies from about 65 to 80 years.

The earlier and the heavier that thinnings are made, the more the present capital value of the land and the growing-stock is raised, so long as such thinnings do not affect the final return from the mature fall of timber ; but, otherwise, such early returns may perhaps only be obtained at the cost of subsequent loss—as is now the case in many British woodlands. With a knowledge of the local market and rates for the small material yielded by early thinnings it is, however, easy to calculate whether it will be most profitable to plant so close as $3\frac{1}{2} \times 3\frac{1}{2}$ ft., or at 4×4 ft., or $4\frac{1}{2} \times 4\frac{1}{2}$ ft. in forming new plantations, and to see how the financial position, as to net cost up to date, of each given crop would thereby be affected at, say, 25 or 30 years of age, in consequence of the thinnings obtainable meanwhile.

(4) **The Valuation of a Growing Crop of Wood.**[1]—If of marketable size, the present market value of single trees and of the whole crop in any compartment may easily be determined by measurement, as already described in Chap. II. If only immature and comparatively young crops of wood, it will usually be most convenient to estimate the value, for such purposes as sale or transfer, according to their cost up to the present, care being taken, however, to discriminate between the actual cost of sowing, planting, &c., and any outlay in the way of fencing against rabbits—all charges of the latter nature being debitable to the game account, and not to the timber-crops. But in either of these cases a deduction must be made on account of the rental value of the land, and of general annual charges, in order to arrive at the true value of the timber-crop alone.

Otherwise, the present value of the crop may also be estimated according to its productivity or prospective value, much in the same way as shown in the previous section with regard to the productivity of the land.

Here the present value, at the age m, of the net returns from the mature fall, F, harvested at n years of age, is $= \frac{F_n}{1{\cdot}0p^{n-m}}$ (Formula II.) ; while the various thinnings T_a, T_b, . . . T_q, at a, b, and q years of age, are, if prolonged to n, so as to give them the same denominator as F_n,

$$= \frac{(T_a \times 1{\cdot}0p^{n-a}) + (T_b \times 1{\cdot}0p^{n-b}) + \ldots + (T_q \times 1{\cdot}0p^{n-q})}{1{\cdot}0p^{n-m}},$$

and any minor produce is similarly calculable. Against these receipts certain charges are, however, debitable for rent of land, r, and general charges, g, which will be incurred during the years n-m. These amount respectively to $\frac{r(1{\cdot}0\,p^{n-m}-1)}{0p^{n-m} \times 0{\cdot}0p}$. (Formula VII.)

$$= \frac{r}{0{\cdot}0p} \times \frac{1{\cdot}0p^{n-m}-1}{1{\cdot}0p^{n-m}}, \text{ and to } \frac{g(1{\cdot}0p^{n-m}-1)}{1{\cdot}0p^{n-m} \times 0{\cdot}0p} = \frac{g}{0{\cdot}0p} \times \frac{1{\cdot}0p^{n-m}-1}{1{\cdot}0p^{n-m}};$$

and they are together $= \frac{r+g}{0{\cdot}0p} \times \frac{1{\cdot}0p^{n-m}-1}{1{\cdot}0p^{n-m}}$.

Subtracting these debits from the prospective returns from the crop, we therefore have the Present Capital Value of the Timber Crop

$$= \frac{[F_n + (T_a \times 1{\cdot}0p^{n-a}) + (T_b \times 1{\cdot}0p^{n-b}) + \ldots + (T_q \times 1{\cdot}0p^{n-q})] - \left[\frac{r+g}{0{\cdot}0p}(1{\cdot}0p^{n-m}-1)\right]}{1{\cdot}0p^{n-m}}.$$

Example.—What is the present value per acre of a 40-year-old crop of Larch, forming part of a working-circle worked with a rotation of 80 years, if the mature fall may be estimated at £250 an acre, and thinnings are probably obtainable having a net worth of £8 at 50 years of age, £10 at 60, and £12 at 70, the rental value of the land being 10s.

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[1] Where ornamental trees and groups of trees have to be valued, estimates must of course be made on some such basis as what they have actually cost, or at what they are worth as timber *plus* something extra for their ornamental effect, according to the given circumstances.

an acre, general annual charges amounting to 5s. an acre, and the rate of interest being 3 per cent?

The Present Value of Crop is here

$$=\frac{[250+(8\times 1{\cdot}03^{30})+(10\times 1{\cdot}03^{20})+(12\times 1{\cdot}03^{10})]-\left[\frac{0{\cdot}5+0{\cdot}25}{0{\cdot}03}\times(1{\cdot}03^{40}-1)\right]}{1{\cdot}03^{40}}$$

$$=\frac{[250+(8\times 2{\cdot}4273)+(10\times 1{\cdot}8061)+(12\times 1{\cdot}3439)]-(25\times 2{\cdot}2620)}{3{\cdot}2620}$$

$$=\frac{250+19{\cdot}42+18{\cdot}06+16{\cdot}13-56{\cdot}55}{3{\cdot}26}=\frac{247{\cdot}06}{3{\cdot}26}=\text{£}75,\ 15\text{s. } 7\text{d. an acre.}$$

One weak point of this method (*e.g.*, when applied to valuations for expropriation) is that the value thus shown may vary considerably according to the age at which the crop is intended to be felled, whereas the true intrinsic value of a timber-crop *per se* ought, one might think, to be capable of being fixed at something definite and irrespective of the future use made of it. This does not suit the nature of the investment, however; and the value of the crop in such cases must be taken to be that shown if the timber be utilised at its most profitable age. In fixing the latter, the above formula can be used quite as well as that for determining the productivity of the land.

If the rental value of the land be estimated too low, the apparent value of the timber-crop will work out too high, and *vice versâ*. But the rotation which indicates the maximum productivity of the land will also indicate the highest present value of the timber-crop, so long as the returns and expenses correspond in both cases, because in either calculation the most profitable age for felling the crop is when the difference between receipts and expenditure is greatest.

5. **The Valuation of the Normal Capital in Wood throughout a Working-Circle.**—If the woods forming a working-circle are in a normal condition, capable of yielding a regular annual fall of equal amount, then it is essential that there should be a regular gradation of age-classes normally distributed throughout the woodlands and varying from 1 to n years (just before the annual fall) or from 0 to $n-1$ years of age (just after the fall), n being the rotation with which the woods are worked. It is therefore of advantage to estimate the monetary value of the normal capital in wood so as to be able to reckon the rate of interest yielded by the working-circle.

Whether this be done by means of long, intricate calculations regarding either the productivity of such normal capital in wood, or what it has cost (or would cost) to produce it, the result in each case works out so as to correspond identically with the present capitalised value of the regularly sustained annual returns from the woodlands, less the capital value of the land itself.

If the annual income from woodlands in a "normal condition"—an ideal standard never attained in actual practice—be capitalised $\left(C=\frac{r}{0{\cdot}0p}\right)$, this amount consists partly of the capital value of the land and partly of that of the normal capital in wood. If worked with a rotation of n years, the annual income from a working-circle of n acres (or other unit of area) is $=F_n+(T_a+T_b+\ldots T_q)-(c+g\times n)$. Capitalising this annual income, we have the Normal Capital in Wood + Capital Value of the Land

$$=\frac{F_n+(T_a+T_b+\ldots+T_q)-(c+g\times n)}{0{\cdot}0p}.$$

Hence, for the whole working-circle, the Normal Capital in Wood

$$=\frac{F_n+(T_a+T_b+\ldots+T_q)-(c+g\times n)}{0{\cdot}0p}-\text{Capital Value of the Land,}$$

and for the acre (or other unit of area)

$$=\frac{F_n+(T_a+T_b+\ldots+T_q)-(c+g\times n)}{n\times 0{\cdot}0p}-\text{Capital Value of Land per acre (or other unit of area).}$$

Or, expressed in words, the value of the Normal Capital in Wood throughout a normal working-circle is equal to the capitalised value of the normal annual income, less the capital value of the land.

Example.—Say the normal annual returns from a working-circle of 800 acres in normal condition, worked with a rotation of 80 years, consist of £2400 for the mature fall of timber, and £300 from thinnings in woods of different ages, that each year the cost of planting the area cleared is £40, and that the gross general charges amount annually to £160; what is the present value of the Normal Capital in Wood, if the annual rental value of the land is 10s. an acre, and the rate of interest be 3 per cent? Here the net receipts are $2700 - 200 = £2500$, and their capitalised value is $\frac{2500}{0{\cdot}03} = £83{,}333\frac{1}{3}$. The rental value of the land being £400 a year, its capital value is $\frac{400}{0{\cdot}03} = £13{,}333\frac{1}{3}$. Hence the capital value of the Normal Capital in Wood is $83{,}333\frac{1}{3} - 13{,}333\frac{1}{3} = £70{,}000$.

The "normal condition" being always a mere ideal, when a valuation of woodlands is made it must necessarily be that of the actual growing-stock or capital in wood. It is only by making such a valuation that the actual rate of interest obtained on the capital invested in the woodlands can be ascertained.

To satisfy the requirements of the Succession Duty Act, the custom in England has generally been to value all the timber and other wood, and to take 3 per cent of this as a fair annual return under good management. This income is then treated as an annuity, aud succession duty has to be paid upon it on a scale laid down in tables annexed to the Act. Thus, if the life-tenant were 40 years of age on entering into succession, and the annual income from the woods were estimated at £500 a year, this annuity would be considered as having a capital value of £7437½ assessable to duty (and not as $£500 \div 00{\cdot}3 = £16{,}666$).

If it be desired to estimate the whole capital value of woodlands (*i.e.*, land *plus* growing-stock of wood) by means of detailed calculations regarding productivity and prospective value, then this must be done by reckoning each of these separately by the formulæ already given and adding the results together. This is rather a cumbersome method, because the value of the land has to be fixed according to the crop which may show the greatest productivity. If, however, it be desired to contrast the present productivity with that of some other method of treatment, then the value of the land must in this latter case be calculated according to the new returns anticipated.

The same practical difficulty is found in trying to estimate the capital value by means of calculating what the land and the growing-stock have actually cost up to the present. In either case it is very difficult to estimate the productivity, and therefrom the value of the land, with correctness; and unless this, as well as the rate of interest at which the calculation is made, be correct, the estimate cannot be reliable. Hence the advantage of using the simple direct formula, capital value of woodlands (land and growing-stock) $= \frac{\text{annual net income}}{\text{rate of interest}}$, wherever the management is sufficiently regular to permit of this method being applied. In copse and coppice yielding only intermittent returns, their annual rental value can be found for this purpose by permuting the former into the latter.

As the monetary returns from woodlands are seldom or never so regular as to produce the same income year by year, it is desirable to introduce such a scheme of management as will tend to give a more regular annual return during fixed periods of ten or twenty years; and from these the capital value of the woodlands can in course of time be estimated with a fairly close approach to accuracy.

In such cases, however, the estimated capital value can only be for the system of treatment adopted under the given circumstances. A different system of working might often indicate a higher capital value for the woodlands, even if the growing-stock or capital in wood represented a smaller monetary capital than that necessary under the present method of working.

This paradox seems absurd; yet the statement is quite correct. For example, if 6000 acres of woodlands are stocked with hardwoods and worked with a rotation of 100 to 120 years, their annual fall will be 50 to 60 acres. But if the area were stocked with mixed Conifers worked with a rotation of 60 to 70 years, the annual fall would be from 86 to 100 acres. And in the latter case it is almost certain that the net annual income would be considerably larger than in the former, although the monetary value of the capital in growing-stock would be very much greater in the case of the hardwoods than of the Conifers, because the capital value of the land, *de facto*, varies so much according to its productivity, as determined by the specific nature of the timber-crop and the treatment under which this is. Hence it follows that, consequent on injudicious treatment in the past with regard to the formation and the general management of the timber-crops, the British woodlands have a present value of probably only about one-third to one-half of what they might otherwise have been estimated at.

In some rare cases it may perhaps be possible to determine in an apparently more direct, but really equally circumstantial, manner the capital value of woodlands for purposes of sale or of raising a loan on their security. Say, for example, that a scheme of management has been drawn up for their treatment on commercial principles, and that the following financial estimate seems justified:—

I. Period (1900-1919)	yielding a net income of	£900	a year,
II. ,, (1920-1939)	,, ,, ,,	£500	,,
III. ,, (1940-1959)	,, ,, ,,	£700	,,
IV. ,, (1960-1979)	,, ,, ,,	£400	,,
and that from 1980 onwards the net income should be		£750	,,

what is their present capital value, the rate of interest being 3 per cent?

Here, after varying periodical rentals for the first four periods of 20 years each, the estimated income becomes a fixed annual return from 1980 onwards. The summarised present value of these is therefore for

I. Period (see Appendix, Table V.), 900 × 14·8775 .	= £13,389·75
II. ,, 500 × 14·8775 = 7438·75, and the present value of this (Table II.) = 7438·75 × 0·5537 . .	= £4,118·84
III. ,, 700 × 14·8775 = 10,414·25; and its present value = 10,414·25 × 0·3066	= £3,193·01
IV. ,, 400 × 14·8775 = 5951·00; and its present value = 5951 = 0·1697	= £1,009·88
from 1980 onwards a perpetual rental of £750, with a capital value of $\frac{750}{0·03}$ = 25,000, the present value of which is 25,000 × 0·094	= £2,350·00

The present capital value of the woodlands therefore amounts to £24,061·48 = £24,061·9·7.

6. **Estimating the Income derivable from Woodlands.**—Besides being necessary in order to determine the capital value of woodlands, definite knowledge as to the net income or rental they yield is desirable so as to be able to draw correct comparisons between forestry and arable or pastural utilisation of the land. With a regularly sustained annual yield under a sound system of management the woods forming a working-circle of n acres give an annual return, in the mature fall (F) and thinnings (T) at various

ages, as also in minor produce, less cost of reproduction and of general charges, $=F_n+(T_a+T_b+\ \dots\ +T_q)-(c+g\times n)$, so that the net annual income per acre is $=\frac{F_n+(T_a+T_b+\ \dots\ +T_q)-c}{n}-g$.

As this includes the net income from the capital in growing-stock as well as that of the land, the result thus obtained cannot be used in comparing the profit of forestry with that of agriculture. It shows the net income merely, but it gives no indication as to this being as profitable as it ought to be for the given land. In this the productivity of the land, as calculated by Faustmann's formula, is the only safe basis of comparison.

As copses and coppices only give a periodical return, R, this can be permuted into an annual rental, r, which gives (Formula XII.) for a rotation of n years, as the rental value of the land and the coppice-stools

$$r=\frac{R}{1{\cdot}0p^n-1}\times 0{\cdot}0p.$$

7. **The Application of Actuarial Methods to Forestry** is, despite the obvious difficulties about the assessment of the different factors used in making calculations, the only correct way of estimating the financial position of timber-crops as a commercial investment. It is only thus that any profit connected with Forestry under given local circumstances can be measured or forecast, so as to enable a correct comparison to be made between timber production on the one hand, and arable occupation, pasturage, deer-forests or grouse-moors, on the other. It is only thus, too, that such important questions can be decided as relate to the selection of particular kinds of timber-crops from among several perhaps suitable for any given soil, situation, and local market, or to the choice of the method and details of formation, the general system of treatment, and the most profitable time of reproduction.

As special reference has already been made to these matters, and more particularly to the financial maturity of timber-crops, in explaining the theoretical principles of woodland management in Chap. II., it is unnecessary to repeat, or to add anything to, what has already been said on pp. 239 to 241.

APPENDICES

I. TABLE OF GIRTHS AND SUPERFICIES (BASAL AREA) CORRESPONDING WITH DIAMETERS FROM 1 TO 48 INCHES.

II. CUBIC CONTENTS OF ROUND LOGS, CALCULATED BY CUSTOMARY BRITISH MEASUREMENT, *i.e.* $\text{Length} \times \left(\frac{\text{Mean Girth}}{4}\right)^2$.

III. AVERAGE YIELD TABLES FOR SCOTS PINE, SPRUCE, BEECH, AND OAK IN GERMANY.

IV. TABLES OF COMPOUND INTEREST AND DISCOUNT.

APPENDIX I.—TABLE OF GIRTHS AND SUPERFICIES (BASAL AREA), corresponding with Diameters from 1 to 48 inches (basal area $= \pi r^2 = \frac{\pi d^2}{4} = 0{\cdot}7854 \times d^2$).

Diameter, inches.	Girth, inches.	Superficies (basal area), sq. ft.	Diameter, inches.	Girth, inches.	Superficies (basal area), sq. ft.
1	3·14	0·00545	25	78·54	3·40885
2	6·28	0·02182	26	81·68	3·68702
3	9·42	0·04908	27	84·82	3·97609
4	12·57	0·08726	28	87·96	4·27607
5	15·71	0·13635	29	91·11	4·58695
6	18·85	0·19635	30	94·25	4·90875
7	21·99	0·26725	31	97·39	5·24145
8	25·13	0·34907	32	100·53	5·58507
9	28·27	0·44179	33	103·67	5·93959
10	31·42	0·54541	34	106·81	6·30502
11	34·56	0·65995	35	109·96	6·68135
12	37·70	0·78540	36	113·10	7·06860
13	40·84	0·92175	37	116·24	7·46675
14	43·98	1·06902	38	119·38	7·87582
15	47·12	1·22718	39	122·52	8·29579
16	50·27	1·39626	40	125·66	8·72667
17	53·41	1·57625	41	128·81	9·16845
18	56·55	1·76715	42	131·95	9·62108
19	59·69	1·96895	43	135·09	10·08475
20	62·83	2·18167	44	138·23	10·55927
21	65·97	2·40527	45	141·37	11·04469
22	69·12	2·63982	46	144·51	11·54103
23	72·26	2·88525	47	147·66	12·04825
24	75·40	3·14160	48	150·80	12·56640

Note.—THE NUMBER OF CUBIC FEET CONTAINED IN A LOG can conveniently be found by multiplying the number of inches in the Quarter-Girth into the length of the Log in feet, as follows:—

Quarter-Girth in Inches.	Number of Cubic Feet in Log equals
6 multiplied into	¼ (length in feet)
7 ,, ,,	⅓ ,, ,,
8½ ,, ,,	½ ,, ,,
10 ,, ,,	⅔ ,, ,,
12 , ,,	1 ,, ,,
13 ,, ,,	1¼ ,, ,,
14¾ ,, ,,	1½ ,, ,,
16 ,, ,,	1¾ ,, ,,
17 ,, ,,	2 ,, ,,
19 ,, ,,	2½ ,, ,,
21 ,, ,,	3 ,, ,,
22½ ,, ,,	3½ ,, ,,
24 ,, ,,	4 ,, ,,
27 ,, ,,	5 ,, ,,
29½ ,, ,,	6 ,, ,,
31¾ ,, ,,	7 ,, ,,
34 ,, ,,	8 ,, ,,
36 ,, ,,	9 ,, ,,

APPENDIX II.—Cubic Contents of Round Logs = Length × $\left(\frac{\text{Mean Girth}}{4}\right)^2$, in Cubic Feet and Decimals of 1 Cubic Foot.

Length in feet.	Mean Girth in Feet and Inches.											
	3′	3′-1″	3′-2″	3′-3″	3′-4″	3′-5″	3′-6″	3′-7″	3′-8″	3′-9″	3′-10″	3′-11″
10	5·6	5·9	6·3	6·6	6·9	7·3	7·7	8·0	8·4	8·8	9·2	9·6
11	6·2	6·5	6·9	7·3	7·6	8·0	8·4	8·8	9·2	9·7	10·1	10·5
12	6·8	7·1	7·5	7·9	8·3	8·8	9·2	9·6	10·1	10·5	11·0	11·5
13	7·3	7·7	8·1	8·6	9·0	9·5	10·0	10·4	10·9	11·4	11·9	12·5
14	7·9	8·3	8·8	9·2	9·7	10·2	10·7	11·2	11·8	12·3	12·9	13·4
15	8·4	8·9	9·4	9·9	10·4	10·9	11·5	12·0	12·6	13·2	13·8	14·4
16	9·0	9·5	10·0	10·6	11·1	11·7	12·2	12·8	13·4	14·1	14·7	15·3
17	9·6	10·1	10·7	11·2	11·8	12·4	13·0	13·6	14·3	14·9	15·6	16·3
18	10·1	10·7	11·3	11·9	12·5	13·1	13·8	14·4	15·1	15·8	16·5	17·3
19	10·7	11·3	11·9	12·5	13·2	13·9	14·5	15·2	16·0	16·7	17·4	18·2
20	11·3	11·9	12·5	13·2	13·9	14·6	15·3	16·1	16·8	17·6	18·4	19·2
21	11·8	12·5	13·2	13·8	14·6	15·3	16·1	16·9	17·6	18·5	19·3	20·1
22	12·4	13·1	13·8	14·5	15·3	16·1	16·8	17·7	18·5	19·3	20·2	21·1
23	12·9	13·7	14·4	15·2	16·0	16·8	17·6	18·5	19·3	20·2	21·1	22·1
24	13·5	14·3	15·0	15·8	16·7	17·5	18·4	19·3	20·2	21·1	22·0	23·0
25	14·1	14·9	15·7	16·5	17·4	18·2	19·1	20·1	21·0	22·0	23·0	24·0
26	14·6	15·4	16·3	17·2	18·1	19·1	19·9	20·9	21·8	22·9	23·9	24·9
27	15·2	16·0	16·9	17·8	18·7	19·7	20·7	21·7	22·7	23·7	24·8	25·9
28	15·8	16·6	17·5	18·5	19·4	20·4	21·4	22·5	23·5	24·6	25·7	26·8
29	16·3	17·2	18·2	19·1	20·1	21·2	22·2	23·3	24·4	25·5	26·6	27·8
30	16·9	17·8	18·8	19·8	20·8	21·9	23·0	24·1	25·2	26·4	27·6	28·8
31	17·4	18·4	19·4	20·5	21·5	22·6	23·7	24·9	26·0	27·2	28·5	29·7
32	18·0	19·0	20·1	21·1	22·2	23·3	24·5	25·7	26·9	28·1	29·4	30·7
33	18·6	19·6	20·7	21·8	22·9	24·1	25·3	26·5	27·7	29·0	30·3	31·6
34	19·1	20·2	21·3	22·4	23·6	24·8	26·0	27·3	28·6	29·9	31·2	32·6
35	19·7	20·8	21·9	23·1	24·3	25·5	26·8	28·1	29·4	30·8	32·1	33·6
36	20·3	21·4	22·6	23·8	25·0	26·3	27·6	28·9	30·2	31·6	33·1	34·5
37	20·8	22·0	23·2	24·4	25·7	27·0	28·3	29·7	31·1	32·5	34·0	35·5
38	21·4	22·6	23·8	25·1	26·4	27·7	29·1	30·5	31·9	33·4	34·9	36·4
39	21·9	23·2	24·4	25·7	27·1	28·5	29·9	31·3	32·8	34·3	35·8	37·4
40	22·5	23·8	25·1	26·4	27·8	29·2	30·6	32·1	33·6	35·2	36·7	38·4

Length in feet.	Mean Girth in Feet and Inches.											
	4′	4′-1″	4′-2″	4′-3″	4′-4″	4′-5″	4′-6″	4′-7″	4′-8″	4′-9″	4′-10″	4′-11″
10	10·0	10·4	10·9	11·3	11·7	12·2	12·7	13·1	13·6	14·1	14·6	15·1
11	11·0	11·5	11·9	12·4	12·9	13·4	13·9	14·4	15·0	15·5	16·1	16·6
12	12·0	12·5	13·0	13·5	14·1	14·6	15·2	15·8	16·3	16·9	17·5	18·1
13	13·0	13·5	14·1	14·7	15·3	15·8	16·5	17·1	17·7	18·3	19·0	19·6
14	14·0	14·6	15·2	15·8	16·4	17·1	17·7	18·4	19·1	19·7	20·4	21·2
15	15·0	15·6	16·3	16·9	17·6	18·3	19·0	19·7	20·4	20·2	21·9	22·7
16	16·0	16·7	17·4	18·1	18·8	19·5	20·2	21·0	21·8	22·6	23·4	24·2
17	17·0	17·7	18·4	19·2	20·0	20·7	21·5	22·3	23·1	24·0	24·8	25·7
18	18·0	18·8	19·5	20·3	21·1	21·9	22·8	23·6	24·5	25·4	26·3	27·2
19	19·0	19·8	20·6	21·4	22·3	23·2	24·0	24·9	25·9	26·8	27·7	28·7
20	20·0	20·8	21·7	22·6	23·5	24·4	25·3	26·3	27·2	28·2	29·2	30·2
21	21·0	21·9	22·8	23·7	24·6	25·6	26·6	27·6	28·6	29·6	30·7	31·7
22	22·0	22·9	23·9	24·8	25·8	26·8	27·8	28·9	29·9	31·0	32·1	33·2
23	23·0	24·0	25·0	26·0	27·0	28·0	29·1	30·2	31·3	32·4	33·6	34·7
24	24·0	25·0	26·0	27·1	28·2	29·3	30·4	31·5	32·7	33·8	35·0	36·3
25	25·0	26·1	27·1	28·2	29·3	30·5	31·6	32·8	34·0	35·3	36·5	37·8
26	26·0	27·1	28·2	29·4	30·5	31·7	32·9	34·1	35·4	36·7	38·0	39·3
27	27·0	28·1	29·3	30·5	31·7	32·9	34·2	35·4	36·7	38·1	39·4	40·8
28	28·0	29·2	30·4	31·6	32·9	34·1	35·4	36·8	38·1	39·5	40·9	42·3
29	29·0	30·2	31·5	32·7	34·0	35·4	36·7	38·1	39·5	40·9	42·3	43·8
30	30·0	31·3	32·6	33·9	35·2	36·6	38·0	39·4	40·8	42·3	43·8	45·3
31	31·0	32·3	33·6	35·0	36·4	37·8	39·2	40·7	42·2	43·7	45·3	46·8
32	32·0	33·3	34·7	36·1	37·5	39·0	40·5	42·0	43·6	45·1	46·7	48·3
33	33·0	34·4	35·8	37·3	38·7	40·2	41·8	43·3	44·9	46·5	48·2	49·9
34	34·0	35·4	36·9	38·4	39·9	41·5	43·0	44·6	46·3	47·9	49·6	51·4
35	35·0	36·5	38·0	39·5	41·1	42·7	44·3	46·0	47·6	49·4	51·1	52·9
36	36·0	37·5	39·1	40·6	42·2	43·9	45·6	47·3	49·0	50·8	52·6	54·4
37	37·0	38·6	40·1	41·8	43·4	45·1	46·8	48·6	50·4	52·2	54·0	55·9
38	38·0	39·6	41·2	42·9	44·6	46·3	48·1	49·9	51·7	53·6	55·5	57·4
39	39·0	40·6	42·3	44·0	45·8	47·5	49·4	51·2	53·1	55·0	56·9	58·9
40	40·0	41·7	43·4	45·2	46·9	48·8	50·6	52·5	54·4	56·4	58·4	60·4

APPENDIX II. (*continued*)—CUBIC CONTENTS OF ROUND LOGS = Length × $\left(\frac{\text{Mean Girth}}{4}\right)^2$, in Cubic Feet and Decimals of 1 Cubic Foot.

Length in feet.	Mean Girth in Feet and Inches.											
	5′	5′-1″	5′-2″	5′-3″	5′-4″	5′-5″	5′-6″	5′-7″	5′-8″	5′-9″	5′-10″	5′-11″
10	15·6	16·2	16·7	17·2	17·8	18·3	18·9	19·5	20·1	20·7	21·3	21·9
11	17·2	17·8	18·4	18·9	19·6	20·2	20·8	21·4	22·1	22·7	23·4	24·1
12	18·8	19·4	20·0	20·7	21·3	22·0	22·7	23·4	24·1	24·8	25·5	26·3
13	20·3	21·0	21·7	22·4	23·1	23·8	24·6	25·3	26·1	26·9	27·6	28·4
14	21·9	22·6	23·4	24·1	24·9	25·7	26·5	27·3	28·1	28·9	29·8	30·6
15	23·4	24·2	25·0	25·8	26·7	27·5	28·4	29·2	30·1	31·0	31·9	32·8
16	25·0	23·8	26·7	27·6	28·4	29·3	30·2	31·2	32·1	33·1	34·0	35·0
17	26·6	27·5	28·4	29·3	30·2	31·2	32·1	33·1	34·1	35·1	36·2	37·2
18	28·1	29·1	30·0	31·0	32·0	33·0	34·0	35·1	36·1	37·2	38·3	39·3
19	29·7	30·7	31·7	32·7	33·8	34·8	35·9	37·0	38·1	39·3	40·4	41·6
20	31·3	32·3	33·4	34·5	35·6	36·7	37·8	39·0	40·1	41·3	42·5	43·8
21	32·8	33·9	35·0	36·2	37·3	38·5	39·7	40·9	42·1	43·4	44·7	45·9
22	34·4	35·5	36·7	37·9	39·1	40·3	41·6	42·9	44·2	45·5	46·8	48·1
23	35·9	37·1	38·4	39·6	40·9	42·2	43·5	44·8	46·2	47·5	48·9	50·3
24	37·5	38·8	40·0	41·3	42·7	44·0	45·4	46·8	48·2	49·6	51·0	52·5
25	39·1	40·4	41·7	43·1	44·4	45·8	47·3	48·7	50·2	51·7	53·2	54·7
26	40·6	42·0	43·4	44·8	46·2	47·7	49·2	50·7	52·2	53·7	55·3	56·9
27	42·2	43·6	45·0	46·5	48·0	49·5	51·0	52·6	54·2	55·8	57·4	59·1
28	43·8	45·2	46·7	48·2	49·8	51·3	52·9	54·6	56·2	57·9	59·5	61·3
29	45·3	46·8	48·4	50·0	51·6	53·2	54·8	56·5	58·2	59·9	61·7	63·4
30	46·9	48·5	50·1	51·7	53·3	55·0	56·7	58·5	60·2	62·0	63·8	65·6
31	48·4	50·1	51·7	53·4	55·1	56·8	58·6	60·4	62·2	64·1	65·9	67·8
32	50·0	51·7	53·4	55·1	56·9	58·7	60·5	62·3	64·2	66·1	68·1	70·0
33	51·6	53·3	55·1	56·8	58·7	60·5	62·4	64·3	66·2	68·2	70·2	72·2
34	53·1	54·9	56·7	58·6	60·4	62·3	64·3	66·2	68·2	70·3	72·3	74·4
35	54·7	56·5	58·4	60·3	62·2	64·2	66·2	68·2	70·2	72·3	74·4	76·6
36	56·3	58·1	60·1	62·0	64·0	66·0	68·1	70·1	72·2	74·4	76·6	78·8
37	57·8	59·8	61·7	63·7	65·8	67·8	70·0	72·1	74·3	76·5	78·7	81·0
38	59·4	61·4	63·4	65·5	67·6	69·7	71·8	74·0	76·3	78·5	80·8	83·1
39	60·9	63·0	65·1	67·2	69·3	71·5	73·7	76·0	78·3	80·6	82·9	85·3
40	62·5	64·6	66·7	68·9	71·1	73·4	75·6	77·9	80·3	82·7	85·1	87·5

Length in feet.	Mean Girth in Feet and Inches.											
	6′	6′-1″	6′-2″	6′-3″	6′-4″	6′-5″	6′-6″	6′-7″	6′-8″	6′-9″	6′-10″	6′-11″
10	22·5	23·1	23·8	24·4	25·1	25·7	26·4	27·1	27·8	28·5	29·2	29·9
11	24·8	25·4	26·1	26·9	27·6	28·3	29·0	29·8	30·6	31·3	32·1	32·9
12	27·0	27·8	28·5	29·3	30·1	30·9	31·7	32·5	33·3	34·2	35·0	35·9
13	29·3	30·1	30·9	31·7	32·6	33·5	34·3	35·2	36·1	37·0	37·9	38·9
14	31·5	32·4	33·3	34·2	35·1	36·0	37·0	37·9	38·9	39·9	40·9	41·9
15	33·8	34·7	35·7	36·6	37·6	38·6	39·6	40·6	41·7	42·7	43·8	44·9
16	36·0	37·0	38·0	39·1	40·1	41·2	42·2	43·3	44·4	45·6	46·7	47·8
17	38·3	39·3	40·4	41·5	42·6	43·7	44·9	46·0	47·2	48·4	49·6	50·8
18	40·5	41·6	42·8	43·9	45·1	46·3	47·5	48·8	50·0	51·3	52·5	53·8
19	42·8	43·9	45·2	46·4	47·6	48·9	50·2	51·5	52·8	54·1	55·4	56·8
20	45·0	46·3	47·5	48·8	50·1	51·5	52·8	54·2	55·6	57·0	58·4	59·8
21	47·3	48·6	49·9	51·3	52·6	54·0	55·5	56·9	58·3	59·8	61·3	62·8
22	49·5	50·9	52·3	53·7	55·2	56·6	58·1	59·6	61·1	62·6	64·2	65·8
23	51·8	53·2	54·7	56·2	57·7	59·2	60·7	62·3	63·9	65·5	67·1	68·8
24	54·0	55·5	57·0	58·6	60·2	61·8	63·4	65·0	66·7	68·3	70·0	71·8
25	56·3	57·8	59·4	61·0	62·7	64·3	66·0	67·7	69·4	71·2	73·0	74·8
26	58·5	60·1	61·8	63·5	65·2	66·9	68·7	70·4	72·2	74·0	75·9	77·7
27	60·8	62·4	64·2	65·9	67·7	69·5	71·3	73·1	75·0	76·9	78·8	80·7
28	63·0	64·8	66·5	68·4	70·2	72·1	73·9	75·8	77·8	79·7	81·7	83·7
29	65·3	67·1	68·9	70·8	72·7	74·6	76·6	78·6	80·6	82·6	84·6	86·7
30	67·5	69·4	71·3	73·2	75·2	77·2	79·2	81·3	83·3	85·4	87·6	89·7
31	69·8	71·7	73·7	75·7	77·7	79·8	81·9	84·0	86·1	88·3	90·5	92·7
32	72·0	74·0	76·1	78·1	80·2	82·3	84·5	86·7	88·9	91·1	93·4	95·7
33	74·3	76·3	78·4	80·6	82·7	84·9	87·1	89·4	91·7	94·0	96·3	98·7
34	76·5	78·6	80·8	83·0	85·2	87·5	89·8	92·1	94·4	96·8	99·2	101·7
35	78·8	81·0	83·2	85·4	87·7	90·1	92·4	94·8	97·2	99·7	102·1	104·7
36	81·0	83·3	85·6	87·9	90·2	92·6	95·1	97·5	100·0	102·5	105·1	107·6
37	83·3	85·6	87·9	90·3	92·8	95·2	97·7	100·2	102·8	105·4	108·0	110·6
38	85·5	87·9	90·3	92·8	95·3	97·8	100·3	102·9	105·6	108·2	110·9	113·6
39	87·8	90·2	92·7	95·2	97·8	100·4	103·0	105·6	108·3	111·1	113·8	116·6
40	90·0	92·5	95·1	97·7	100·3	102·9	105·6	108·4	111·1	113·9	116·7	119·6

APPENDIX II. (*continued*)—CUBIC CONTENTS OF ROUND LOGS = Length × $\left(\frac{\text{Mean Girth}}{4}\right)^2$, in Cubic Feet and Decimals of 1 Cubic Foot.

Length in feet.	Mean Girth in Feet and Inches.											
	7′	7′-1″	7′-2″	7′-3″	7′-4″	7′-5″	7′-6″	7′-7″	7′-8″	7′-9″	7′-10″	7′-11″
10	30·6	31·4	32·1	32·9	33·6	34·4	35·2	35·9	36·7	37·5	38·4	39·2
11	33·7	34·5	35·3	36·1	37·0	37·8	38·7	39·5	40·4	41·3	42·2	43·1
12	36·8	37·6	38·5	39·4	40·3	41·3	42·2	43·1	44·1	45·0	46·0	47·0
13	39·8	40·8	41·7	42·7	43·7	44·7	45·7	46·7	47·8	48·8	49·9	50·9
14	42·9	43·9	44·9	46·0	47·1	48·1	49·2	50·3	51·4	52·6	53·7	54·8
15	45·9	47·0	48·2	49·3	50·4	51·6	52·7	53·9	55·1	56·3	57·5	58·8
16	49·0	50·2	51·4	52·6	53·8	55·0	56·2	57·5	58·8	60·1	61·4	62·7
17	52·1	53·3	54·6	55·8	57·1	58·4	59·8	61·1	62·5	63·8	65·2	66·6
18	55·1	56·4	57·8	59·1	60·5	61·9	63·3	64·7	66·1	67·6	69·0	70·5
19	58·2	59·6	61·0	62·4	63·9	65·3	66·8	68·3	69·8	71·3	72·9	74·4
20	61·3	62·7	64·2	65·7	67·2	68·8	70·3	71·9	73·5	75·1	76·7	78·3
21	64·3	65·9	67·4	69·0	70·6	72·2	73·8	75·5	77·1	78·8	80·5	82·3
22	67·4	69·0	70·6	72·3	73·9	75·6	77·3	79·1	80·8	82·6	84·4	86·2
23	70·4	72·1	73·8	75·6	77·3	79·1	80·9	82·7	84·5	86·3	88·2	90·1
24	73·5	75·3	77·0	78·8	80·7	82·5	84·4	86·3	88·2	90·1	92·0	94·0
25	76·6	78·4	80·3	82·1	83·0	85·9	87·9	89·9	91·8	93·8	95·9	97·9
26	79·6	81·5	83·5	85·5	87·4	89·4	91·4	93·4	95·5	97·6	99·7	101·8
27	82·7	84·7	86·7	88·7	90·7	92·8	94·9	97·0	99·2	101·4	103·5	105·8
28	85·8	87·8	89·9	92·0	94·1	96·3	98·4	100·6	102·9	105·1	107·4	109·7
29	88·8	90·9	93·1	95·3	97·5	99·7	102·0	104·2	106·5	108·9	111·2	113·6
30	91·9	94·1	96·3	98·6	100·8	103·1	105·5	107·8	110·2	112·6	115·1	117·5
31	94·9	97·2	99·5	101·8	104·2	106·6	109·0	111·4	113·9	116·4	118·9	121·4
32	98·0	100·3	102·7	105·1	107·6	110·0	112·5	115·0	117·6	120·1	122·7	125·3
33	101·1	103·5	105·9	108·4	110 9	113·5	116·0	118·6	121·2	123·9	126·6	129·3
34	104·1	106·6	109·1	111·7	114·3	116·9	119·5	122·2	124·9	127·6	130·4	133·2
35	107·2	109·8	112·4	115·0	117·6	120·3	123·0	125·8	128·6	131·4	134·2	137·1
36	110·3	112·9	115·6	118·3	121·0	123·8	126·6	129·4	132·2	135·1	138·1	141·0
37	113·3	116·0	118·8	121·6	124·4	127·2	130·1	133·0	135·9	138·9	141·9	144·9
38	116·4	119·2	122·0	124·8	127·7	130·6	133·6	136·6	139·6	142·6	145·7	148·8
39	119·4	122·3	125·2	128·1	131·1	134·1	137·1	140·2	143·3	146·4	149·6	152·8
40	122·5	125·4	128·4	131·4	134·4	137·5	140·6	143·8	146·9	150·2	153·4	156·7

Length in feet.	Mean Girth in Feet and Inches.											
	8′	8′-1″	8′-2″	8′-3″	8′-4″	8′-5″	8′-6″	8′-7″	8′-8″	8′-9″	8′-10″	8′-11″
10	40·0	40·8	41·7	42·5	43·4	44·3	45·2	46·0	46·9	47·9	48·8	49·7
11	44·0	44·9	45·9	46·8	47·7	48·7	49·7	50·7	51·6	52·6	53·6	54·7
12	48·0	49·0	50·0	51·0	52·1	53·1	54·2	55·3	56·3	57·4	58·5	59·6
13	52·0	53·1	54·2	55·3	56·4	57·6	58·7	59·9	60·0	62·2	63·4	64·6
14	56·0	57·2	58·4	59·6	60·8	62·0	63·2	64·5	65·7	67·0	68·3	69·6
15	60·0	60·3	62·5	63·8	65·1	66·4	67·7	69·1	70·4	71·8	73·2	74·5
16	64·0	65·3	66·7	68·1	69·4	70·8	72·2	73·7	75·1	76·6	78·0	79·5
17	68·0	69·4	70·9	72·3	73·8	75·3	76·8	78·3	79·8	81·3	82·9	84·5
18	72·0	73·5	75·0	76·6	78·1	79·7	81·3	82·9	84·5	86·1	87·8	89·4
19	76·0	77·6	79·2	80·8	82·5	84·1	85·8	87·5	89·2	90·9	92·6	94·4
20	80·0	81·7	83·4	85·1	86·8	88·6	90·3	92·1	93·9	95·7	97·5	99·4
21	84·0	85·8	87·5	89·3	91·1	93·0	94·8	96·7	98·6	100·5	102·4	104·4
22	88·0	89·8	91·7	93·6	95·5	97·4	99·3	101·3	103·3	105·3	107·3	109·3
23	92·0	93·9	95·9	97·8	99·8	101·8	103·9	105·9	108·0	110·1	112·2	114·3
24	96·0	98·0	100·0	102·1	104·2	106·3	108·4	110·5	112·7	114·8	117·0	119·3
25	100·0	102·1	104·2	106·3	108·5	110·7	112·9	115·1	117·4	119·6	121·9	124·2
26	104·0	106·2	108·4	110·6	112·8	115·1	117·4	119·7	122·1	124·4	126·8	129·2
27	108·0	110·3	112·5	114·9	117·2	119·5	121·9	124·3	126·7	129·2	131·7	134·2
28	112·0	114·3	116·7	119·1	121·5	124·0	126·4	128·9	131·4	134·0	136·5	139·1
29	116·0	117·4	120·9	123·4	125·9	128·4	131·0	133·5	136·1	138·8	141·4	144·1
30	120·0	122·5	125·1	127·6	130·2	132·8	135·5	138·1	140·8	143·6	146·3	149·1
31	124·0	126·6	129·2	131·9	134·5	137·3	140·0	142·7	145·5	148·3	151·2	154·0
32	128·0	130·7	133·4	136·1	138·9	141·7	144·5	147·3	150·2	153·1	156·1	159·0
33	132·0	134·8	137·6	140·4	143·2	146·1	149·0	152·0	154·9	157·9	160·9	164·0
34	136·0	138·8	141·7	144·6	147·6	150·5	153·5	156·6	159·6	162·7	165 8	169·0
35	140·0	142·9	145·9	148·9	151·9	155·0	158·8	161·2	164·3	167·5	170·7	173·9
36	144·0	147·0	150·1	153·1	156·2	159·4	162 6	165·8	169·0	172·3	175·6	178·9
37	148·0	151·1	154·2	157·4	160·6	163·8	167·1	170·4	173·7	177·1	180·4	183·9
38	152·0	155·2	158·4	161·6	164·9	168·2	171·6	175·0	178·4	181·8	185·3	188·8
39	156·0	159·3	162·6	165·9	169·3	172·7	176·1	179·6	183·1	186·6	190·2	193·8
40	160·0	163·4	166·7	170·2	173·6	177·1	180·6	184·2	187·8	191·4	195·1	198·8

Appendix II. (*continued*)—Cubic Contents of Round Logs = Length × $\left(\frac{\text{Mean Girth}}{4}\right)^2$, in Cubic Feet and Decimals of 1 Cubic Foot.

Length in feet.	Mean Girth in Feet and Inches.											
	9′	9′-1″	9′-2″	9′-3″	9′-4″	9′-5″	9′-6″	9′-7″	9′-8″	9′-9″	9′-10″	9′-1″
10	50·6	51·6	52·5	53·5	54·4	55·4	56·4	57·4	58·4	59·4	60·4	61·5
11	55·7	56·7	57·8	58·8	59·9	61·0	62·0	63·1	64·2	65·4	66·5	67·6
12	60·8	61·9	63·0	64·2	65·3	66·5	67·7	68·9	70·1	71·3	72·5	73·8
13	65·8	67·0	68·3	69·5	70·8	72·0	73·3	74·6	75·9	77·2	78·6	79·9
14	70·9	72·2	73·5	74·9	76·2	77·6	79·0	80·4	81·8	83·2	84·6	86·0
15	75·9	77·4	78·8	80·2	81·7	83·1	84·6	86·1	87·6	89·1	90·7	92·2
16	81·0	82·5	84·0	85·6	87·1	88·7	90·2	91·8	93·4	95·1	96·7	98·3
17	86·1	87·7	89·3	90·9	92·6	94·2	95·9	97·6	99·3	101·0	102·7	104·5
18	91·1	92·8	94·5	96·3	98·0	99·8	101·5	103·3	105·1	106·9	108·8	110·6
19	96·2	98·0	99·8	101·6	103·4	105·3	107·2	109·1	111·0	112·9	114·8	116·8
20	101·3	103·1	105·0	107·0	108·9	110·8	112·8	114·8	116·8	118·8	120·9	122·9
21	106·3	108·3	110·3	112·3	114·3	116·4	118·5	120·5	122·6	124·8	126·9	129·1
22	111·4	113·4	115·5	117·6	119·8	121·9	124·1	126·3	128·5	130·7	133·0	135·2
23	116·4	118·6	120·8	123·0	125·2	127·5	129·7	132·0	134·3	136·7	139·0	141·4
24	121·5	123·8	126·0	128·3	130·7	133·0	135·4	137·8	140·2	142·6	145·0	147·5
25	126·6	128·9	131·3	133·7	136·1	138·6	141·0	143·5	146·0	148·5	151·1	153·7
26	131·6	134·1	136·5	139·0	141·6	144·1	146·7	149·2	151·8	154·5	157·1	159·8
27	136·7	139·2	141·8	144·4	147·0	149·6	152·3	155·0	157·7	160·4	163·2	165·9
28	141·8	144·4	147·0	149·7	152·4	155·2	157·9	160·7	163·5	166·4	169·2	172·1
29	146·8	149·5	152·3	155·1	157·9	160·7	163·6	166·5	169·4	172·3	175·3	178·2
30	151·9	154·7	157·6	160·4	163·3	166·3	169·2	172·2	175·2	178·2	181·3	184·4
31	156·9	159·9	162·8	165·8	168·8	171·8	174·9	177·9	181·0	184·2	187·3	190·5
32	162·0	165·0	168·1	171·1	174·2	177·3	180·5	183·7	186·9	190·1	193·4	196·7
33	167·1	170·2	173·3	176·5	179·7	182·9	186·1	189·4	192·7	196·1	199·4	202·8
34	172·1	175·3	178·6	181·8	185·1	188·4	191·8	195·2	198·6	202·0	205·5	209·0
35	177·2	180·6	183·8	187·1	190·6	194·0	197·4	200·9	204·4	207·9	211·5	215·1
36	182·3	185·6	189·1	192·5	196·0	199·5	203·1	206·6	210·2	213·9	217·6	221·3
37	187·3	190·8	194·3	197·9	201·4	205·1	208·7	212·4	216·1	219·8	223·6	227·4
38	192·4	196·0	199·6	203·2	206·9	210·6	214·3	218·1	221·9	225·8	229·6	233·6
39	197·4	201·1	204·8	208·6	212·3	216·1	220·0	223·9	227·8	231·7	235·7	239·7
40	202·5	206·3	210·1	213·9	217·8	221·7	255·6	229·6	233·6	237·7	241·7	245·9

Length in feet.	Mean Girth in Feet and Inches.											
	10′	10′-1″	10′-2″	10′-3″	10′-4″	10′-5″	10′-6″	10′-7″	10′-8″	10′-9″	10′-10″	10′-11″
10	62·5	63·5	64·6	65·7	66·7	67·8	68·9	70·0	71·1	72·2	73·4	74·6
11	68·8	69·9	71·1	72·2	73·4	74·6	75·8	77·0	78·2	79·4	80·7	81·9
12	75·0	76·3	77·5	78·8	80·1	81·4	82·7	84·0	85·3	86·7	88·0	89·4
13	81·3	82·6	84·0	85·4	86·8	88·2	89·6	91·0	92·4	93·9	95·4	96·8
14	87·5	89·0	90·4	91·9	93·4	94·9	96·5	98·0	99·6	101·1	102·7	104·3
15	93·8	95·3	96·9	98·5	100·1	101·7	103·4	105·0	106·7	108·3	110·0	111·7
16	100·0	101·7	103·4	105·1	106·8	108·5	110·2	112·0	113·8	115·6	117·4	119·2
17	106·3	108·0	109·8	111·6	113·5	115·3	117·1	119·0	120·9	122·8	124·7	126·6
18	112·5	113·4	116·3	118·2	120·1	122·1	124·0	126·0	128·0	130·0	132·0	134·1
19	118·8	120·7	122·7	124·8	126·8	128·9	130·9	133·0	135·1	137·2	139·4	141·5
20	125·0	127·1	129·2	131·3	133·5	135·6	137·8	140·0	142·2	144·5	146·7	149·0
21	131·3	133·4	135·7	137·9	140·1	142·4	144·7	147·0	149·3	151·7	154·0	156·4
22	137·5	139·8	142·1	144·5	146·8	149·2	151·6	154·0	156·4	158·9	161·4	163·9
23	143·8	146·2	148·6	151·0	153·5	156·0	158·5	161·0	163·6	166·1	168·7	171·3
24	150·0	152·5	155·0	157·6	160·2	162·8	165·4	168·0	170·7	173·3	176·0	178·8
25	156·3	158·9	161·5	164·2	166·8	169·5	172·3	175·0	177·8	180·6	183·4	186·2
26	162·5	165·2	168·8	170·7	173·5	176·3	179·2	182·0	184·9	187·8	190·7	193·7
27	168·8	171·6	174·4	177·3	180·2	183·1	186·0	189·0	192·0	195·0	198·0	201·1
28	175·0	177·9	180·9	183·9	186·9	189·9	192·9	196·0	199·1	202·2	205·4	208·6
29	181·3	184·3	187·3	190·4	193·5	196·7	199·8	203·0	206·2	209·5	212·7	216·0
30	187·5	190·6	193·8	197·0	200·2	203·5	206·7	210·0	213·3	216·7	220·1	223·5
31	193·8	197·0	200·3	203·6	206·9	210·2	213·6	217·0	220·4	223·9	227·4	230·9
32	200·0	203·3	206·2	210·1	213·6	217·0	220·5	224·0	227·6	231·1	234·7	238·3
33	206·3	209·7	213·2	216·7	220·2	223·8	227·4	231·0	234·7	238·3	242·1	245·8
34	212·5	216·1	219·6	223·3	226·9	230·6	234·3	238·0	241·8	245·6	249·4	253·2
35	218·8	222·4	226·1	229·8	233·6	237·4	241·2	245·0	248·9	252·8	256·7	260·7
36	225·0	228·8	232·6	236·4	240·2	244·1	248·1	252·0	256·0	260·0	264·1	268·1
37	231·3	235·1	239·0	243·0	246·9	250·9	255·0	259·0	263·1	267·2	271·4	275·6
38	237·5	241·5	245·5	245·5	253·6	257·7	261·8	266·0	270·2	274·5	278·7	283·0
39	243·8	247·8	251·9	256·1	260·3	264·5	268·7	273·0	277·3	281·7	286·1	290·5
40	250·0	254·2	258·4	262·7	266·9	271·3	275·6	280·0	284·4	288·9	293·4	297·9

APPENDIX III.—Average Yield Tables,

For Scots Pine, Spruce, Beech, and Oak in Germany (compiled chiefly from *Forst- und Jagd-Kalendar* and Lorey's *Handbuch der Forstwissenschaft*, 1903).

Note.—The **average annual increment** of the crop at any given age may be found by dividing the total yield by the number of years in age. The **current annual increment** can be found approximately for short periods of 5 or 10 years by subtracting the estimated yield at present age from that anticipated 10 years hence, and dividing the result by 10.

In Germany **timber** includes everything down to a top-diameter of $2\frac{3}{4}$ inches (7 centimetres) *measured over bark.* To reduce the tables to the customary British (square-of-quarter-girth) measurement down to 3 inches top-diameter, the German data have been reduced by only 20 per cent (in place of the $21\frac{1}{2}$ per cent, so that the result is somewhat more than the correct amount) for measurement over bark; and a further reduction of 15 per cent (or 35 per cent in all) is made for *the usual bark-allowance* of 1 inch per foot of mean girth.

There are no German tables which give the yield of Oak and other hardwoods down to 6 inches top-diameter only, as is the customary timber measurement in Britain. And concerning the tables here given for Scots Pine, Spruce, and Beech, it will be seen that, as regards the number of trees per acre, and their small size up to 30 or 40 years of age, very great differences exist between British and Continental methods of growing timber-crops. Consequently these tables are not likely to be of much practical value for any part of the United Kingdom.

Scots Pine (*after* Schwappach and Weise).

I. Soil and Situation—**Very Good.**

Age.	Mean timber-height (to $2\frac{3}{4}$ in. diameter *over bark*).	No. of trees per acre.	Average.		True cubic contents, *measured over bark.*						Cubic contents in British (*square-of-quarter-girth*) measurement *over bark.*						Cubic contents (British measure), with a reduction of 15 per cent for *bark allowance*[1] ($\frac{1}{12}$th of girth).					
					Whole crop.			Removable as thinnings.			Whole crop.			Removable as thinnings.			Whole crop.			Removable as thinnings.		
			Growing-space per tree.	Distance from stem to stem.	Total quantity.	Timber only (3 in. diameter and above).	Faggot-wood (below $2\frac{3}{4}$ in. diameter).	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.
Years.	Feet.		Sq. ft.	Feet.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.
20	30	1710	25	5·0	2290	780	1510	210	...	210	1840	620	1220	170	...	170	1490	510	980	140	...	130
30	44	1090	40	6·3	3610	2200	1410	280	60	220	2890	1750	1140	230	50	180	2350	1430	920	180	40	130
40	56	700	62	7·8	4760	3840	920	410	300	110	3810	3070	740	330	240	90	3090	2500	590	270	190	80
50	66	470	90	9·5	5760	5010	750	480	420	60	4610	4010	600	380	340	40	3750	3260	490	310	270	40
60	74	330	132	11·4	6690	5960	730	550	510	40	5350	4770	580	440	410	30	4350	3870	480	360	330	30
70	81	260	167	12·9	7440	6730	710	500	460	40	5950	5380	570	400	370	30	4840	4370	470	330	300	30
80	87	220	198	14·0	8060	7350	710	480	440	40	6450	6280	570	380	350	30	5240	4780	460	310	290	20
90	93	200	217	14·7	8580	7880	700	400	380	20	6870	6300	570	320	300	20	5570	5120	450	260	250	10
100	97	180	242	15·5	9020	8310	710	330	310	20	7220	6650	570	260	250	10	5860	5400	460	210	200	10
110	101	165	264	16·2	9410	8700	710	280	270	10	7520	6960	560	230	220	10	6110	5650	460	180	170	10
120	105	155	281	16·8	9690	8980	710	...	...	...	7750	7190	560	...	...	...	6300	5840	460	...	...	...

II. Soil and Situation—Good.

20	23	2140	20	4·5	1510	70	1440	160	...	160	1210	60	1150	130	...	130	980	45	935	100	...	100
30	37	1430	30	5·5	2730	1160	1570	220	...	220	2190	930	1260	180	...	180	1780	750	1030	140	...	140
40	48	960	45	6·7	3820	2800	1020	310	100	210	3060	2240	820	250	80	170	2490	1820	670	200	65	135
50	57	650	67	8·1	4700	3910	790	380	270	110	3760	3130	630	310	200	110	3060	2540	520	250	175	75
60	65	460	94	9·7	5370	4650	720	440	380	60	4300	3720	580	350	310	40	3490	3020	470	290	250	40
70	71	340	128	11·3	5910	5200	710	400	370	30	4730	4160	570	320	300	20	3840	3380	460	260	240	20
80	76	280	155	12·4	6350	5670	680	350	330	20	5080	4530	550	280	260	20	4120	3680	440	230	210	20
90	81	240	181	13·4	6730	6050	680	330	310	20	5380	4840	540	260	250	10	4370	3930	440	210	200	10
100	85	210	207	14·4	7030	6350	680	260	240	20	5620	5080	540	200	190	10	4570	4120	450	170	160	10
110	89	190	229	15·1	7310	6630	680	210	200	10	5850	5300	550	170	160	10	4750	4310	440	140	130	10
120	93	175	248	15·7	7560	6890	670	...	...	...	6050	5510	540	...	...	...	4920	4480	440	...	...	...

III. Soil and Situation—Medium.

20	17	2630	16	4·0	1270	30	1240	130	...	130	1020	25	995	100	...	100	830	20	810	85	...	85
30	30	1810	24	4·9	2120	820	1300	170	...	170	1700	660	1040	140	...	140	1380	530	850	110	...	110
40	40	1240	35	5·9	2870	1950	920	240	60	180	2300	1560	740	190	50	140	1870	1270	600	160	40	120
50	47	860	50	7·1	3500	2680	820	300	170	130	2800	2140	660	240	140	100	2270	1740	530	190	110	80
60	53	600	72	8·5	4020	3270	750	340	270	70	3220	2620	600	270	220	50	2610	2130	480	220	180	40
70	58	445	97	9·8	4490	3780	710	330	300	30	3600	3030	570	260	240	20	2920	2460	460	210	190	20
80	63	350	124	11·2	4900	4220	680	300	270	30	3920	3380	540	240	220	20	3190	2750	440	190	170	20
90	68	295	147	12·1	5250	4570	680	240	230	10	4200	3660	540	190	180	10	3410	2970	440	160	150	10
100	73	260	167	12·9	5520	4860	660	200	180	20	4420	3890	530	160	150	10	3590	3160	430	130	120	10
110	77	230	189	13·7	5760	5100	660	170	160	20	4610	4080	530	140	120	20	3740	3320	420	110	100	10
120	80	210	207	14·4	5950	5280	670	...	...	...	4760	4230	530	...	...	...	3870	3430	440	...	...	...

IV. Soil and Situation—Inferior.

20	12	...	...	...	1050	...	1050	100	...	100	840	...	840	80	...	80	680	...	680	65	...	65
30	23	2420	18	4·2	1730	440	1290	140	...	140	1380	350	1030	110	...	110	1120	290	830	90	...	90
40	31	1610	27	5·2	2350	1270	1080	200	...	200	1880	1020	860	160	...	160	1530	830	700	130	...	130
50	37	1090	40	6·6	2890	2030	860	240	60	180	2310	1620	690	190	50	140	1880	1320	560	160	35	125
60	42	780	55	7·4	3330	2590	740	270	160	110	2660	2070	590	220	120	100	2160	1680	480	170	95	75
70	47	595	73	8·5	3700	3040	660	260	200	60	2960	2440	520	200	160	40	2400	1980	420	170	120	50
80	51	470	92	9·6	3950	3310	640	230	200	30	3160	2650	510	180	160	20	2570	2150	420	150	120	30
90	55	390	111	10·5	4140	3500	640	...	...	...	3310	2800	510	...	...	...	2690	2270	420	...	...	...
100	59	330	132	11·4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
110	63	280	155	12·4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
120	66	240	181	13·4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

[1] The reduction for *bark-allowance* is here made on the original measurements (true cubic contents), and not on the converted (square-of-quarter-girth) contents. **Larch; Weymouth, Austrian,** and **Corsican Pines**.—The yield is at all ages somewhat larger than that of Scots Pine, except where the soil and situation are inferior for Larch.

Spruce[1] (*after* Lorey).

I. Soil and Situation—**Very Good**.

Age.	Mean timber-height (to 2¾ in. diameter *over bark*).	No. of trees per acre.	Average.		True cubic contents, *measured over bark*.						Cubic contents in British (*square-of-quarter-girth*) measurement *over bark*.						Cubic contents (British measure), with a reduction of 15 per cent for *bark allowance* ($\frac{1}{12}$th of girth).					
					Whole crop.			Removable as thinnings.			Whole crop.			Removable as thinnings.			Whole crop.			Removable as thinnings.		
			Growing-space per tree.	Distance from stem to stem.	Total quantity.	Timber only (3 in. diameter and above).	Faggot-wood (below 2¾ in. diameter).	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.
Years.	Feet.		Sq. ft.	Feet.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.
20	20	2520	17·2	4·1	1980	710	1270	...	...	...	1680	570	1110	...	...	...	1290	460	830	...	...	...
30	34	1560	27·8	5·2	3760	2340	1420	350	170	180	3010	1870	1140	280	140	140	2440	1520	920	230	110	120
40	50	960	45·3	6·7	5890	4530	1360	610	410	200	4710	3620	1090	480	320	160	3830	2940	890	400	260	140
50	65	620	70·2	8·3	8370	7040	1330	670	470	200	6690	5630	1060	530	370	160	5440	4570	870	440	300	140
60	77	460	94·7	9·7	10,390	9070	1320	780	650	130	8310	7260	1050	620	520	100	6750	5890	860	510	420	90
70	88	340	125·1	11·1	11,960	10,620	1340	910	830	80	9560	8500	1060	720	660	60	7770	6900	870	590	540	50
80	96	270	161·3	12·7	13,320	11,960	1360	850	780	70	10,650	9570	1080	680	620	60	8660	7770	890	550	510	40
90	103	240	181·5	13·2	14,490	13,130	1360	780	720	60	11,590	10,500	1090	620	570	50	9420	8530	890	510	470	40
100	110	220	198·0	14·0	15,510	14,170	1340	640	580	60	12,400	11,340	1060	510	460	50	10,080	9210	870	420	380	40
110	114	210	207·4	14·5	16,430	15,100	1330	560	520	40	13,140	12,080	1060	450	410	40	10,680	9810	870	360	340	20
120	118	200	217·8	14·7	17,260	15,840	1420	...	...	...	13,800	12,670	1130	...	...	...	11,220	10,290	930	...	...	...

II. Soil and Situation—Good.																						
20	15	...	...	...	1400	210	1190	...	...	...	1120	170	950	...	...	...	910	140	770	...	...	...
30	24	2330	18·7	4·3	2620	1060	1560	400	...	400	2090	850	1240	320	...	320	1700	690	1010	260	...	260
40	34	1520	28·6	5·3	4120	2480	1640	450	310	140	3290	1980	1310	360	250	110	2670	1610	1060	290	200	90
50	46	1040	41·9	6·4	5700	4250	1530	530	300	230	4560	3400	1160	420	240	180	3690	2760	930	340	200	140
60	59	710	61·3	7·8	7580	6260	1320	620	440	180	6060	5000	1060	490	350	140	4920	4070	850	400	290	110
70	70	500	87·1	9·3	9210	7850	1360	730	590	140	7330	6280	1050	580	470	110	5980	5100	880	470	380	90
80	80	360	121·0	11·0	10,440	9150	1290	680	590	90	8350	7320	1030	540	470	70	6780	5950	830	440	380	60
90	89	290	150·2	12·2	11,560	10,300	1260	630	570	60	9240	8240	1000	500	450	50	7510	6690	820	410	370	40
100	93	260	165·2	12·8	12,530	11,330	1200	560	520	40	10,020	9060	960	450	420	30	8140	7360	780	360	340	30
110	102	250	174·2	13·2	13,360	12,270	1090	450	410	40	10,680	9810	870	360	330	30	8680	7970	710	290	270	20
120	106	240	181·5	13·4	14,170	13,040	1130	...	...	...	11,330	10,430	900	...	...	...	9210	8470	740	...	...	...
III. Soil and Situation—Medium.																						
20	9	...	...	...	850	...	850	...	...	...	680	...	680	...	...	...	550	...	550	..	...	...
30	16	3720	11·7	3·4	1580	140	1440	300	...	300	1260	110	1150	240	...	240	1030	90	940	195	...	195
40	25	2510	17·3	4·1	2500	890	1610	350	270	80	2000	710	1290	280	220	60	1630	580	1050	230	170	60
50	35	1620	26·9	5·1	3780	2290	1490	420	210	210	3020	1830	1190	340	170	70	2460	1490	970	270	130	140
60	47	1060	41·1	6·4	5240	3990	1250	500	340	160	4190	3190	1000	400	270	130	3410	2590	820	330	220	110
70	58	720	60·5	7·7	6700	5570	1130	550	410	140	5360	4460	900	440	330	110	4350	3620	730	360	260	100
80	68	450	96·8	9·8	7970	6840	1130	520	430	90	6370	5470	900	420	340	80	5180	4450	730	340	280	60
90	76	360	121·0	11·0	9030	7900	1130	470	410	60	7220	6320	900	380	330	50	5870	5140	730	310	260	50
100	83	310	140·5	11·8	9880	8780	1100	420	380	40	7900	7020	880	340	300	40	6420	5710	710	270	250	20
110	88	290	150·1	12·2	10,570	9520	1050	340	310	30	8460	7620	840	270	250	20	6870	6190	680	220	200	20
120	91	280	155·5	12·7	11,190	10,090	1100	...	...	...	8950	8070	880	...	...	...	7270	6560	710	...	...	...
IV. Soil and Situation—Inferior.																						
20	7	...	...	...	520	...	520	...	...	...	420	...	420	...	...	...	340	...	340	...	...	...
30	12	...	...	...	1020	...	1020	210	...	210	820	...	820	170	...	170	660	...	660	140	...	140
40	18	3480	12·5	3·1	1670	240	1430	240	...	240	1340	190	1150	190	...	190	1090	150	940	160	...	160
50	27	2150	20·2	4·5	2550	1130	1420	280	40	240	2040	900	1140	220	30	190	1660	730	930	180	30	150
60	37	1340	32·5	5·7	3650	2480	1170	320	140	180	2920	1980	940	260	110	150	2370	1610	760	210	90	120
70	46	890	48·9	7·0	4880	3820	1060	370	240	130	3900	3050	850	300	190	110	3170	2480	690	240	150	90
80	55	600	72·6	8·5	5920	4860	1060	350	250	100	4740	3880	860	280	200	80	3850	3160	690	230	160	70
90	63	430	101·3	10·0	6750	5690	1060	310	240	70	5400	4550	850	250	190	60	4390	3700	690	200	150	50
100	68	360	121·0	11·0	7430	6370	1060	290	230	60	5940	5100	840	230	180	50	4830	3950	880	190	150	40
110	72	340	128·1	11·3	8000	6940	1060	270	220	50	6400	5550	850	220	180	40	5200	4300	900	180	140	40
120	75	330	132·0	11·5	8500	7370	1130	...	...	...	6800	5890	910	...	...	...	5530	4790	740	...	...	...

[1] Spruce does not grow so well in Britain as in Central Germany, and the above yield is probably much above what could be here obtainable, especially from crops over 60 years in age.

Silver Fir.—Up to about 85 years of age the yield is a little below that of Spruce, but after that it is somewhat greater. **Silver Fir** does **not**, however, grow well in Britain after 70 years of age.—**Douglas Fir** and **Menzies Spruce** should yield considerably more than the above at all ages of the crop.

Beech (*after* Baur).

I. Soil and Situation—**Very Good.**

Age.	Mean timber-height (to 2¾ in. diameter *over bark*).	No. of trees per acre.	Average.		True cubic contents, *measured over bark.*						Cubic contents in British (*square-of-quarter-girth*) measurement *over bark.*						Cubic contents (British measure), with a reduction of 15 per cent for *bark allowance* (1/12th of girth).					
					Whole crop.			Removable as thinnings.			Whole crop.			Removable as thinnings.			Whole crop.			Removable as thinnings.		
			Growing-space per tree.	Distance from stem to stem.	Total quantity.	Timber only (3 in. diameter and above).	Faggot-wood (below 2¾ in. diameter).	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.	Total quantity.	Timber only.	Faggot-wood.
Years.	Feet.		Sq. ft.	Feet.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.
20	17	...	...	...	1130	230	900	170	...	170	910	180	730	140	...	140	740	150	590	110	...	110
30	33	...	...	...	2280	860	1420	280	...	280	1820	690	1130	230	...	230	1480	560	920	180	...	180
40	49	1380	31	5·6	3510	1960	1550	400	130	270	2810	1560	1250	320	100	220	2280	1270	1010	260	80	180
50	62	785	55	7·4	4790	3510	1280	500	300	200	3830	2810	1020	400	240	160	3110	2280	830	320	190	130
60	72	510	85	9·2	5980	5020	960	540	370	170	4780	4010	770	430	300	130	3890	3260	630	350	240	110
70	80	390	111	10·5	7110	6080	1030	540	450	90	5690	4860	830	430	360	70	4620	3950	670	350	290	60
80	86	330	132	11·4	8220	6960	1260	500	430	70	6570	5560	1010	400	340	60	5340	4520	820	320	280	40
90	93	290	152	12·3	9220	7810	1410	400	350	50	7380	6240	1140	320	280	40	5990	5070	920	260	230	30
100	99	260	167	12·9	10,210	8660	1550	340	300	40	8170	6920	1250	270	240	30	6640	5630	1010	220	190	30
110	102	225	193	13·9	11,110	9450	1660	280	250	30	8890	7560	1330	220	200	20	7220	6140	1080	180	170	10
120	106	195	223	14·9	11,910	10,160	1750	...	...	..	9530	8130	1400	...	...	...	7740	6600	1140	...	...	...

II. Soil and Situation—Good.

20	14	...	...	...	820	...	820	160	..	160	660	...	660	120	...	120	530	...	530	100	...	100
30	27	...	...	...	1620	650	970	240	...	240	1290	520	770	190	...	190	1050	420	630	160	...	160
40	41	1700	25	5·0	2650	1540	1110	340	30	310	2120	1240	880	270	20	250	1720	1000	720	220	20	200
50	54	980	44	6·6	3740	2750	990	400	200	200	2990	2200	790	320	160	160	2430	1790	640	260	130	130
60	63	655	66	8·1	4860	3870	990	430	300	130	3890	3090	800	340	240	100	3160	2510	650	280	190	90
70	70	450	96	9·8	5890	4700	1190	440	350	90	4720	3760	960	350	280	70	3830	3060	770	290	230	60
80	76	370	117	10·8	6830	5680	1150	410	350	60	5460	4540	920	330	280	50	4440	3690	750	270	230	40
90	83	310	140	11·8	7710	6460	1250	340	300	40	6170	5170	1000	270	240	30	5010	4200	810	220	190	30
100	88	275	158	12·5	8540	7210	1330	310	270	40	6830	5770	1060	250	220	30	5550	4690	860	200	175	25
110	92	250	174	13·2	9340	7920	1420	240	210	30	7470	6340	1130	190	170	20	6070	5150	920	160	150	10
120	95	225	193	13·9	10,100	8600	1500	...	...	...	8080	6880	1200	...	...	...	6570	5590	980	...	...	...

III. Soil and Situation—Medium.

20	10	...	...	...	570	...	570	130	...	130	450	...	450	100	...	100	370	...	370	85	...	85
30	20	...	...	...	1190	300	890	200	...	200	950	240	710	160	...	160	770	190	580	130	...	130
40	33	2060	21	4·6	1970	1050	920	260	...	260	1580	840	740	200	...	200	1290	680	610	170	...	170
50	46	1210	36	6·0	2750	2000	750	280	60	120	2200	1600	600	230	45	185	1790	1300	490	180	40	120
60	56	780	55	7·4	3560	2960	600	330	180	150	2840	2370	470	260	150	110	2310	1920	390	210	120	90
70	63	570	76	8·7	4390	3800	590	350	260	90	3510	3040	470	280	200	80	2850	2470	380	230	170	60
80	69	440	99	9·9	5170	4550	620	330	260	70	4140	3640	500	260	200	60	3360	2960	400	210	170	40
90	73	380	114	10·7	5950	5260	690	280	240	40	4760	4200	560	230	190	40	3870	3420	450	180	160	20
100	76	340	128	11·3	6690	5890	800	240	210	30	5350	4720	630	190	170	20	4350	3830	520	160	140	20
110	80	310	140	11·8	7370	6460	910	180	160	20	5890	5170	720	140	120	20	4790	4200	590	120	100	20
120	83	285	152	12·3	8030	6980	1050	...	...	...	6430	5590	840	...	...	...	5220	4540	680	...	...	...

IV. Soil and Situation—Inferior.

20	8	...	...	...	350	...	350	100	...	100	280	...	280	80	...	80	220	...	220	65	...	65
30	16	...	...	...	850	...	850	140	...	140	680	...	680	110	...	110	550	...	550	90	...	90
40	26	2750	15	3·9	1460	470	990	170	...	170	1170	370	800	140	...	140	950	300	650	110	...	110
50	36	1660	26	5·1	2070	1110	960	210	15	195	1660	880	780	170	15	155	1340	720	620	140	10	130
60	45	1090	40	6·3	2720	1810	910	240	70	170	2180	1450	730	190	60	130	1770	1180	590	160	50	110
70	51	785	55	7·4	3360	2480	880	260	140	120	2690	1980	710	200	110	90	2180	1610	570	170	90	80
80	58	575	75	8·7	3970	3120	850	230	160	70	3170	2490	680	180	120	60	2580	2030	550	150	100	50
90	62	465	93	9·6	4530	3750	780	200	160	40	3630	3000	630	160	120	40	2950	2440	510	130	100	30
100	65	390	111	10·5	5100	4340	760	...	...	...	4080	3470	610	...	...	...	3320	2820	500	...	...	...
110	68	340	128	11·3	...	...	...	...	...	..	...	...	...	...	...	...	...	...	...	...	...	...
120	72	300	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Oak (*after* Burckhardt, for Hanover).

Canopy (see remarks).	Height of crop, in feet.				
	85 to 105 ft. or more.	75 to 90 ft.	65 to 80 ft.	60 to 70 ft.	50 to 60 ft.
	True cubic contents in cubic feet (down to 2¾ in. top-diameter *over bark*) per acre.				
I. Full	7850-8610	6640-7270	5580-6190	4420-4900	3400-3880
II. Fairly good	6260-7010	5330-5950	4420-4900	3400-3880	2640-3120
III. Rather light	4960-5580	4050-4660	3400-3880	2640-3120	1900-2370
IV. Thin	4000-4600	3400-3880	2760-3240	2010-2490	1400-1760
	Cubic contents (cubic feet) by square-of-quarter-girth measurement (down to 2¾ in. diameter *over bark*).				
I. Full	6280-6890	5320-5810	4470-4950	3540-3920	2720-3110
II. Fairly good	5010-5610	4260-4760	3540-3020	2720-3110	2100-2490
III. Rather light	3970-4470	3240-3730	2720-3100	2110-2490	1520-1890
IV. Thin	3200-3680	2720-3110	2210-2600	1610-2000	1120-1410
	Cubic contents in square-of-quarter-girth measurement, but further reduced by 15 per cent for *bark-allowance*.				
I. Full	5100-5600	4320-4720	3630-4020	2870-3190	2210-2520
II. Fairly good	4070-4560	3460-3870	2870-3190	2210-2520	1710-2030
III. Rather light	3220-3630	2630-3030	1210-2520	1710-2030	1230-1540
IV. Thin	2600-2990	2210-2520	1800-2110	1310-1620	910-1140

The above Classification as to **Density of Canopy** is as follows :—

I. Includes full-canopied, good, mature crops that have grown up in normal leaf-canopy, and comprises what one would, in a general way, call very good canopy.

II. Includes mature crops growing in fairly good canopy, but not so good as Class I. It also comprises denser crops that are only approaching their full maturity, and the better classes of mature plantations originally formed on grazing land at distances of 14 to 16 ft. from plant to plant.

III. Includes wide plantations, or similar crops having large crowns forming a fair canopy, now mostly mature. It also comprises younger crops of the better class that have grown well in height, and are now partially cleared for the purpose of thickening more rapidly in girth.

IV. Includes thin crops of backward growth that are mature, and also old wide plantations having a broken canopy and poor annual increment.

The branchwood varies from 4 to 7 per cent of the total crop, and may even amount to about 10 per cent.

Burckhardt (1861) found that in the Hanoverian forests the **Average Annual Increment** in the timber crops (*here reduced to square-of-quarter-girth measurement*) was approximately as follows :—

Tree.	Quality of soil and situation.					Age at maturity.	
	I.	II.	III.	IV.	V.	I. and II.	IV. and V.
	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.	Years.	Years.
Oak Highwoods	50-56	45-50	37-45	34-37	28-32	160	120
Beech ,,	56-62	48-56	40-48	34-40	28-34	140 ; 120	90
Beech, with Spruce, &c.	...	...	...	45-50	40-45	...	100
Spruce	80-90	70-80	60-70	48-60	36-48	120	70
Scots Pine	60-70	45-60	37-45	30-36	21-30	120 ; 100	60
Birch Highwoods	64-72	50-60	35-40	18-25	12	60	40
Alder ,,	56-60	45-50	35-40	...	...	70	50
Birch Coppice	56-60	48-54	40-48	30-36	24-30	20	30
Alder ,,	70-75	60-63	45-55	30-36	18-24	25	35

For timber only, a further reduction of 12 per cent (=15 per cent of true cubic contents) is necessary as *bark-allowance*.

Oak Coppices, with 12 to 17 years' rotation (compiled by Bernhardt from various data).

Quality of Soil.	Dry bark.	Wood.	Remarks.
	Per acre and per annum.		
	Cwts.	Cubic feet (true contents).	
I. Very Good .	4	100	I. On a very good soil, and in a very favourable climate.
II. Good . .	3 to 3¼	85	II. Good soil, and good climate.
III. Medium .	2	70	III. Moderately good soil, and in climate of N.W. Germany.
IV. Inferior .	1½	56	IV. Good, fresh loamy-sandy soil, in climate of centre, N. and W. of Germany.
V. Poor . .	1 to 1¼	56	V. Fresh sandy soil, in climate of Northern Germany.

APPENDIX IV.—Tables of Compound Interest and Discount.

Table I.—The Summarised Future Value of a Capital (C) of 1, accumulating at Compound Interest for n years, the rate of Interest being p.

$$Cn = C \times 1{\cdot}0p^n.$$

,, II.—The Discounted Present Value of a Capital (Cn) of 1, to be realised n years hence, the rate of Interest being p.

$$C = \frac{Cn}{1{\cdot}0\,p^n}.$$

,, III.—The Discounted Present Value (C) of a Perpetual Periodic Rental or Return (R) of 1, obtainable every n years, the rate of Interest being p.

$$C = \frac{R}{1{\cdot}0p^n - 1}.$$

,, IV.—The Summarised Future Value (Cn) of an Annual Rental or Return (r) of 1, obtainable for n years in all, the rate of Interest being p.

$$Cn = \frac{r(1{\cdot}0\,p^n - 1)}{0{\cdot}0\,p}.$$

,, V.—The Discounted Present Value (C) of an Annual Rental or Return (r) of 1, obtainable for n years in all, the rate of Interest being p.

$$C = \frac{r(1{\cdot}0\,p^n - 1)}{1{\cdot}0\,p^n \times 0{\cdot}0\,p}.$$

Examples of the Use of the Tables :—

Table I.—A capital of 1 at 3 per cent in 20 years becomes 1·8061 ; therefore £100 would become $100 \times 1{\cdot}8061 = 180{\cdot}61$ = **£180, 12s. 2d.**

,, II.—A capital of 1 obtainable in 40 years has, at 3 per cent, a present value of only 0·3066 ; therefore £100 would only have a present value of $100 \times 0{\cdot}3066 = 30{\cdot}66$ = **£30, 13s. 2d.**

,, III.—A return of 1 due 10 years hence, and every 10 years after that, has at 4 per cent a present value of 2·0823; therefore a similar return of £20 (as, for example, the net income from a piece of coppice cut every 10 years) would have a present value of $20 \times 2{\cdot}0823 = 41{\cdot}646$ = **£41, 12s. 11d.**

,, IV.—A return of 1 obtainable for the next 20 years represents, at 3 per cent interest, 26·8704 at the end of that time ; therefore a hunt leasing a piece of woodland as a fox-covert for 20 years at a rental of £20 a year, will by the end of that time have paid a sum equal to $20 \times 26{\cdot}8704 = 537{\cdot}408$ = **£537, 8s. 2d.**

Note.—And conversely, this table can be used to ascertain the annual payment necessary to establish a Fund which will amount to a certain sum in n years, through dividing the capital by the final value

$$\left(r = \frac{C}{1{\cdot}0\,p^n - 1} \times 0{\cdot}0\,p\right).$$

For example, if £5000 are payable 20 years hence, what sum must be invested annually at 3 per cent to form a fund that will clear the debt then ? Here $r = 5000 \div 26{\cdot}8704 = 186{\cdot}07$ = **£186, 1s. 5d.**

,, V.—An annual return of 1 obtainable for the next 20 years has, at 3 per cent interest, a present value of 14·8775 ; therefore a rental of £20 a year payable by a hunt leasing a wood for 20 years as a fox-covert would, at 3 per cent, be equal to a present total payment of $20 \times 14{\cdot}8775 = 297{\cdot}55$ = **£297, 11s.**

Note.—And conversely, the annual sum required to liquidate within the course of n years a debt now incurred, is ascertained through dividing this sum by the present value as shown in this table

$$\left(r = C \times \frac{1{\cdot}0\,p^n \times 0{\cdot}0\,p}{1{\cdot}0\,p^n - 1}\right).$$

For example, if a debt of £5000 be now incurred, it can, reckoning 3 per cent interest, be gradually liquidated (along with the interest due on it) in 20 years by an annual payment of $r = 5000 \div 14{\cdot}8775 = 336{\cdot}077$ = **£336, 1s. 6d.**

TABLE I.—The Summarised Future Value of a Capital (C) of 1, accumulating at Compound Interest for n years, the rate of Interest being p.

$$C_n = C \times 1{\cdot}0\,p^n.$$

Years n.	Rate of interest (p) per cent. 2	2½	3	3½	4	4½	5
1	1·0200	1·0250	1·0300	1·0350	1·0400	1·0450	1·0500
2	1·0404	1·0506	1·0609	1·0712	1·0816	1·0920	1·1025
3	1·0612	1·0769	1·0927	1·1087	1·1249	1·1412	1·1576
4	1·0824	1·1038	1·1255	1·1475	1·1699	1·1925	1·2155
5	1·1041	1·1314	1·1593	1·1877	1·2167	1·2462	1·2763
6	1·1262	1·1597	1·1941	1·2293	1·2653	1·3023	1·3401
7	1·1487	1·1887	1·2299	1·2723	1·3159	1·3609	1·4071
8	1·1717	1·2184	1·2668	1·3168	1·3686	1·4221	1·4775
9	1·1951	1·2489	1·3048	1·3629	1·4233	1·4861	1·5513
10	1·2190	1·2801	1·3439	1·4106	1·4802	1·5530	1·6289
11	1·2434	1·3121	1·3842	1·4600	1·5395	1·6229	1·7103
12	1·2682	1·3449	1·4258	1·5111	1·6010	1·6959	1·7959
13	1·2936	1·3785	1·4685	1·5640	1·6651	1·7722	1·8856
14	1·3195	1·4130	1·5126	1·6187	1·7317	1·8519	1·9799
15	1·3459	1·4483	1·5580	1·6753	1·8009	1·9353	2·0789
16	1·3728	1·4845	1·6047	1·7340	1·8730	2·0224	2·1829
17	1·4002	1·5216	1·6528	1·7947	1·9479	2·1134	2·2920
18	1·4282	1·5597	1·7024	1·8575	2·0258	2·2085	2·4066
19	1·4568	1·5986	1·7535	1·9225	2·1068	2·3079	2·5269
20	1·4859	1·6386	1·8061	1·9898	2·1911	2·4117	2·6533
21	1·5157	1·6796	1·8603	2·0594	2·2788	2·5202	2·7860
22	1·5460	1·7216	1·9161	2·1315	2·3699	2·6337	2·9253
23	1·5769	1·7646	1·9736	2·2061	2·4647	2·7522	3·0715
24	1·6084	1·8087	2·0328	2·2833	2·5633	2·8760	3·2251
25	1·6406	1·8539	2·0938	2·3632	2·6658	3·0054	3·3864
26	1·6734	1·9003	2·1566	2·4460	2·7725	3·1407	3·5557
27	1·7069	1·9478	2·2213	2·5316	2·8834	3·2820	3·7335
28	1·7410	1·9965	2·2879	2·6202	2·9987	3·4297	3·9201
29	1·7758	2·0464	2·3566	2·7119	3·1187	3·5840	4·1161
30	1·8114	2·0976	2·4273	2·8068	3·2434	3·7453	4·3219
35	1·9999	2·3732	2·8139	3·3336	3·9461	4·6673	5·5160
40	2·2080	2·6851	3·2620	3·9593	4·8010	5·8164	7·0400
45	2·4379	3·0379	3·7816	4·7024	5·8412	7·2482	8·9850
50	2·6916	3·4371	4·3839	5·5849	7·1067	9·0326	11·4674
55	2·9717	3·8888	5·0821	6·6331	8·6464	11·2563	14·6356
60	3·2810	4·3998	5·8916	7·8781	10·5196	14·0274	18·6792
65	3·6225	4·9780	6·8300	9·3567	12·7987	17·4807	23·8399
70	3·9996	5·6321	7·9178	11·1128	15·5716	21·7841	30·4264
75	4·4158	6·3722	9·1789	13·1986	18·9453	26·1470	38·8327
80	4·8754	7·2096	10·6409	15·6757	23·0498	33·8301	49·5614
90	5·9431	9·2289	14·3005	22·1122	34·1193	52·5371	80·7304
100	7·2446	11·8137	19·2186	31·1914	50·5049	81·5885	131·5013
110	8·8312	15·1226	25·8282	43·9986	74·7597	126·7045	214·2017
120	10·7652	19·3581	34·7110	62·0643	110·6626	196·7682	348·9120
130	13·1227	24·7801	46·6486	87·5478	163·8076	305·5750	568·3409
140	15·9965	31·7206	62·6919	123·4949	242·4753	474·5486	925·7674
150	19·4996	40·6050	84·2527	174·2017	358·9227	736·9594	1507·978
160	23·7699	51·9779	113·2286	245·7287	531·2932	1144·475	2456·336
170	28·9754	66·5361	152·1697	346·6247	786·4438	1777·335	4001·113
180	35·3208	85·1718	204·5033	488·9484	1164·1289	2760·147	6517·392
190	43·0559	109·0271	274·8354	689·7100	1723·1912	4286·425	10616·14
200	52·4849	139·5639	369·3558	972·9039	2550·7498	6656·686	17292·58

TABLE II.—THE DISCOUNTED PRESENT VALUE OF A CAPITAL (C_n) of 1, to be realised n years hence, the rate of Interest being p.

$$C = \frac{C_n}{1{\cdot}0\,p^n}.$$

Years n.	Rate of interest (p) per cent. 2	2½	3	3½	4	4½	5
1	0·9804	0·9756	0·9709	0·9662	0·9615	0·9569	0·9524
2	0·9612	0·9518	0·9426	0·9335	0·9246	0·9157	0·9070
3	0·9423	0·9286	0·9151	0·9019	0·8890	0·8763	0·8638
4	0·9238	0·9060	0·8885	0·8714	0·8548	0·8386	0·8227
5	0·9057	0·8839	0·8626	0·8420	0·8219	0·8025	0·7835
6	0·8880	0·8623	0·8375	0·8135	0·7903	0·7679	0·7462
7	0·8706	0·8413	0·8131	0·7860	0·7599	0·7348	0·7107
8	0·8535	0·8207	0·7894	0·7594	0·7307	0·7032	0·6768
9	0·8368	0·8007	0·7664	0·7337	0·7026	0·6729	0·6446
10	0·8203	0·7812	0·7441	0·7089	0·6756	0·6439	0·6139
11	0·8043	0·7621	0·7224	0·6849	0·6496	0·6162	0·5847
12	0·7885	0·7436	0·7014	0·6618	0·6246	0·5897	0·5568
13	0·7730	0·7254	0·6810	0·6394	0·6006	0·5643	0·5303
14	0·7579	0·7077	0·6611	0·6178	0·5775	0·5400	0·5051
15	0·7430	0·6905	0·6419	0·5969	0·5553	0·5167	0·4810
16	0·7284	0·6736	0·6232	0·5767	0·5339	0·4945	0·4581
17	0·7142	0·6572	0·6050	0·5572	0·5134	0·4732	0·4363
18	0·7002	0·6412	0·5874	0·5384	0·4936	0·4528	0·4155
19	0·6864	0·6255	0·5703	0·5202	0·4746	0·4333	0·3957
20	0·6730	0·6103	0·5537	0·5026	0·4564	0·4146	0·3769
21	0·6598	0·5954	0·5375	0·4856	0·4388	0·3968	0·3589
22	0·6468	0·5809	0·5219	0·4692	0·4220	0·3797	0·3418
23	0·6342	0·5667	0·5067	0·4533	0·4057	0·3633	0·3256
24	0·6217	0·5529	0·4919	0·4380	0·3901	0·3477	0·3101
25	0·6095	0·5394	0·4776	0·4231	0·3751	0·3327	0·2953
26	0·5976	0·5262	0·4637	0·4088	0·3607	0·3184	0·2812
27	0·5859	0·5134	0·4502	0·3950	0·3468	0·3047	0·2678
28	0·5744	0·5009	0·4371	0·3817	0·3335	0·2916	0·2551
29	0·5631	0·4887	0·4243	0·3687	0·3207	0·2790	0·2429
30	0·5521	0·4767	0·4120	0·3563	0·3083	0·2670	0·2314
35	0·5000	0·4214	0·3554	0·3000	0·2534	0·2143	0·1813
40	0·4529	0·3724	0·3066	0·2526	0·2083	0·1719	0·1420
45	0·4102	0·3292	0·2644	0·2127	0·1712	0·1380	0·1113
50	0·3715	0·2909	0·2281	0·1791	0·1407	0·1107	0·0872
55	0·3365	0·2572	0·1968	0·1508	0·1157	0·0888	0·0683
60	0·3048	0·2273	0·1697	0·1269	0·0951	0·0713	0·0535
65	0·2760	0·2009	0·1464	0·1069	0·0781	0·0572	0·0419
70	0·2500	0·1776	0·1263	0·0900	0·0642	0·0459	0·0329
75	0·2265	0·1569	0·1089	0·0758	0·0528	0·0368	0·0258
80	0·2051	0·1387	0·0940	0·0638	0·0434	0·0296	0·0202
90	0·1683	0·1084	0·0699	0·0452	0·0293	0·0190	0·0124
100	0·1380	0·0847	0·0520	0·0321	0·0198	0·0123	0·0076
110	0·1132	0·0661	0·0387	0·0227	0·0134	0·0079	0·0047
120	0·0929	0·0517	0·0288	0·0161	0·0090	0·0051	0·0029
130	0·0762	0·0404	0·0214	0·0114	0·0061	0·0033	0·0018
140	0·0625	0·0315	0·0159	0·0081	0·0041	0·0021	0·0011
150	0·0513	0·0246	0·0119	0·0057	0·0028	0·0014	0·0007
160	0·0421	0·0192	0·0088	0·0041	0·0019	0·0009	0·0004
170	0·0345	0·0150	0·0066	0·0029	0·0013	0·0006	0·00025
180	0·0283	0·0117	0·0049	0·0020	0·0009	0·0004	0·00015
190	0·0232	0·0092	0·0036	0·0015	0·0006	0·0002	0·00009
200	0·0191	0·0072	0·0027	0·0010	0·0004	0·00015	0·00006

TABLE III.—THE DISCOUNTED PRESENT VALUE OF A PERPETUAL PERIODIC RENTAL OR RETURN (R) of 1, obtainable every n years, the rate of Interest being p.

$$C = \frac{R}{1{\cdot}0\,p^n - 1}.$$

Years. n.	Rate of interest (p) per cent. 2	2½	3	3½	4	4½	5
1	50·0000	40·0000	33·3333	28·5714	25·0000	22·2222	20·0000
2	24·7525	19·7531	16·4204	14·0400	12·2549	10·8666	9·7561
3	16·3377	13·0055	10·7843	9·1981	8·0087	7·0839	6·3442
4	12·1312	9·6327	7·9676	6·7786	5·8873	5·1943	4·6402
5	9·6079	7·6099	6·2785	5·3280	4·6157	4·0620	3·6195
6	7·9263	6·2620	5·1533	4·3620	3·7690	3·3084	2·9403
7	6·7256	5·2998	4·3502	3·6727	3·1652	2·7711	2·4564
8	5·8255	4·5787	3·7485	3·1565	2·7132	2·3691	2·0944
9	5·1258	4·0183	3·2811	2·7556	2·3623	2·0572	1·8138
10	4·5663	3·5703	2·9077	2·4355	2·0823	1·8084	1·5901
11	4·1089	3·2042	2·6026	2·1741	1·8537	1·6055	1·4078
12	3·7280	2·8995	2·3487	1·9567	1·6638	1·4370	1·2565
13	3·4059	2·6419	2·1343	1·7732	1·5036	1·2950	1·1291
14	3·1301	2·4215	1·9509	1·6163	1·3667	1·1738	1·0205
15	2·8913	2·2307	1·7922	1·4807	1·2485	1·0692	0·9268
16	2·6825	2·0640	1·6537	1·3624	1·1455	0·9781	0·8454
17	2·4985	1·9171	1·5317	1·2584	1·0550	0·8982	0·7740
18	2·3351	1·7868	1·4236	1·1662	0·9748	0·8275	0·7109
19	2·1891	1·6704	1·3271	1·0840	0·9035	0·7646	0·6549
20	2·0578	1·5659	1·2405	1·0103	0·8395	0·7084	0·6049
21	1·9392	1·4715	1·1624	0·9439	0·7820	0·6578	0·5599
22	1·8316	1·3859	1·0916	0·8838	0·7300	0·6121	0·5194
23	1·7334	1·3079	1·0271	0·8291	0·6827	0·5707	0·4827
24	1·6436	1·2365	0·9682	0·7792	0·6397	0·5330	0·4494
25	1·5610	1·1710	0·9143	0·7335	0·6003	0·4986	0·4190
26	1·4850	1·1107	0·8646	0·6916	0·5642	0·4671	0·3913
27	1·4147	1·0551	0·8188	0·6529	0·5310	0·4382	0·3658
28	1·3495	1·0035	0·7764	0·6172	0·5003	0·4116	0·3424
29	1·2889	0·9556	0·7372	0·5842	0·4720	0·3870	0·3209
30	1·2325	0·9111	0·7006	0·5535	0·4458	0·3643	0·3010
35	1·0001	0·7282	0·5513	0·4285	0·3394	0·2727	0·2214
40	0·8278	0·5934	0·4421	0·3379	0·2631	0·2076	0·1656
45	0·6955	0·4907	0·3595	0·2701	0·2066	0·1600	0·1252
50	0·5912	0·4103	0·2955	0·2181	0·1638	0·1245	0·0955
55	0·5072	0·3462	0·2450	0·1775	0·1308	0·0975	0·0733
60	0·4384	0·2941	0·2044	0·1454	0·1050	0·0768	0·0566
65	0·3813	0·2514	0·1715	0·1197	0·0848	0·0607	0·0438
70	0·3334	0·2159	0·1446	0·0989	0·0686	0·0481	0·0340
75	0·2928	0·1861	0·1223	0·0820	0·0557	0·0382	0 0264
80	0·2580	0·1610	0·1037	0·0681	0·0454	0·0305	0·0206
90	0·2023	0·1215	0·0752	0·0474	0·0302	0·0194	0·0125
100	0·1601	0·0925	0·0549	0·0331	0·0202	0·0124	0·0077
110	0·1277	0·0708	0·0403	0·0233	0·0136	0·0080	0·0047
120	0·1024	0·0545	0·0297	0·0164	0·0091	0·0051	0·0029
130	0·0825	0·0421	0·0219	0·0116	0·0061	0·0033	0·0018
140	0·0667	0·0326	0·0162	0·0082	0·0041	0·0021	0·0011
150	0·0541	0·0253	0·0120	0·0058	0·0028	0·0014	0·0007
160	0·0439	0·0196	0·0089	0·0041	0·0019	0·0009	0·0004
170	0·0358	0·0153	0·0066	0·0029	0·0013	0·0006	0·00025
180	0·0291	0·0119	0·0049	0·00205	0·00086	0·00036	0·00015
190	0·0238	0·0093	0·0036	0·00145	0·00058	0·00023	0·00009
200	0·0194	0·0072	0·0027	0·00103	0·00039	0 00015	0·00006

TABLE IV.—The Summarised Future Value of an Annual Rental or Return (r) of 1, obtainable for n years in all, the rate of Interest being p.

$$C_n = \frac{r(1{\cdot}0\,p^n - 1)}{0{\cdot}0p}.$$

Years. n.	Rate of interest (p) per cent.						
	2	2½	3	3½	4	4½	5
1	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000	1·0000
2	2·0200	2·0250	2·0300	2·0350	2·0400	2·0450	2·0500
3	3·0604	3·0756	3·0909	3·1062	3·1216	3·1370	3·1525
4	4·1216	4·1525	4·1836	4·2149	4·2465	4·2782	4·3101
5	5·2040	5·2563	5·3091	5·3625	5·4163	5·4707	5·5256
6	6·3081	6·3877	6·4684	6·5502	6·6330	6·7169	6·8019
7	7·4343	7·5474	7·6625	7·7794	7·8983	8·0192	8·1420
8	8·5830	8·7361	8·8923	9·0517	9·2142	9·3800	9·5491
9	9·7546	8·9545	10·1591	10·3685	10·5828	10·8021	11·0266
10	10·9497	11·2034	11·4639	11·7314	12·0061	12·2882	12·5779
11	12·1687	12·4835	12·8078	13·1420	13·4864	13·8412	14·2068
12	13·4121	12·7956	14·1920	14·6020	15·0258	15·4640	15·9171
13	14·6803	15·1404	15·6178	16·1130	16·6268	17·1599	17·7130
14	15·9739	16·5190	17·0863	17·6770	18·2919	18·9321	19·5986
15	17·2934	17·9319	18·5989	19·2957	20·0236	20·7841	21·5786
16	18·6393	19·3802	20·1569	20·9710	21·8245	22·7193	23·6575
17	20·0121	20·8647	21·7616	22·7050	23·6975	24·7417	25·8404
18	21·4123	22·3863	23·4144	24·4997	25·6454	26·8551	28·1324
19	22·8406	23·9460	25·1169	26·3572	27·6712	29·0636	30·5390
20	24·2974	25·5447	26·8704	28·2797	29·7781	31·3714	33·0660
21	25·7833	27·1833	28·6765	30·2695	31·9692	33·7831	35·7193
22	27·2990	28·8629	30·5368	32·3289	34·2480	36·3034	38·5052
23	28·8450	30·5844	32·4529	34·4604	36·6179	38·9370	41·4305
24	30·4219	32·3490	34·4265	36·6665	39·0826	41·6892	44·5020
25	32·0303	34·1578	36·4593	38·9499	41·6459	44·5652	47·7271
26	33·6709	36·0117	38·5530	41·3131	44·3117	47·5706	51·1135
27	35 3443	37·9120	40·7096	43·7591	47·0842	50·7113	54·6691
28	37·0512	39·8598	42·9309	46·2906	49·9676	53·9933	58·4026
29	38·7922	41·8563	45·2189	48·9108	52·9663	57·4230	62·3227
30	40·5681	43·9027	47·5754	51·6227	56·0849	61·0071	66·4388
35	49·9945	54·9282	60·4621	66·6740	73·6522	81·4966	90·3203
40	60·4020	67·4026	75·4013	84·5503	95·0255	107·030	120·800
45	71·8927	81·5161	92·7199	105·782	121·029	138·850	159·700
50	84·5794	97·4843	112·797	130·998	152·667	178·503	209·348
55	98·5865	115·551	136·072	160·947	191·159	227·918	272·713
60	114·052	135·992	163·053	196·517	237·991	289·498	353·584
65	131·126	159·118	194·333	238·763	294·968	366·238	456·798
70	149·988	185·284	230·594	288·938	364·290	461·870	588·529
75	170·792	214·888	272·631	348·530	448·631	581·044	756·654
80	193·772	248·383	321·363	419·307	551·245	729·558	971·229
90	247·157	329·154	443·349	603·205	827·983	1145·27	1594·61
100	312·232	432·549	607·288	862·612	1237·62	1790·86	2610·03
110	391·559	564·902	827·608	1228·53	1843·99	2793·43	4264·03
120	488·258	734·326	1123·70	1774·69	2741·56	4350·40	6958·24
130	606·134	951·203	1521·62	2472·80	4070·19	6768·33	11346·8
140	749·823	1228·82	2056·40	3499·85	6036·88	10523·3	18495·3
150	924·980	1584·20	2775·09	3948·62	8948·07	16354·7	30139·6
160	1138·50	2039·11	3740·95	6992·25	13257·3	25410·6	49106·7
170	1398·77	2621·44	5038·99	9874·99	19636·1	39474·1	80002·3
180	1716·04	3366·87	6783·45	13941·4	29078·2	61314·4	130328
190	2102·79	4321·08	9127·85	19677·4	43054·9	95231·7	212303
200	2574·24	5542·55	12278·5	27768·7	63743·8	147904	345832

TABLE V.—THE DISCOUNTED PRESENT VALUE OF AN ANNUAL RENTAL OR RETURN (r) of 1, obtainable for n years in all, the rate of Interest being p.

$$C = \frac{r(1{\cdot}0\,p^n - 1)}{1{\cdot}0\,p^n \times 0{\cdot}0\,p}.$$

Years. n.	Rate of interest (p) per cent.						
	2	2½	3	3½	4	4½	5
1	0·9804	0·9756	0·9709	0·9662	0·9615	0·9569	0·9524
2	1·9416	1·9274	1·9135	1·8997	1·8861	1·8727	1·8594
3	2·8839	2·8560	2·8286	2·8016	2·7751	2·7490	2·7232
4	3·8077	3·7620	3·7171	3·6731	3·6299	3·5875	3·5460
5	4·7135	4·6458	4·5797	4·5151	4·4518	4·3900	4·3295
6	5·6014	5·5081	5·4172	5·3286	5·2421	5·1579	5·0757
7	6·4720	6·3494	6·2303	6·1145	6·0021	5·8927	5·7864
8	7·3255	7·1701	7·0197	6·8740	6·7327	6·5959	6·4632
9	8·1622	7·9709	7·7861	7·6077	7·4353	7·2688	7·1078
10	9·9826	8·7521	8·5302	8·3166	8·1109	7·9127	7·7217
11	9·7869	9·5142	9·2526	9·0016	8·7605	8·5289	8·3064
12	10·5753	10·2578	9·9540	9·6633	9·3851	9·1186	8·8633
13	11·3484	10·9832	10·6350	10·3027	9·9857	9·6829	9·3936
14	12·1062	11·6909	11·2961	10·9205	10·5631	10·2228	9·8986
15	12·8493	12·3814	11·9379	11·5174	11·1184	10·7395	10·3797
16	13·5777	13·0550	12·5611	12·0941	11·6523	11·2340	10·8378
17	14·2919	13·7122	13·1661	12·6513	12·1657	11·7072	11·2741
18	14·9920	14·3534	13·7535	13·1897	12·6593	12·1600	11·6896
19	15·6785	14·9789	14·3238	13·7098	13·1339	12·5933	12·0853
20	16·3514	15·5892	14·8775	14·2124	13·5903	13·0079	12·4622
21	17·0112	16·1845	15·4150	14·6980	14·0292	13·4047	12·8212
22	17·6580	16·7654	15·9369	15·1671	14·4511	13·7844	13·1630
23	18·2922	17·3321	16·4436	15·6204	14·8568	14·1478	13·4886
24	18·9139	17·8850	16·9355	16·0584	15·2470	14·4955	13·7986
25	19·5235	18·4244	17·4131	16·4815	15·6221	14·8282	14·0939
26	20·1210	18·9506	17·8768	16·8904	15·9828	15·1466	14·3752
27	20·7069	19·4640	18·3270	17·2854	16·3296	15·4513	14·6430
28	21·2813	19·9649	18·7641	17·6670	16·6631	15·7429	14·8981
29	21·8444	20·4535	19·1885	18·0358	16·9837	16·0219	15·1411
30	22·3965	20·9303	19·6004	18·3920	17·2920	16·2889	15·3725
35	24·9986	23·1452	21·4872	20·0007	18·6646	17·4610	16·3742
40	27·3555	25·1028	23·1148	21·3551	19·7928	18·4016	17·1591
45	29·4902	26·8330	24·5187	22·4955	20·7200	19·1563	17·7741
50	31·4236	28·3623	25·7298	23·4556	21·4822	19·7620	18·2559
55	33·1748	29·7140	26·7744	24·2641	22·1086	20·2480	18·6335
60	34·7609	30·9087	27·6756	24·9447	22·6235	20·6380	18·9293
65	36·1975	31·9646	28·4529	25·5178	23·0467	20·9510	19·1611
70	37·4986	32·8979	29·1234	26·0004	23·3945	21·2021	19·3427
75	38·6771	33·7227	29·7018	26·4067	23·6804	21·4036	19·4850
80	39·7445	34·4518	30·2008	26·7488	23·9154	21·5653	19·5965
90	41·5869	35·6658	31·0024	27·2793	24·2673	21·7992	19·7523
100	43·0984	36·6141	31·5989	27·6554	24·5050	21·9499	19·8479
110	44·3382	37·3549	32·0428	27·9221	24·6656	22·0468	19·9066
120	45·3554	37·9337	32·3730	28·1111	24·7741	22·1093	19·9427
130	46·1898	38·3858	32·6188	28·2451	24·8474	22·1495	19·9648
140	46·8743	38·7390	32·8016	28·3401	24·8969	22·1754	19·9784
150	47·4358	39·0149	32·9377	28·4074	24·9303	22·1921	19·9867
160	47·8965	39·2304	33·0389	28·4552	24·9529	22·2028	19·9199
170	48·2744	39·3988	33·1143	28·4890	24·9682	22·2097	19·9950
180	48·5844	39·5304	33·1703	28·5130	24·9785	22·2142	19·9969
190	48·8387	39·6331	32·2120	28·5300	24·9855	22·2170	19·9981
200	49·0473	39·7134	33·2431	28·5421	24·9902	22·2189	19·9988

PART VI.

THE UTILISATION OF WOODLAND PRODUCE.

BRITISH LITERATURE.

Brown and Nisbet, *The Forester*, 6th edit., 1894, vol. ii., chapter xi. K. Gayer, *Forest Utilization* (trans. by W. R. Fisher, as vol. v. of Schlich's *Manual of Forestry*, 1896).

Parts of this subject are dealt with by G. S. Boulger, *Wood*, 1902; P. Charpentier, *Timber* (trans. by J. Kennell, 1894); T. Laslett, *Timber and Timber Trees* (2nd edit., by H. Marshall Ward, 1894); and also in various articles in the *Transactions of the Highland and Agricultural Society of Scotland*, the *Transactions of the Royal Scottish Arboricultural Society*, the *Journal of the Royal Agricultural Society of England*, the *Transactions of the Royal English Arboricultural Society*, the *Timber Trades Journal*, and other technical publications.

CHAPTER I.

THE TECHNICAL PROPERTIES OF TIMBER.

THE wood produced by the various kinds of trees, growing under suitable conditions as to climate, soil, and environment, is characterised by definite generic and specific differences, which determine its technical properties as **timber** (see pp. 292, 453), and its suitability for practical uses.

These **Technical Properties** are immediately dependent on the **anatomical structure** and the **chemical composition** of the wood, and they may be classed in three groups, according to (1) **Outward Appearance**, (2) **Material Condition**, and (3) **Relation towards External Influences** (see p. 432).

As regards **Anatomical Structure**, the ligneous portions of trees consist chiefly of **woody fibres**, together with **wood-vessels** and also **wood-cells** (except in the case of some Conifers).

The **woody fibres** are elongated and pointed at both ends, and have thickened walls, the thickening being sometimes so great that the central interstices or *lumina* are much diminished in size. The two main characteristic forms of woody fibres are **sclerenchyma** or "hard tissue," which are thick-walled fibres, whose walls are dotted with small pits, and **tracheids**, or tubes with large internal spaces (*lumina*), whose walls are dotted with large bordered pits ; but there is also a third or subordinate form of wood-fibre, shaped like the true hard tissue, and filled with protoplasm, starch, and similar matters.

The **wood-vessels** are long narrow tubes, closed at both ends, with thin walls and large lumina. On making a transverse section of any stem or branch, these vessels are seen as **pores**.

The **wood-cells** which form the **parenchyma** or "soft tissue" are somewhat thin-walled and more or less cubical cells, mostly with flattened ends. They are chiefly found near the vessels, where they are built up one above the other, and they serve for the storage of reserve nutrients (starch, glucose, &c.) to be used in forming leaves, flowers, &c., whereas the conveyance of water and sap takes place through the sclerenchyma, the tracheids, and the vessels.

There are, however, important differences between **broad-leaved trees** and **Conifers** with regard to the anatomical structure of their wood. That of broad-leaved trees is formed of all three kinds of woody fibres, and the hard tissue has walls which are much thicker than those of the tracheids or the subordinate form of fibre ; and the greater the proportion of hard tissue, of course the heavier, the harder, and the stronger is the wood produced. The hard tissue forms the bulk of the summer zone of wood ; and the broader the annual zone formed, the larger the proportion of hard tissue, and the denser, heavier, and more durable the wood for each different kind of broad-leaved tree. The wood of Conifers, on the other hand, consists only of tracheid fibres. Those formed during the spring have thin walls and large lumina, whereas the others produced during the warmer summer period have thicker walls and are more compressed, through the lumina becoming contracted. Again, in Conifers vessels are only formed around the pith, so that on a transverse section being made pores can only be seen there ; whereas in broad-leaved trees each annual ring of wood contains a greater or less number of vessels, the number, distribution, and appearance of which form characteristic generic and specific differences between the various kinds of trees. Thus the pores appearing on a transverse section are often found distributed in definite bands or in wavy lines, and to wood of this class (*e.g.*, Oak, Ash, Elm, Sweet-Chestnut, Robinia, &c.) the name *ring-pored* has been given. In the spring zone the pores are often considerably larger than in the summer or autumn zone of the annual ring, and in such cases the autumn wood is of course much the denser and heavier part of the ring.

In broad-leaved trees the soft tissue formed of wood-cells is chiefly to be found near the vessels, though it sometimes (*e.g.*, in Oak) appears as a lighter-coloured zone in the dark, dense, hard autumn wood. In Conifers, however, the wood-cells, when formed at all, are either to be found only around the resin-ducts (*e.g.*, in the *Abietineæ*), or sparsely scattered throughout the tracheids (*e.g.*, Juniper).

Both broad-leaved and coniferous trees have **medullary rays** formed of wood-cells, which extend radially from the bark to the pith, or to some annual ring near the pith. These medullary rays, which serve partly for the winter storage of reserve nutrients, vary greatly in number as well as in length, height, and breadth—as may be seen in making respectively a *transverse*, a *radial*, and a *tangential* section of any stem; and their number and size affect considerably the technical properties of the wood. In Conifers they are so narrow and close together as to give a sort of silky gloss to any very thin transverse section. They are largest of all in Oak, as may be seen in the "flowering" of panels or slabs.

In addition to having many smaller rays, Oak and Alder have the *highest* medullary rays, and Oak and Beech the *broadest*. Those of Ash, Elm, Maple, Sycamore, Plane, and Hornbeam are fairly broad, and those of Alder, Birch, Sweet-Chestnut and Horse-Chestnut, Lime, Robinia, Cherry, and Hazel are narrow, while those of Willows and Poplars are so narrow as to be almost indistinguishable by the naked eye.

The wood of Conifers is further differentiated from that of broad-leaved trees by **resin-ducts** or tubular spaces surrounded by resiniferous cells. but without having definitely constructed walls. These resin-ducts are not only to be found running longitudinally throughout the stem and branches, and mostly in the summer zone of each annual ring, as may be seen on a transverse section, but also occur along the medullary rays. Both of these two kinds of resin-ducts communicate with each other, and the quantity of resin produced and stored up within the wood has a considerable influence on its technical properties.

The width of the **annual ring**, the uniformity or differences in its breadth from year to year, and the relative breadth of the spring and the summer zones of each ring, are also of great importance with regard to the technical properties of the wood of any tree. In most kinds of trees the annual rings are fairly well marked by the difference in density between the summer zone and the spring zone of the following year's ring ; and this distinction is clearest of all in the wood of Conifers, and in the ring-pored trees. But when the pores in broad-leaved trees are fairly evenly distributed throughout both zones of the annual ring (*e.g.*, as in Maple and Sycamore, Hornbeam, Willow, Poplar, Birch, Alder, Lime, and Horse-Chestnut), it is then often difficult to distinguish and count the annual rings.[1]

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[1] In making borings with Pressler's Increment-gauge to determine the rate of growth of such trees (see Part V. p. 325), the counting is facilitated by brushing the spill lightly with a weak solution of aniline or permanganate of potash in alcohol.

Sometimes **false-rings** are partially or even completely formed as the result of damage to the foliage by frost, drought, or insects, which occasions interruptions of the normal tension throughout the cambial layer; but such false-rings are far rarer in this than in warmer climates.

The **width** of the annual rings depends mainly on the suitability of the soil and situation for the given tree, and on the amount and intensity of light to which the foliage is exposed during the annual period of active vegetation. Suitability of soil and situation is no doubt the chief factor, because, without favourable conditions of soil and atmosphere, mere intensity of sunlight will not of itself produce rapid growth of wood and broad annual rings. But, other things being equal, the deeper, fresher, and more fertile the soil, the greater the general vitality, the longer the annual period of active vegetation, and the more the crowns and branches of the trees are exposed to bright sunshine, the broader is the ring formed each year. And of course any sylvicultural measure, such as thinning or partial clearance, which provides the crowns of trees with increased enjoyment of sunlight is directly followed by an increase in the breadth of the annual rings formed during the next few years—provided always that the tree-crops are not already too old or enfeebled to respond to the stimulus of increased exposure to light and air. The broadest rings are formed during damp but warm years, when the denser summer zone is especially broader than during dry seasons. And of course anything that tends to check the activity of vegetation, such as a crowded condition of the crop, a heavy seed-year, frost, drought, attacks on foliage by insects or fungous diseases, &c., likewise affects the breadth of the annual ring.

The annual rings are usually broader in young and in middle-aged than in older trees. They are seldom of anything like equal breadth all round the axis of the stem, the roots, and the branches, and this eccentricity is often very marked. On hillsides the longer radius is generally on the side facing downwards, but otherwise it is usually on the warm southern side.

The broadest rings are always formed at the base of the stem to ensure its support, and thus the trunks of trees have always a more or less thickened or buttressed appearance just above the ground. So long as the trees have a large and free growing-space the stem distinctly tapers from below upwards, the annual rings being either about uniformly broad throughout, or else somewhat broader below than above. But in young woods growing in close canopy, so long as the struggle for individual existence finds its chief expression in energetic growth in height, the annual rings formed in the upper portions of the trees are broader than those lower down. On dominated poles (true thinnings) the annual rings are also broader above than below, owing to the relatively small quantity of sap which can be elaborated by the sparse foliage in the subdued light.

Uniformity in the breadth of successive annual rings and a **relatively broad and dense summer zone**, as compared with the more porous or less thickened spring zone, enhance the technical qualities of wood. These favourable conditions far more than counterbalance any little disadvantage due to mere eccentricity arising from continuous difference in the breadth of the woody rings annually superposed upon the stem and branches.

As regards **Chemical Composition**, green, freshly-felled wood consists of the **woody substance** and the **sap**. The framework of the **woody substance** forming the walls of the woody fibres, vessels, and cells is composed of **cellulose**, which undergoes transformation by a process termed **lignification**. Pure cellulose ($C_6H_{10}O_5$) consists of 44·14 per cent carbon, 6·17 per cent hydrogen, and 49·39 per cent oxygen, but the lignified tissue contains more carbon and less oxygen than cellulose, and in addition contains nitrogen and mineral constituents. The elementary composition of the dry woody substance varies slightly, as it consists[1] of from 49·5 to 51·5 per cent carbon, 6·0 to 6·8 per cent hydrogen, 42·0 to 44·0 per cent oxygen, 0·1 to 0·3 per cent nitrogen, and 0·1 to 1·0 per cent ash.

It was formerly supposed that the cellulose itself remained unchanged, and was merely incrusted and impregnated with some nitrogenous substance, to which the name *lignin* was given. Recent investigations have shown, however, that in the lignified cell-wall several carbohydrates of the character of cellulose are to be found, which differ from each other in the resistance they offer to the action of weak solutions of mineral acids, alkaline ferments, and oxidising agencies.[2] But besides these subordinate forms of cellulose, another substance is contained in the lignified tissues, which is still known as **lignin**; and as it is supposed that such lignin substances unite with the different kinds of cellulose to form æther-like combinations, they are classed as **ligno-cellulose**. The composition of lignin is not yet definitely known. It seems to be a variable mixture of different substances, and it gives certain characteristic reactions, which can be applied to determine ligneous tissue. Approximately, however, the dry woody substance of our woodland trees consists of from 47 to 62 per cent cellulose, and 38 to 53 per cent lignin. Cellulose is elastic and permeable for fluids, while lignin is stiff, hard, and less hygroscopic (see also p. 580).

Pure cellulose is white and silky, translucent and hygroscopic, and without taste or smell; but it is never found pure in any plant. The nearest approach to pure cellulose in plants is found in raw cotton, in the pith of certain plants, and in young cells generally; but in these two latter cases a gradual process of lignification takes place with the growth of the plant.

The **sap** in plants consists of water, in which organic and mineral substances are partly held in solution, and partly suspended. The quantity of water in freshly-felled, green wood usually varies from about 25 to 50 per cent, and even exceptionally from under 20 to over 60 per cent; but it is liable to considerable differences, according to the kind of tree and its age, the soil and situation on which it is grown, the state of the weather, and even the time of the day or night. Timber that is floated contains on the average about 60 per cent of water.

No great differences can be proved in the quantity of water contained in hardwoods and softwoods as forming separate classes of trees, as the following figures for green wood show (Schwackhöfer, *op. cit.*, p. 290):—

Hornbeam	20 per cent of water	*Note.*—After seasoning, wood on the average still consists of water to the extent of from 8 to 12 per cent of its weight.
Maple, Sycamore, Ash, Birch	25-30 ,, ,,	
Oak, Beech, Silver Fir, Scots Pine	35-40 ,, ,,	
Alder, Spruce	40-45 ,, ,,	
Lime, Larch, Black Poplar	45-50 ,, ,,	

The older the wood in a tree, the less the percentage of water it contains. Thus the percentage according to weight is smaller in the heartwood than in the middle portion of the stem, and smaller in the middle part than in the sapwood. But the quantity of water contained of course varies according to (1) *the species of tree;* (2) *the portion of the tree;* (3) *the nature of the soil and situation;* and (4) *the time of the year at which the tree is felled.*

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[1] F. Schwackhöfer, *Forstlich-chemische Technologie*, in Lorey's *Handbuch der Forstwissenschaft*, 2nd edit., 1903, vol. ii. p. 287.

[2] The kind which offers the strongest resistance is *Dextroso-cellulose*, or true cellulose. This forms the bulk of the cellulose in trees, and it is only in broad-leaved trees that large quantities (up to 20 per cent) of the more easily affected kinds of cellulose are to be found. This partly explains why broad-leaved trees are on the whole less suitable than Conifers for preparing cellulose, and why they also usually give a smaller out-turn in prepared material.

A fair idea may be formed of the difference in weight due to the moisture contained in British timber by the following facts (Mackenzie ; see also p. 438) :—

One ton weight consists, on the average, of			
Kind of timber.		In the green rough state with the bark on.	After being sawn up and seasoned.
		Cubic feet.	Cubic feet.
Larch . .	Young trees . .	30-32	70-80
	Old ,, . .	32-34	56-70
Scots Pine .	Young ,, . .	26-28	72-80
	Old ,, . .	28-30	52-68
Spruce . .	Young ,, . .	29-31	80-86
	Old ,, . .	32-35	70-80

The quantity of water contained in the wood is usually greatest in spring, when the flow of the sap is most active, and least in autumn.[1] During bright sunshine it diminishes gradually till about 2 P.M., and then increases till the following morning. Deciduous trees usually contain more water than evergreen Conifers, and especially in winter (owing to transpiration on dry, warm, sunny days).

Only from about one-third to two-thirds of the total quantity of water contained in the wood is to be found in a fluid condition, the remaining one-third to two-thirds being "water of imbibition" absorbed by the cell-walls of the woody substance. Here, again, the proportion existing between the fluid and the imbibed water varies greatly, according to the kind of tree, and the season of the year, and the time of the day. When green wood is barked or converted and exposed to the air, the water it contains becomes gradually evaporated until a certain condition is reached in which there appears to be a sort of equilibrium between the hygroscopicity of the wood and the quantity of atmospheric moisture; and when it attains this condition the wood is said to be **seasoned** or **air-dried**. It then still retains from about 10 to 18 per cent of hygroscopic water, which it can only be made to part with completely when subjected to an artificial process of drying at a temperature of 212-230° Fahr. (boiling-point or above).

The **organic and mineral substances** held in solution or suspended in the sap, and which are in part really portions of the cell-wall or products of its transformation, include the following :[2]—

1. **Protein** or **Nitrogenous substances.**—The quantity of nitrogen is usually small, amounting only to about 0·1-0·2 per cent (equal to 0·58-1·16 of protein) in barked wood; and the older wood contains less nitrogen than the younger parts of the tree. They occur in largest proportion in the cambium and the young unlignified wood. Most is contained in summer, and least in winter and spring. By far the greater portion of the nitrogenous substances are found in an insoluble condition; and their chief interest

[1] Prof. R. Hartig's investigations, however, gave the following results as regards the quantity of water found in certain trees :—

Kind of tree.	Maximum.	Minimum.
Birch	March	October
Oak	July	End of December
Beech	July and end of December	May and October
Scots Pine	End of December	May
Spruce	July	March and April
Larch	July	March and April

[2] Besides those here mentioned, the wood of certain trees produced in tropical countries also contains such substances as caoutchouc, indiarubber, camphor, cutch and many other dye-stuffs, &c.

from a technical point of view lies in the fact that, along with the water contained, they form the main cause of decomposition in wood, because it is from them that saprophytic fungi obtain some of their essentially necessary food-supplies.

2. **Carbohydrates** and **Glycosides**.—To this class starch, glucose, sugar, and gums belong. The glycosides include all the substances capable of being transformed by chemical agencies into sugar or any other combination belonging to an aromatic or fatty class. The glycosides are chiefly contained in the bark, although some are also to be found in the wood-sap, as, for instance, the coniferin ($C_{16}H_{23}O_8$) present in the cambial-sap of all Conifers. Starch and sugar are chiefly found in the younger parts of the tree, where they are stored as reserve nutrients. As starch and sugar form the food of insects, wood containing any large proportion of these is specially liable to be attacked.

3. **Resins, Oils, Oleo-resins, and Aromatic substances.**—Every kind of wood has its own peculiar aroma, both when green and after seasoning. The most important of this class of substances in European trees is the resin or turpentine contained in Conifers. It is found in the resin-ducts occurring among the tracheids and passing along the medullary rays, the largest number of longitudinal resin-ducts being formed in or near the summer zone of each annual ring. Resin may impregnate the whole of the wood, and it is of importance as regards the technical qualities of coniferous timber (see also Chap. V. p. 608).

4. **Tannic, Oxalic, and other Plant Acids.**—Tannin or tannic acid occurs in almost every kind of wood, but is chiefly to be found in the bark (*e.g.*, Oak). Among European trees Sweet-Chestnut contains most tannin in its wood. Tannic acid corrodes iron imbedded in or brought into contact with it. Thus Oak is not used for the construction of steamships built of iron and steel, but has given place to the Teakwood (*Tectona grandis*) of India, Burma, and Siam, the æthereal oil contained in which is preservative of metal bolts, &c.

5. **Dye-stuffs.**—These give to each kind of wood, and often to the different parts of the wood (sapwood, heartwood), its own peculiar colour. Wood darkens with age by a gradual process of slight oxidisation, while its colour may be considerably deepened by steaming it.

6. **Ash or Mineral substances** are contained partly in the sap and partly in the wood, especially in the young wood, and usually average from 0·2 to 0·6 per cent of the weight of barked, seasoned stem-timber. The specific composition of the ash varies according to the soil on which the tree has been grown; but the chief constituents are always potash, lime, magnesia, and phosphoric acid, while the proportion of mineral acids is small. The metallic oxides are mostly found in the form of organic acid salts, which furnish carbonates on the wood being burned. Hence carbonic acid is always very conspicuous in wood-ashes, although it really forms no component part of the wood itself. As wood-ashes consist mostly of carbonates, potashes can easily be prepared from wood, and till about forty years ago this was the only mode of producing them.

The sapwood and the youngest parts of trees are paler in colour, more watery, and contain more substances held in solution, and especially more nitrogenous substances, than the older portions, and they are therefore more easily decomposed. As the sapwood grows older it usually undergoes a process of variation differing with each kind of tree, although in many softwoods and also in some other trees there is no very definite division or line of demarcation between sapwood and heartwood. Thus a classification may be made into (1) **Sapwood-trees,** in which the *alburnum* or sapwood undergoes but little or no real or visible change, such as Aspen, Birch, Lime, Alder, Maple, Sycamore, Plane, and Hornbeam; (2) **Heartwood-trees,** in which *duramen* or heartwood is produced containing much less water and becoming of a distinctly different colour from the younger portions of the stem, as in Oak, Elm, Chestnut, Robinia, Cherry, Walnut, Apple, Larch, Pine, Thuja, Juniper, and Yew; and (3) **trees with imperfect duramen,** in which a definite transformation from sapwood to heartwood really takes place as regards the amount of water contained, though without this being accompanied by any very marked and distinctive deepening in the colour of the older wood, such as in Ash, Beech, Willow, Poplar, Horse-Chestnut, Pear, Spruce, and Silver Fir.

Perfectly formed *duramen* or heartwood is wood that has ceased to perform vital functions; there is no ascent of sap throughout the heartwood. It contains much less water, protein, and starch than the sapwood, and the walls and lumina of the woody substance are impregnated and filled with colouring matters, resins, oleo-resins, gums, or mineral matters, usually, but not always, rendering the timber heavier, harder, and more durable than the sapwood. Consequently, the greater the proportion of heartwood to sapwood in any tree, the more durable and valuable is usually the wood it contains.

If an Oak, Larch, or Pine be "girdled" (as is done to season Teak in Burma, and to render it floatable) by cutting a ring all round the stem, right through the sapwood into the darker heartwood, the ascent of the sap ceases, the leaves will soon wither, and the tree will die. But if a Birch or Aspen be ringed by cutting a girdle all round the stem, the trees will not necessarily be killed, because the sap can still ascend to the crown through the older, non-indurated sapwood, and the girdled zone will in course of time cicatrise and become overgrown. The broader, however, and the deeper such a girdle be made, the greater is the physiological disturbance in the sapwood-trees, and the more likely they are to die from its effects, especially if the operation be repeated one or two years later.

The general proportion which exists between the quantity of **timber, branchwood**, and **brushwood** in woodland crops varies according to (1) *the species of tree;* (2) *the density of the crop;* (3) *the age of the crop;* and (4) *the nature of the soil and situation.*

Among the broad-leaved trees the most regular stems are formed by Alder, Oak (especially Sessile Oak), and Ash, then by Poplar, Birch, and Aspen; but the Conifers generally, and more particularly the shade-bearing kinds (Douglas Firs, Spruces, Silver Firs), surpass even the light-demanding broad-leaved trees in their formation of a good bole.

As a general rule, the greater the density of crop, the larger will be the proportion of timber, and the smaller the relative proportion of branchwood and brushwood. Hence highwood crops produce a larger proportion of long logs than is obtainable from standards over coppice.

In young woods the proportion of timber is of course small; but as the crops approach maturity the percentage of branchwood and brushwood decreases in well-managed woods, so that, in general, in most tree-crops the percentage of timber contained in the stem amounts to between 80 and 90 per cent of the total quantity of wood. And as regards the nature of the soil and situation, the percentage of timber contained in the stems of the trees forming the crop is more or less directly proportional to the quality of the land.

With regard to the straightness of stem, the various kinds of timber-crops differ greatly. The straightest boles are formed by Larch, Douglas Fir, Spruce, and Silver Fir, then by Scots and Weymouth Pines, Poplar, Alder, and Sessile Oak. But the density of the crop exerts a decided influence in this respect with most kinds of trees. Oak, Ash, Scots Pine, Beech, Maple and Sycamore, and Hornbeam all gain in straightness by being grown as close together as does not interfere with their normal activity in assimilation and in producing woody-fibrous tissue; while at the same time the freedom of the bole from branches and knots directly depends on the density of canopy maintained in any given crop. The importance of these two factors can hardly be over-estimated with regard to the technical value of timber for general purposes, which usually determines its market-value. The relative proportion of the top-end of the bole as compared with the butt-end is another factor determining the selling-price of timber; hence any sylvicultural measures are advantageous which will raise the *form-factor* of the stems forming the crop. It is also often profitable to stimulate the increment in timber-crops approaching maturity by *partial clearance* when once they have completed their main growth in height, after being previously grown in close canopy.

The percentage of the different classes of wood yielded at an advanced age by the different kinds of **highwood crops** of normal density, and growing on favourable soil and situation, has been tabulated by Gayer as follows:—

Kind of tree.	Percentage of total quantity of wood (according to investigations of Pfeil and Hartig).		
	Stem.	Branchwood.	Brushwood.
Aspen	80 to 90	5 to 10	5 to 10
Birch	78 ,, 90	5 ,, 10	5 ,, 12
Larch	77 ,, 82	6 ,, 8	12 ,, 15
Alder	75 ,, 80	8 ,, 10	12 ,, 15
Spruce	65 ,, 77	8 ,, 10	15 ,, 25
Scots Pine	65 ,, 77	8 ,, 15	15 ,, 20
Silver Fir	60 ,, 77	8 ,, 10	15 ,, 30
Elm	65 ,, 75	10 ,, 15	15 ,, 20
Hornbeam	60 ,, 75	10 ,, 20	15 ,, 20
Weymouth Pine	57 ,, 86	5 ,, 23	9 ,, 20
Beech, Maple, and Sycamore	55 ,, 70	10 ,, 20	20 ,, 25
Oak and Ash	50 ,, 65	15 ,, 25	20 ,, 25
Lime	65 ,, 70	20 ,, 25	12 ,, 15

The percentage in **copse standards** is, according to Lauprecht:—

Beech	59 to 60	51	28 to 40
Oak	58	42	18 ,, 25
Aspen	40	40	25 ,, 29
Birch	35 to 40	35 to 44	34 ,, 40

As already stated, the **technical properties** dependent on the anatomical structure and chemical composition of different kinds of wood may be classified with regard to (1) **Ornamental Qualities**, (2) **Physical Properties**, and (3) **Mechanical Properties**. These three groups include the following different properties:—

I. **Ornamental Qualities** or **Outward Appearance.**—1. *Colour;* 2. *Lustre;* 3. *Grain;* 4. *Texture and Marking;* 5. *Odour.*

II. **Physical Properties** or **Material Condition.**—1. *Density and Weight;* 2. *Percentage of Water contained: Moistness and Seasoning;* 3. *Relation towards Water: Shrinkage, Cracking, Warping, and Expansion;* 4. *Defects and Unsoundness.*

III. **Mechanical Properties** or **Relation towards External Influences.**—1. *Strength;* 2. *Elasticity, Flexibility and Toughness;* 3. *Fissibility* 4. *Hardness;* 5. *Heating-Power;* 6. *Durability.* Nos. 1 to 4 concern changes in form which do not destroy the cohesiveness of the woody substance, whereas Nos. 5 and 6 concern changes in form which destroy the cohesiveness of the wood.

I. **Ornamental Qualities** or **Outward Appearance** include all those that can be tested by sight, touch, or smell. They are natural properties which may vary with the soil and the rate of growth, but which are only partially subject to the control of the forester; and they chiefly determine the market-value of the wood for decorative purposes, such as making art-furniture, panelling, parquetry, &c.

1. **Colour** varies in wood not only in its primary composition, but also in tone or depth. When much colouring matter is contained it may, besides giving a rich look to the wood, be extracted as a dye-stuff (as in the case of the Sumach, *Rhus*

cotinus, and the root-wood of barberry among European trees and shrubs, and as in many sub-tropical and tropical trees). Most of the richly coloured decorative woods (Mahogany, Ebony, &c.) are imported from hot climates. There is a distinct fashion in woods as regards colour—*e.g.*, in the preference given to Alder for clogs, and to Willows and Maples for bread-platters and kitchen utensils. Apart from variations in normal colour, due to soil and rate of growth, in some cases the heartwood of old trees assumes a specially dark colour, giving additional value to the wood for furniture and other decorative purposes. Such is the case with the "brown Oak," obtained chiefly from the English midland counties, the deep rich colour of which is probably only a sign of abnormally perfected heartwood, although it may perhaps be due either to the deposition of soluble matter decomposed in younger parts of the tree, or to incipient decomposition in the heartwood itself. Similarly, some of the Larch grown on the Barnard Castle estate (King's County, Ireland) is almost liver-coloured when green, and exceedingly hard.

Green freshly-felled wood is generally lighter in colour than seasoned wood, but the difference in colour between the sapwood and the heartwood is usually increased by seasoning. Bright-coloured woods often turn greyish after long contact with the air. Spruce retains its colour better than Silver Fir, and is therefore preferred for interior work. Alder quickly changes by oxidisation from fleshy-red to yellow-red, and especially in the younger parts containing most water. The wood of trees grown on suitable soil and with a large individual growing-space is, both when green and seasoned, more richly coloured than that of trees grown in close canopy or on wet land. Uniformity of colour is a good sign, and the richer the colour of the heartwood, the better the timber usually is for general purposes. The usual colour of healthy wood is about as follows:—

Colour.	Green Wood.	Seasoned Wood.
Yellowish-white . .	Birch, Spruce, Silver Fir.	...
Whitish-yellow . .	Willow, Poplar.	Birch, Silver Fir.
Yellow	Robinia.	...
Greyish-yellow . .	Ash, Beech, Maple, Sycamore, Hornbeam.	Willow, Maple, Sycamore.
Reddish-yellow . .	Larch, Douglas Fir, Scots Pine.	Beech, Hornbeam.
Brownish-yellow .	Oak, Scots Elm, Chestnut.	Spruce.
Yellowish-brown . .	Mountain Ash.	Chestnut, Poplar, Robinia, Ash, Cherry.
Brown	...	Oak, Elm, Mountain Ash.
Red-brown . . .	English Elm, Alder.	Larch, Douglas Fir, Scots Pine, Alder; Apple, Plum.
Dark-brown . . .	Walnut.	Walnut.

Note.—The natural colour of wood is always darkened by steaming, and can of course easily be changed by staining with acids, washing with lime, &c. Beech turns reddish to red-brown on being steamed. Unpolished, unvarnished Oak furniture, wainscotting, stair-steps, balustrading, &c., can be deepened in colour and made to assume an ancient look by being occasionally rubbed with linseed oil. Nearly every conservative process darkens the colour of wood.

2. **Lustre**.—Like other smooth surfaces, wood, when planed, is more or less lustrous. This power of reflecting light varies in different kinds of trees, and can be greatly increased by polishing and varnishing; but the differences in lustre are noticeable even on ordinary split surfaces without any artificial treatment. When wood is split radially, so as to expose the medullary rays lengthways and to their full height, many kinds of wood show a considerable degree of lustre, as in the "silver grain" of Oak, and in Maple and Sycamore, although in Aspen and some other Poplars the medullary rays somewhat diminish the lustre. Like

colour and texture, lustre is one of the ornamental qualities determining the value of wood for decorative use.

3. **Grain.**—The fineness or coarseness of the grain in wood is of importance as regards the method of working up the wood and the future value of the finished product. Woods which show few or no visible signs of their structure are termed "fine-grained," while others are more or less "coarse-grained." In fine-grained woods it is difficult to distinguish the annual rings on the transverse section, or the spring and summer zones of each ring on the radial section, because there is not much variation in the size of the different woody fibres and cells in different parts, in different annual rings, and in the old and the young wood. Even when the fibres and cells are rather large, the wood may sometimes be even-grained (*e.g.* Lime), though most fine-grained woods have small fibres and cells. In fine-grained wood the woody tissue is so close together that the medullary rays are not visible on the transverse section ; the cells of these rays are about the same size as those of the wood-parenchym, and the smaller rays are closely interwoven with the woody tissue. In coarse-grained wood the opposite is the case ; the wood-vessels can be easily recognised, the wood is marked by a clear grouping of the elementary tissues, by the differences and marked distinctions between the annual rings, and between the spring and summer zones in each, and by the breadth and height of the medullary rays. Oak, Elm, and Corsican and Austrian Pines are typical coarse-grained woods, difficult to plane or turn, while Box, Apple, and Pear have a much finer grain than any of our true woodland trees. Most coarse-grained woods can, however, take a high polish, as the material used settles easily in the pores.

4. **Texture and Marking.**—Texture is really synonymous with the anatomical structure characterising each kind of wood, although the term is commonly applied to the "marking" or outward appearance of the converted surface of wood. The coarser the grain of the wood, the more easily distinguishable is its texture, and the more striking its marking. The marking of the wood varies according as it is seen on a transverse, a radial, or a tangential section; the first only showing the annual rings, while the other two exhibit the more or less parallel layers of wood. The greatest variety of marking is of course produced in the radial section, the "flowering" of which, along with its colour, determines the value of wood for furniture-making and interior decoration. Wherever a stem forks, or a branch is thrown out, the annual rings are no longer formed in more or less parallel-straight lines, and the "flowering" thus obtainable in the wood gives the timber a special value for furniture-making, &c. Anything, in fact (*e.g.*, branches, wounds), which causes deviation from the ordinary parallel position of the annual rings, such as is desired in clean straight timber for other technical purposes, or which leads to abnormal distribution of colouring matters, resins, &c., tends to improve the marking of wood for ornamental purposes ; and this is especially the case with the "burrs" produced by masses of adventitious, dormant buds, usually near the base, on Poplar, Elm, Oak, Ash, Alder, Birch, Walnut, Maple, and Lime, although these excrescences can only be considered defects as regards the use of such timber for constructive purposes. The larger the burr, and the more fantastic the markings to which it gives rise, the more valuable are such pieces for veneering and furniture-making.

5. **Odour.**—Every kind of wood emits its own characteristic odour when green, and many of them retain it strongly after seasoning. This is particularly the case with Conifers, and they may sometimes be so resinous as to be unsuitable for interior work. Most of the strongly-scented woods are produced only in hot climates (*e.g.*, Deodar, Cinnamon, Sandalwood, Camphorwood, &c.), and even in the south of Europe the odour of those of our woodland trees which also thrive there is stronger than in this climate. Oakwood smelling strongly like tanning-bark is said to be always of superior quality.

II. **Physical Properties** or **Material Condition.**—The group of physical properties now to be considered, and on which the mechanical properties are directly dependent, are of considerably more importance than the mere outward appearance in determining the general value of different kinds of wood for technical purposes. These properties all constantly act and react on each other. The density or specific weight is directly affected by the moistness or dryness of the wood, which also produces changes in its volume; and as the shrinking or the swelling thus caused does not take place equally in all directions, change in the quantity of water contained likewise produces change in form (*warping*). So long, therefore, as the wood remains in sound condition, any alteration in density, moistness, volume, or form is bound to affect all the other three conditions to some greater or less extent.

1. **Density and Weight.**—The proportion of the wood-fibres forming the framework, and of the other elementary substances contained in wood, varies in different parts of the tree, as well as in different kinds of trees, and also according to age, soil, situation, and sylvicultural method of treatment. Many other substances are present besides the woody tissue, and all kinds of wood contain, to a greater or less extent, lumina and hollow spaces filled with air or water and distributed throughout it in groups or otherwise.

The only convenient standard for the density of wood is its **specific gravity**—*i.e.*, its weight as compared with an equal volume of pure water at 4° C. The independent investigations of Sachs and R. Hartig agreed in determining the facts that no great difference is noticeable in the specific weight of the pure woody substance (exclusive of the lumina and other hollow spaces) of our chief timber-trees; that it may be taken as 1·56 for Oak, Beech, Birch, Scots Pine, and Spruce; and that there is no perceptible difference between the specific weight in the substance of the sapwood and the duramen in the same stem. According to Exner (*Die Technischen Eigenschaften der Hölzer*, in Lorey's *Handbuch*, vol. ii. p. 118), it is 1·53 for Beech, 1·52 for Elm, 1·48 for Lime, Birch, and Poplar, and 1·46 for Maple, Sycamore, and Silver Fir, or about 1·5 on a general average. Such scientific investigations will of course vary in their results, according to the state of the atmosphere in which they are carried out.

It is not, however, the specific weight of the actual woody substance which is of technical importance, but the specific gravity of the wood per cubic foot, or per load or ton. This of course varies considerably according to the amount of sap or water still in the tree, the specific weight of **green** wood being greater than that of **seasoned** or **air-dried** timber, and greater still than that still further dried by artificial processes; because even in seasoned air-dried wood on the average from 8 to 12 per cent of the weight still consists of water, which can only be driven off by subjecting the wood to a temperature of 105° to 110° C. (221° to 230° Fahr.) until no further loss of weight is observable, and the wood becomes as thoroughly **dessicated** as is practicable (see p. 533).

Whereas the specific weight of green wood shows whether it is floatable or not, it is only that of seasoned wood which is of practical use in estimating the technical properties of different kinds of timber for constructive and other purposes. And while the specific weight varies for each kind of wood, both when green and after seasoning, with soil, local climate, aspect, part of tree, and season of the year, even in seasoned wood variations in weight are caused by hygroscopicity according to the amount of moisture in the atmosphere. The results of many investigations into the specific gravity of European woods are as follows:[1]—

[1] These data are taken from Gayer's *Forstbenutzung*, and Exner, *op. cit.*

Kind of wood.	Specific weight.			
	GREEN.		SEASONED (air-dried).	
	Range and limits.	Average.	Range and limits.	Average.
(*a*) **Very Heavy** (sp. gr. 0·75 or above).				
Olive (Exner)	...	...	0·84-1·12	0·98
Service-tree (*Sorbus aria:* Exner)	1·02-1·21	1·12	0·73-1·02	0·88
Pedunculate Oak (Exner)	0·93-1·28	1·11	0·69-1·03	0·86
Turkey Oak	1·02-1·17	1·10	0·83-0·87	0·85
Yew	0·97-1·10	1·04	0·74-0·94	0·84
Service-tree	0·87-1·13	1·00	0·67-0·89	0·80
(*S. torminalis:* Exner)	0·87-1·13	1·00	0·69-0·89	0·79
Plum (Exner)	0·87-1·17	1·02	0·68-0·90	0·79
Pedunculate Oak	0·90-1·28	1·04	0·54-1·05	0·76
Ash	0·74-1·14	0·88	0·57-0·94	0·75
Maple	...	...	...	0·75
Beech (Exner) [1]	0·90-1·12	1·01	0·66-0·83	0·75
Apple-tree (Exner) [2]	0·95-1·26	1·11 [2]	0·66-0·84	0·75 [2]
(*b*) **Heavy** (sp. gr. 0·70 to 0·75).				
Sessile Oak	0·87-1·16	1·01	0·53-0·96	0·74
Hornbeam	0·92-1·25	1·08	0·62-0·82	0·72
Pear-tree	0·96-1·07	1·02	0·71-0·73	0·72
Robinia	0·75-1·00	0·87	0·58-0·85	0·72
Beech	0·88-1·12	0·98	0·63-0·83	0·71
(*c*) **Light** (sp. gr. 0·55 to 0·70).				
Elm	0·73-1·18	0·95	0·56-0·82	0·69
Maple (Exner)	0·90-1·02	0·96	0·56-0·81	0·69
Field Maple	0·87-1·05	0·96	0·61-0·74	0·68
Walnut (Exner)	0·91-0·92	0·91	0·65-0·71	0·68
Apple-tree [2]	0·95-1·26	1·01 [2]	0·66-0·84	0·67 [2]
Chestnut	0·84-1·14	0·99	0·60-0·72	0·66
Sycamore	0·83-1·14	0·93	0·53-0·79	0·66
Cypress (Exner)	...	...	...	0·66
Plane (Exner)	0·78-0·99	0·89	0·61-0·68	0·65
Birch	0·80-1·09	0·95	0·51-0·77	0·64
Juniper (Exner)	1·02-1·12	1·07	0·53-0·70	0·62
Larch	0·52-1·00	0·81	0·44-0·83	0·59
Horse-Chestnut	0·76-1·04	0·90	0·52-0·63	0·57
(*d*) **Very Light** (sp. gr. under 0·55).				
Alder	0·63-1·01	0·82	0·42-0·64	0·53
Sallow	0·73-0·97	0·85	0·43-0·63	0·53
Scots Pine	0·38-1·03	0·70	0·31-0·74	0·52
Aspen	0·58-0·99	0·81	0·43-0·57	0·50
Austrian Pine (Exner)	0·90-1·11	1·00	0·38-0·76	0·57
White Alder	0·61-1·00	0·80	0·43-0·55	0·49
Silver Fir (Exner) [2]	0·77-1·23	1·00 [2]	0·37-0·60	0·49 [2]
White Poplar	0·80-1·10	0·95	0·40-0·57	0·48
Silver Fir (Gayer) [2]	0·77-1·23	0·97 [2]	0·37-0·60	0·47 [2]
Spruce (Exner) [2]	0·40-1·07	0·74 [2]	0·35-0·60	0·47 [2]
,, (Gayer) [2]	0·40-1·07	0·76 [2]	0·35-0·60	0·45 [2]
Lime	0·61-0·87	0·74	0·32-0·59	0·45
Weymouth Pine (Exner) [2]	0·45-1·02	0·74	0·31-0·56	0·44 [2]
,, ,, (Gayer) [2]	0·55-1·02	0·83	0·31-0·56	0·39 [2]
Wellingtonia	...	...	...	0·38

[1] British Beech is denser and heavier than German Beech (see p. 452).

[2] Several such discrepancies are noticeable between Exner's and Gayer's tables. The former always, and the latter nearly always, has evidently taken as the average the *arithmetical mean* between the two extreme limits of range. Nothing shows that in any one case a *true average* of all the specimens weighed has been taken.

Note.—As the weight of water is 62½ lb. per cubic foot, the average weight avoirdupois of any kind of wood per cubic foot may be found by multiplying its specific gravity by 62½. And in the same way, the actual dead-weight of a 40 cub. ft. *load*, or a 50 cub. ft. *ton*, or any other quantity of timber, can easily be found for estimating the haulage necessary; and the weight of beams and scantlings may be similarly calculated for structural purposes.

The dead-weight of common British coniferous wood has been found by Mr. D. F. Mackenzie (*Transactions of the Highland and Agricultural Society of Scotland*, 1901, p. 143) to be as follows :—

Kind of tree.	One ton by weight is contained in the following quantities of wood :—			
	In the round, green, and including bark.		Sawn and seasoned timber.	
	Young trees.	Old well-matured trees.	Young trees.	Old well-matured trees.
	Cub. ft.	Cub. ft.	Cub. ft.	Cub. ft.
Larch . . .	30-32	32-34	70-80	56-70
Scots Pine . .	26-28	28-30	72-80	52-68
Spruce . . .	29-31	32-35	80-86	70-80

The tables on pages 438–439 show the results of investigations made many years ago by Mr. Rait, forester at Castle Forbes, regarding the weight of home-grown timber in the north of Scotland.

The specific weight of any wood not only determines its floatability and the cost of haulage, but for one and the same kind of wood it also gives a clear indication of its hardness, heating-power, and general durability. A short spring and a long warm summer generally tend, and especially in ring-pored trees (Oak, Ash, Elm, Sweet-Chestnut, Robinia, &c.), to increase the weight of the wood produced, owing to the greater density of the summer zone. But this is not always the case, as in woods with evenly distributed pores (Beech, Maple, Sycamore, and softwoods) the density hardly varies with the breadth of the ring. And this is further evidenced by the superior quality of the Scots Pine and Larch grown in the north of Scotland, as compared with the milder and warmer southern districts of England ; and, as a matter of fact, narrow-ringed coniferous wood is usually heavier than that showing broad rings. But there can be no hard-and-fast rule about the matter, as so many factors concerning the climate, elevation, aspect, physical properties of soil, &c., come into operation with regard to the energy of nutrition and the amount of woody substance actually produced each year. In Conifers, the greater the quantity of resin contained in the wood of any given species, the higher is its specific gravity.

No definite rule seems to hold with regard to the specific gravity of the wood in the upper or the lower, or the inner and the outer portions of a stem. In the case of the trees with a very distinct difference in colour between heartwood and sapwood (Oak, Larch, and Scots Pine : trees which have all a deep tap-root, and are also decidedly light-demanding), the heartwood is heavier than the sapwood ; but in most other cases nothing like any constant variation is traceable, and in Birch the younger outer wood is heavier than the older inner portion. The wood in young trees is usually closer and heavier than in old trees, because of the relatively larger space required to be provided in large trees for the upward conveyance of sap ; and at the same time the annual rings formed are broader, owing to the trees then being in their most vigorous period of growth. This effect of the age of trees on the specific gravity of their wood showed itself clearly in R. Hartig's investigations concerning the Beech.

Branchwood, however, is usually heavier than the wood of the bole, while this is (except in very resinous Conifers) heavier than that of the roots. The starchy reserve-nutrients and the mineral salts do not much affect the specific gravity of the wood, as they are mostly contained in the bark, cambium, and youngest wood (see vol. i. p. 306).

A.—TABLE SHOWING THE WEIGHT OF LARCH, SCOTS PINE, and SPRUCE, both in the Round and Converted, and both when Green and Seasoned (but see also pp. 436 and 437).

Kind of timber.	Age.	IN THE ROUND. Weight per cubic foot. By Rule 1.* With bark.	By Rule 1.* Without bark.	By Rule 2.† With bark.	By Rule 2.† Without bark.	Number of cubic feet to a ton. By Rule 1. With bark.	By Rule 1. Without bark.	By Rule 2. With bark.	By Rule 2. Without bark.
	Years.	lb.	lb.	lb.	lb.				
Larch	60	70	62	55	48	31	35	40	45
Do.	60	77	69	61	54	28	32	36	41
Do.	60	68	61	53	47	33	36	42	47
Scots Pine	60	81	75	63	59	27	29	35	38
Do.	60	84	78	66	61	26	28	34	36
Do.	60	83	77	65	61	27	29	34	36
Do.	100	75	69	58	54	29	32	37	41
Spruce	35	74	69	58	55	30	32	38	40
Do.	50	74	69	58	55	30	32	38	40
Do.	90	64	57	50	44	35	39	44	50

Kind of timber.	Age.	CONVERTED. Inch boards. Weight per cubic foot. Green.	Dry.	Number of cubic feet to a ton. Green.	Dry.	Scantlings. Weight per cubic foot. Green.	Dry.	Number of cubic feet to a ton. Green.	Dry.	Heartwood. Weight per cubic foot. Green.	Dry.	Number of cubic feet to a ton. Green.	Dry.	Sapwood. Weight per cubic foot. Green.	Dry.	Number of cubic feet to a ton. Green.	Dry.
	Years.	lb.	lb.			lb.	lb.			lb.	lb.			lb.	lb.		
Larch	60	..	...	...	...	43	29	51	75	35	31	64	71	48	32	46	69
Do.	60	54	39	41	57	46	34	48	64	...	...	...	...	...	...	...	...
Do.	60	44	28	50	78	39	28	56	79	...	...	...	...	...	...	...	...
Scots Pine	60	...	...	...	...	58	30	38	73	37	33	60	66	63	29	35	76
Do.	60	60	30	36	74	55	28	40	80	...	...	...	...	...	...	...	...
Do.	60	59	29	37	75	55	30	40	73	...	...	...	...	...	...	...	...
Do.	100	54	32	41	68	49	32	45	69	...	...	...	...	...	...	...	...
Spruce	35	...	...	...	...	52	27	42	80	32	26	70	83	61	28	36	80
Do.	50	56	26	40	85	50	28	44	80	34	26	64	85	62	26	35	84
Do.	90	43	31	51	71	39	33	56	67	32	28	69	79	62	34	35	64

* Rule 1, common measurement; one-fourth of the girth squared and multiplied by the length.

† Rule 2, measurement which would be nearly correct were trees perfectly cylindrical; one-fifth of the girth squared and multiplied by twice the length. This was to ascertain how nearly it and the weight of the newly-sawn boards would approach each other.

B.—TABLE showing the Weight of Oak, Ash, Elm, Beech, Birch, Plane, and Horse-Chestnut, both in the Round and Converted, and both when Green and Seasoned.

In the Round.							Converted (sections of 1 ft. ×3 in. ×2 in.).				
Kind of tree.	Age.	With or without bark.	Girth.	Comparative weight of a piece with and without bark.	Weight per cubic foot.	No. of cubic feet to a ton weight.	Where cut from.	Weight per cubic foot. Green.	Weight per cubic foot. Dry.	Cubic feet to a ton. Green.	Cubic feet to a ton. Dry.
	Years.		Inches.	lb.	lb.			lb.	lb.		
Oak . . .	100	With bark	32	35	90	24	Heartwood	69	53	32	42
		Without bark	30	31	81	27	Sapwood	62	41	36	54
Oak . . .	52	With bark	27	24	93	24	Heartwood	73	50	30	44
		Without bark	24	22	83	26	Sapwood	67	48	33	46
Ash . . .	52	With bark	38	41	73	30	Heartwood	51	42	43	53
		Without bark	36	36	65	34	Sapwood	53	42	42	52
Elm . . .	70	With bark	27	21	76	29	Heartwood	53	37	41	59
		Without bark	25	18	65	34	Sapwood	54	38	41	58
Beech . .	70	With bark	36	44	84	26	Heartwood	63	46	35	48
		Without bark	35	42	80	28	Sapwood	64	45	34	49
Birch . .	70	With bark	38	43	82	27	Heartwood	58	40	38	55
		Without bark	34	37	71	31	Sapwood	57	42	39	53
Sycamore . .	52	With bark	39	52	87	25	Heartwood	62	43	36	51
		Without bark	37	47	78	28	Sapwood	63	46	35	48
Horse-Chestnut	52	With bark	38	40	69	32	Heartwood	52	32	43	69
		Without bark	36	35	61	36	Sapwood	53	33	42	67

2. **Percentage of Water contained: Moistness and Seasoning.**—The green unseasoned timber of *hardwoods* contains on the average water to the extent of about 42 per cent of its total weight, that of *softwoods* about 52 per cent, and that of *Conifers* about 57 per cent. Hence green wood in general may be said to contain water to the extent, in round numbers, of about half its weight; but the actual quantity varies with the kind of tree, season of the year, part of the tree, soil and situation, &c. It is never pure water, but here too the kind and quantity of sap-substances it contains vary also according to the tree, season, soil, &c. This water, contained throughout the tissues and in the intercellular spaces, begins to diminish in quantity by evaporation into the air after a tree is felled; and this evaporation of the imbibition-water contained in the wood goes on, at a gradually diminishing rate, until a condition is reached when there is more or less of equilibrium between the tension of the atmosphere and the power of evaporating the water still contained in the wood. When this condition is attained the wood is said to be *seasoned* or *air-dried*, but it still contains a considerable quantity of water, varying according to the nature of the woody tissue and the other substances within the wood, and to their power of retaining water. It varies from 8 to 12 per cent of the weight, but is greater in coniferous than in broad-leaved wood owing to the resin that it contains; and the more resinous the wood, the larger is the quantity of water retained.[1] To differentiate this ordinary residual portion from the *water of imbibition* originally present when the tree was alive in the full flow of sap, it has been called *hygroscopic water*, because its quantity constantly varies proportionately with the atmospheric moisture. This natural residuum can only be expelled from the wood by artificial dessication (see p. 533).

Wood in the round usually takes from two to four years to season, and unbarked logs still longer. Logs that have been floated absorb more water than they originally contained, but when afterwards stored in depots they dry sooner than other timber. The evaporation of the water takes place more quickly longitudinally (in the run of the fibres) than radially. Light porous wood of course seasons sooner than heavy close-grained wood, and sapwood usually sooner than heart-wood. To dry thoroughly, wood should be well raised above the ground; and the freer the circulation of air around it, the more rapid will the seasoning take place. Split or sawn wood of course seasons much sooner than wood in the round; and the larger the surface exposed to the air, the quicker it parts with its moisture. To save time and money it is customary to artificially season all the finer kinds of wood in special drying-chambers by means of hot air, as this does not diminish its strength.

3. **Relation towards Water: Shrinkage, Cracking, Warping, and Expansion.**—As it loses water in seasoning, wood **shrinks** or decreases in volume as soon as the water contained in the woody tissue begins to be evaporated, after that contained in the intercellular spaces has been parted with. The more water the woody tissue gives off, the greater must be the **shrinkage** in volume, and the

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[1] Hartig's investigations showed the following results as regards percentage of water *by volume*:—

Kind of wood.	Percentage of water, by volume.	
	Green.	Seasoned (air-dried).
Birch . . .	44·3	8·8
Oak . . .	43·7	11·5
Beech . . .	42·6	12·3
Spruce . . .	40·5	11·5
Scots Pine . .	38·3	12·1
Larch . . .	27·5	15·0

greater the tendency to warp ; while the extent to which the shrinkage and warping take place depends mainly on the anatomical structure of the wood and the extent to which it parts with the water contained. As the shrinkage depends on the rate and extent of seasoning, the dense slow-drying heartwood shrinks more gradually and to a less extent than sapwood, while shrinkage is less in Conifers (and especially when very resinous) than in the wood of broad-leaved trees. But no connection can be proved between the specific weight of green or dry wood and its shrinkage, nor any usual proportion between the quantity of water contained and the shrinkage of wood generally.

Nördlinger classified wood in the following scale with regard to **shrinkage** while seasoning :—

Shrinking most (5 to 8 per cent of the volume when green): Walnut, Lime, Beech, Hornbeam, Elm, Chestnut, Wild Cherry, Turkey Oak, Alder (?), Birch, Apple-tree.

Shrinking moderately (3 to 5 per cent of the volume when green): Maple and Sycamore, Austrian Pine, Scots Pine, Poplar, Yew, Horse-Chestnut, Ash, Aspen, Sessile Oak, Robinia.

Shrinking least (2 to 3 per cent of the volume when green): Weymouth Pine, Spruce, Larch, Silver Fir, Arborvitæ, Pedunculate Oak (?).

He also found that there was no practical difference between the shrinkage of wood that had been floated for a short time and of wood not floated at all.

The shrinkage *longitudinally* (in the direction of the fibre) is only nominal; but *radially* (in the direction of the radius) it can amount to about 6 per cent, and *tangentially* (in the direction of the circumference) to about 10 per cent. And, of course, the greater and the more rapid the shrinkage, the greater will be the number and the depth of the cracks thus made in the wood. Hence the timber of trees felled in summer, while the sap is in full flow, is more apt to be damaged by shrinkage than that of those felled in autumn or winter, and barked logs crack more than those on which the bark is wholly or partially left (see log-ends, Fig. 136).

The following table gives the results of investigations made regarding shrinkage in different directions (Exner) and as regards total volume (R. Hartig, Frey, Schwappach) :—

Kind of wood.	Percentage of shrinkage.					
	Longitudinally.	Radially.	Tangentially.	Of total volume when green.		
				(R. Hartig.)	(Frey.)	(Schwappach.)[1]
Hornbeam	0·21	6·82	8·00	...	...	...
Lime	0·10	5·73	7·17	...	16·9	...
Ash	0·26	5·35	6·90	...	16·5	...
Beech	0·20	5·25	7·03	13·5	14·4	15·0
Alder	0·30	3·16	4·15	...	...	...
Oak	0·00	2·65	4·13	12·2	13·1	...
Maple and Sycamore	0·11	2·06	4·13	...	8·9	...
Elm	0·05	3·85	4·10	...	11·5	...
Aspen	0·00	3·97	3·33	...	12·1	...
Birch	0·50	3·05	3·19	13·2	...	...
Scots Pine	0·00	2·49	2·87	7·7	13·5	11·8
Silver Fir	...	...	...	...	...	11·8
Spruce	0·09	2·08	2·62	8·0	11·3	13·2
Larch	...	...	...	8·0	10·5	...
Weymouth Pine	...	...	...	...	...	9·1

[1] An abstract of Schwappach's investigations into the Specific Gravity and Resistance to Crushing will be found in *Transactions of the Royal Scottish Arboricultural Society*, vol. xv., part iii., 1898, pp. 279-291.

In consequence of the want of uniformity in the shrinkage in different directions, the wood is liable to **crack** or **split** while still in bulk, and to **warp** when converted. The larger the logs, beams, planks, and scantlings, the more liable they are to become cracked, especially at the ends; while the smaller the pieces of wood, and the further a beam or a board is cut from the centre of the stem, the more likely it is to warp, owing to the greater amount of tangential shrinkage in its fibres. The slower the process of drying, the fewer and the slighter are the cracks formed during seasoning. Cracks in the ends of logs can be prevented by painting or smearing these with any greasy or tarry substance to check evaporation. In timber-yards the logs are sawn into planks, scantlings, sleepers, &c., of standard sizes and put under shade to season, while the cracking of the ends can be minimised by greasing them or driving S-shaped clamps into them (see p. 533). The wood of Conifers, especially when very resinous, is less liable to warp than that of broad-leaved trees, and heartwood generally warps less than sapwood. By steaming wood, besides being thereby made much more flexible, it also becomes less liable to warp, without its other technical properties being impaired. Beech, Ash, Oak, Walnut, and other furniture woods are therefore treated in this manner to make them more flexible, less liable to warp, and of a darker and better ornamental colour.

In proportion as wood gradually shrinks when seasoning, it also, in consequence of its hygroscopicity, gradually **expands** again by the absorption of water during a moist condition of the atmosphere. Although there are differences between the rate of shrinking and of expanding, yet for all practical purposes the co-efficient of shrinkage may also be taken as that of **expansion** for any given kind of wood. Converted wood therefore expands much more tangentially than radially, and very much more radially than longitudinally; and expansion must be allowed for in fixing beams and other wood-work in house-building, &c.

The absorption of water and the expansion of seasoned wood do not, however, take place at the same rate. Weissbach's investigations showed that while the expansion was completed within 1½ to 2 months, the weight increased (by absorption of water) for about 6 months, and sometimes for 2 to 3 years. The variation in specific weight, volume, and absolute weight in consequence of saturation with water is thus shown by Exner:—

Kind of wood.	Specific gravity.		Increase due to saturation.		Power of absorbing water in percentage of volume (Hampel).
	Thoroughly air-dried.	Thoroughly saturated.	In volume per cent.	In weight per cent.	
Maple and Sycamore	0·612-0·686	1·098-1·172	7·1-9·8	71-79	58
Birch . . .	0·591-0·623	1·090-1·091	7·0-8·8	91-97	39
Beech . . .	0·634-0·762	1·035-1·179	9·5-11·8	63-99	43
Oak. . . .	0·629-0·750	1·050-1·171	5·5-7·9	60-91	...
Alder . . .	0·423-0·503	1·040-1·121	5·8-6·8	136-163	...
Ash. . . .	0·700	1·105	7·5	70	47
Spruce . . .	0·366-0·526	0·761-0·921	4·4-8·6	70-166	34
Scots Pine . .	0·463	0·890	4·8	102	39
Silver Fir . .	0·455-0·505	0·874-0·948	3·6-7·2	83-123	...
Elm. . . .	0·609	1·123	9·7	102	36

Defects and Unsoundness.—The value of wood for technical purposes is often diminished by **defects** due to structural and other conditions, and by **unsoundness** occasioned by disease. Such defects include **branch-knots, twisted fibre**, old **wound-surfaces**, and **shakes**, or internal cracks usually formed in the tree before the seasoning of the timber begins; while unsoundness in the form of **rot** of one kind or another is usually directly due to saprophytic and parasitic fungi.

(1) **Branch-knots** are a common defect in many classes of British timber. As

the national system, centuries old, of growing Oak for shipbuilding was to give each tree a large growing-space, this method was (and still is) applied generally to other trees, and usually results in the formation of large branch-knots, which make the timber difficult to work. They improve the ornamental qualities of wood for furniture, &c., and increase its density, weight, and toughness; but they impair the quality and diminish the market-value of coniferous timber for general constructive purposes. Timber free from knots is therefore more useful for many, but not for all, purposes; it gives longer logs, and it involves less waste in conversion.

The more shade-enduring a tree is, the more likely it is to have snags of dead branches embedded in the wood of the stem, which are apt to fall out when the timber is converted into boards and dries thoroughly. The knots in Conifers become saturated with resin, and are then, especially in Larch, exceedingly hard to plane and work.

(2) **Twisted Fibre** may occur in any kind of tree, but it is commonest in Horse-Chestnut, Sweet-Chestnut, Oak, Sycamore, Elm, Beech, and White Poplar (also Walnut and Pear-tree) among broad-leaved trees, and in Scots Pine among Conifers. Usually the twist goes from left to right, especially in the Horse-Chestnut, Sycamore, and Scots Pine, though it often also runs from right to left. Planks, beams, and scantlings sawn from trees with twisted fibre are more liable to warp, and are less strong than those cut from straight-fibred stems. Sycamore boles with a slight twist are often preferred for mill-rollers.

(3) **Wound-surfaces** and **Rind-galls** that have become completely occluded by cicatrisation often fail to unite with the older wood, and then form blemishes and weak spots when the timber is converted into scantling, beams, and planks. When the defect is serious, it often necessitates the bad part being cut off altogether, as useless for timber.

(4) **Shakes**[1] are sometimes to be found in the shape of radial clefts (**heart-shakes**), or of cracks following the circumference of old internal annual rings (**cup-** or **ring-shakes**), or of longitudinal clefts (**frost-shakes**), and in each case they greatly diminish the technical quality and value of the wood. **Heart-shakes** may be either *star-shaped* if several clefts are produced near the centre of the stem, or *simple* if they occur merely singly between the centre and the circumference, though both kinds may be found together, especially in large stems. Heart-shakes are often formed, especially in old Oaks and Sweet-Chestnuts, long before the trees are felled (in which case they will be found on the stump too); but they may also be produced by the jar or shock when the tree crashes on the ground, or by shrinkage during seasoning. The liability to shake is less in winter-felled wood than in summer-felled, and less when the axe is used than when felling takes place with the saw. To what extent heart-shakes may interfere with the conversion of the wood depends of course on the nature and size of the cracks, but star-shaken logs are spoiled for the sawing of thin planks. **Cup- or Ring-shakes,** whether due to internal tension and rupture, wind, frost, or fungi, spoil, as far up as they extend, the wood for sawing into planks and beams, &c. This class of defect occurs chiefly in old trees, and especially among Sweet-Chestnut, Beech, Oak, Elm, Willows, and Poplars. **Frost-shakes** occur oftenest on Sweet-Chestnut, Oak, Elm, Horse-Chestnut, Beech, and Lime, and seldom become occluded without enclosing rot within them, so that a considerable portion of the wood is thereby rendered useless.

Unsoundness or **Rot** in timber is a diseased condition, due to the injurious action of fungi (see pp. 182–4, 187, 190). Whereas saprophytic fungi only attack lifeless wood (*e.g.*, branches, dead-wood at wound-surfaces, &c.), they sometimes develop into parasites and attack the living tissues in the same way as the specially parasitic

[1] See also Part IV., *Protection of Woodlands*, p. 206.

fungi which effect their entrance at wound-surfaces, however minute. Even in the incipient stages of disease the unsoundness of the tissue is generally sufficient to discolour the wood, and often to affect it as timber, while of course in all the advanced stages of decay up to actual rottenness it is useless as timber, and often worth little even as fuel. In many kinds of wood incipient decomposition produces a dark-blue, a coppery-green, or a very dark colour near the centre of the stem, or along star-shakes (as in Maple, Sycamore, and Elm), or along the outer edge of the heartwood (as in Elm). From deep, old, open wounds, too, a dark-coloured product of decomposition often percolates downwards and produces "false heartwood" of specially dark tint in the lower portions of the tree. A somewhat more advanced stage of decomposition sometimes causes the wood to become greenish (as in Oak, Birch, and Beech), but the most destructive of all the diseases of timber-trees are those occasioning the various kinds of **canker** and of **red-** and **white-rot**, which may occur on or in the stem, the roots, and the branches of all kinds of trees. The fungous diseases of trees have been fully dealt with in Part IV., Chap. V., and it need only be remarked here that—

Canker is caused chiefly by *Peziza* (*Dasyscypha*) *Willkommii* (Larch); *Nectria ditissima* (Ash and Beech mostly, but also other broad-leaved trees); *Aecidium elatinum* (Silver Fir); *Cronartium* (*Peridermium Pini corticola:* Scots Pine).

Red-rot, owing to the decomposition of the cellulose, is caused chiefly by *Trametes Pini* (Scots Pine), *Fomes annosus* (*Trametes radiciperda:* Scots and Weymouth Pines, Spruce, Silver Fir, and also broad-leaved trees); *Polyporus sulphureus* (Oak and Birch chiefly); *P. vaporarius* (Spruce, Silver Fir); *P. betulinus* (Birch); *P. sistotrematis* (Scots and Weymouth Pines).

White-rot, owing to the decomposition of the lignin, is caused chiefly by *Fomes* (*Polyporus*) *igniarius* (Oak and Willows mostly, but also other broad-leaved trees); *F. fomentarius* (Beech; Oak and Elm); *F. fulvus* (Plum-trees; Aspen, Hornbeam); *Polyporus dryadeus* (Oak); *P. squamosus* (most broad-leaved trees); *Agraricus melleus* (all kinds of trees); *Hydnum diversidens* (Oak, Beech).

White-piping, or rings of white decomposing wood spreading from the branches round the stem and appearing as long whitish or yellowish stripes on a longitudinal section, is caused by *Stereum hirsutum* (Oak).

Blueing of Conifer timber is caused by *Ceratostoma piliferum* (especially common in Scots Pine sapwood).

Root-rot is often produced in consequence of unsuitable soil (*e.g.*, as in Larch on moist or imperfectly drained land, and often even on gravelly soil), but it is not of much consequence technically unless it spreads up into the bole and makes the wood "foxy" or "dosed," or still worse, "pumped" and hollow. **Branch-rot** is also in itself of comparatively little consequence unless it affects the wood of the stem, as it is very apt to do; hence the advantage of treating all such wound-surfaces antiseptically, after pruning broken branches, whenever necessary. It is sometimes impossible to tell from the outward appearance of a tree whether or not it be sound in the stem; but if tapped sharply with the back of an axe, extensive **stem-rot** will make its presence known by a somewhat hollow sound quite different from the dull, solid tone emitted from a sound, healthy trunk. Very old trees are of course much more likely to be unsound than younger trees still in vigorous growth.

Dry-rot is often occasioned, both in wood in the round and in converted timber, by *Merulius lacrymans* and other saprophytic fungi; and the more the wood is exposed to warmth and moisture simultaneously, the greater is the chance of its becoming attacked. (See p. 187, also Agricultural Leaflet No. 113—*Dry-Rot.*)

III. **Mechanical Properties** or **Relation towards External Influences.**— In many respects these are by far the most important of all the factors in determining the technical properties or **quality** of timber required for constructive purposes. They are, however, very intimately connected with the physical properties, because they necessarily vary according to the density and the moistness of the wood, and this close relationship between the physical and the mechanical properties must always be kept in view in considering the quality of wood. And further, when investigations are being made to try and ascertain the relationship between, say, the strength and the elasticity of any given kind of wood on the one hand, and its density and moistness on the other, the question is always rendered intensely complex by the fact that both the physical and the mechanical properties are affected by the kind of soil on which the wood was grown, the elevation, the aspect, the part of the tree from which the specimen was taken, &c. And these are all influences which come into account to a greater or less extent in determining the **durability** of any kind of wood for any special purpose.

1. **Strength** in wood signifies the resistance offered to any force tending to separate its fibres. Strength may be considered from different points of view, all important as regards the use of timber in construction, according to the resistance offered to—

(1) **Tension,** or force applied longitudinally at the ends, along the grain of the wood, as if to pull the woody fibres apart.

(2) **Crushing,** or force applied longitudinally at the ends, along the grain of the wood, as if to press the woody fibres together (as in piles and upright wooden posts).

(3) **Transverse Pressure** or **Breaking-Strain,** when force is applied at right angles to the grain of the wood, as if to break it across (as in beams, &c.). (When only one end of the wood is fixed the pressure applied is called a *cantilever strain.*)

(4) **Torsion,** or force applied (at one or at both ends) so as to twist the fibres (as in a windlass).

(5) **Shearing,** or force applied more or less parallel to the grain, so as to displace the woody fibres and separate them sideways (as in mill-rollers).

Of these five kinds of strength, resistance to **Transverse Pressure** or **Breaking-Strain** is by far the most important as regards wood used for constructive purposes, such as bridge- and house-building, though where great strength is required iron and steel have now in large measure supplanted timber. Very numerous investigations have been made by scientific men to try and determine the different kinds of strength, and of course the results all vary more or less owing to variations in the technical properties of the wood experimented on. As a matter of common experience, Oak, Ash, and Larch stand pressure best, then other hardwoods; while the softwoods and very resinous Conifers resist it least. Tetmajer of Zürich, in experiments regarding the strength of Swiss building-wood, ranged them thus as regards resistance—

To	Transverse pressure.	Tension.	Crushing.	Shearing.
1	Beech.	Beech.	Oak.	Beech.
2	Oak.	Oak.	Beech.	Oak.
3	Larch.	Scots Pine.	Larch.	Larch.
4	Silver Fir.	Larch.	Silver Fir.	Spruce.
5	Spruce.	Spruce.	Spruce.	Silver Fir.
6	Scots Pine.	Silver Fir.	Scots Pine.	Scots Pine.

Note.—He found that of these Scots Pine had the lowest "technical value," and that in seasoned wood (containing from 11 to 20 per cent of moisture) the technical value of Silver Fir was about 19 per cent greater, Spruce 26 per cent, Larch 66 per cent, and Oak and Beech about 95 per cent greater than Scots Pine.

Mikolaschek's experiments with Bohemian wood showed that both the **strength** and the **elasticity** were greatest in (1) *branchwood*, (2) *lower part of stem*, and (3) *upper part of stem*, from which he concluded that the strongest wood is also the most elastic.

Bauschinger of Munich, in experiments made to ascertain the comparative influence of soil, situation, and felling-time on the strength and elasticity of Spruce and Scots Pine grown in Bavaria, found that (1) both in Spruce and in Scots Pine trees of the same age, and having about the same diameter, each kind of wood has, independently of soil and situation, the same mechanical properties when it contains the same quantity of moisture; (2) that when trees of the same age show differences in diameter, then those of quicker growth (*i.e.*, having broader annual rings) are not so strong as those which have grown more slowly; and (3) that both Spruce and Scots Pine felled in winter, when experimented on two to three months after felling, showed under otherwise similar conditions about 25 per cent. greater strength than those felled in summer (Exner, *op. cit.*, p. 156).

As regards **resistance to tension**, he found that this kind of strength is independent of the relative breadth of the whole annual ring, and is only dependent on the nature of the two zones; and as the spring zone is of almost constant density, the power of resistance is therefore mainly dependent on the strength of the summer zone and also on its relative breadth. It was further found (1) that in Spruce and Pine wood a dense summer zone of relatively great breadth gave additional strength, while a loosely-constructed and comparatively narrow summer zone always showed less strength for the whole transverse section; and (2) that the low degree of strength in the heartwood did not depend so much on the great breadth of the annual rings, as on the loose texture and the relatively smaller width of the autumn zone. It has since been found, however, that these conclusions have no general application even for Spruce and Pine, and that the total breadth of the annual rings does not necessarily determine the resistance to tension. But a relatively broad summer zone increases the density of the wood, and its strength as to tension. Besides the anatomical structure of the wood, however, the quality and the chemical composition of the woody substance also influence its strength; and it was found that the strength as to tension increased with the quantity of cellulose contained, and decreased with the quantity of lignin, although the latter seems to make wood harder, firmer, and better able to resist transverse pressure. Differences were in some cases noted, but nothing definite could be formulated as regards the influence of soil and situation; while with reference to the time of felling, if the experiments were made only a short time, say, about one month, after the fall, this influence could not be traced. The elasticity for tension varied greatly with the strength, increasing and diminishing with the latter, but as a rule nothing like proportionately; while the limit of elasticity nearly coincided with the breaking-limit.

As regards **resistance to transverse pressure**, it was found that this kind of strength was also influenced, though not to so great an extent as in tension, by the nature of the wood in different portions of the stem. No decided connection could be proved between the density and the strength, because, although both with Spruce and Pine the heavier wood also stood the greater strain, the strength did not vary in proportion with the specific gravity. The season of felling could not be shown to have any influence.

As regards **resistance to vertical pressure** or **crushing**, the pieces of heartwood showed less strength than pieces from the sides of the tree, but no difference was found in specimens from the N., E., S., or W. sides. As also for transverse pressure, the wood with greater specific gravity offered the stronger resistance, but without any proportionate connection being traceable between weight and strength. Winter-felled wood was, however, stronger than summer-felled in the ratio of 1·22 to 1 for seasoned wood.[1]

As regards **resistance to sideward pressure** or **shearing**, this was found to be independent of the breadth of the annual rings. It was least in the heartwood, but increased towards the circumference; very frequently, however, it was found to be less next the sapwood than between it and the heartwood. No differences were traceable on wood taken from the N., E., S., or W. sides of a tree, nor was any decided difference shown by wood taken from various heights up the tree. The influence of soil and situation was found to be small, but winter-felled wood was on the average stronger than summer-felled in the ratio of 1·27 to 1.

With regard to **resistance to torsion**, the British Postal Department has found that in Oak used for cross-arms on telegraph poles and subjected to two strains (cantilever and torsion), the average for home-grown timber is the better; and in the torsional tests the results "are almost universally very much in favour of native timber" (average, native Oak, 100; foreign Oak, 79·7).

"I am unable to express any definite opinion as to the reason why native Oak as a rule stands such a much greater torsional or twisting strain than Oak grown on the Continent, but I have reason to think it is owing to English Oak being, as a rule, grown in open situations instead of its being close together in woods" (Roberts in App. xvii. p. 187, of *Report on Departl. Com. on British Forestry*, 1903).

When one compares the investigations made within recent years into the elasticity and the different kinds of strength of wood, one cannot fail to be struck with the hoplessness of trying to obtain mean average figures of real use for technical purposes. The combined influence of locality, soil, and situation are so strong in the production of wood, that such tests hold good only locally, and not generally.

2. **Elasticity, Flexibility, and Toughness.**—Elasticity in wood is the resistance offered to any force producing a temporary change of shape. Any body the shape of which changes under pressure is said to be *pliable;* if it completely resumes its former shape it is termed *elastic;* while if the shape becomes more or less altered, the body is called *flexible.* If it breaks suddenly under the applied pressure, it is said to be *brittle;* and when it has a high power of resisting force tending to produce change of form, it is called *tough.* Flexibility and toughness mean, from a technical point of view, the capacity of wood to submit to a permanent change of form without breaking, cracking, or splintering; while the limit of elasticity is passed long before the breaking point is approached.

The **elasticity** of wood varies with its strength, the strongest wood being also the most elastic (see p. 446). The **flexibility** and the **toughness** are usually increased by the quantity of moisture, being greater in green than in partially or wholly seasoned wood. If dry wood be soaked in water this usually increases these two latter properties, and the effect is greatly increased if it be steamed (*e.g.*, as in making bent-wood furniture, basket-work, felloes of wheels, walking-sticks, &c.).

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[1] Schwappach found in experiments with Beech, Scots Pine, Spruce, Silver Fir, and Weymouth Pine that the specific gravity and resistance to crushing depended on the kind of wood—and for each kind of wood, on the part of the tree, the locality, soil, and situation. The sp. gr. of the dry wood was found to be on the average for Beech 0·67, Scots Pine 0·49, Spruce 0·46, Silver Fir 0·41, and Weymouth Pine 0·37; while the average resistance to crushing was, Beech 540, Scots Pine 480, Spruce 460, Weymouth Pine 420, and Silver Fir 400 atmospheres (14·22 lb. per square inch). As regards different parts of the stem, he found that the wood of Scots Pine (the only kind investigated on this point) was heaviest and hardest in the lower parts of the tree, that sound old wood is better than younger wood except from poor situations, and that where there is only 30 per cent or less of summer wood, the sp. gr. and the resistance to crushing are always low.

Heating withes at a fire also increases their flexibility. Dry wood is more elastic, but less flexible, than moist wood.

The most flexible and the toughest fibres are formed in young stool-shoots of Osiers, Willows, Ash, Birch, Hazel, Hornbeam, Sweet-Chestnut, Lime, Aspen, Oak, and Elm. The branches of Birch and Spruce, and the young root-strands of Pine and Spruce in sandy soil, are also very pliable. **The toughest and most flexible stem-wood** is found in Ash, Birch, Willow, Mountain-Ash, Poplar, Robinia, Hornbeam, and Elm, and in poles of Oak and Hazel. Beech becomes tough and flexible when steamed, but is not so otherwise. For one and the same kind of wood, however, the elasticity, flexibility, and toughness depend on the length and straightness of the woody fibres ; while branches, knots, and abnormal growth of any kind all tend to make wood less flexible. Softwoods are more flexible than hardwoods. In Conifers a certain amount of resin increases the elasticity and flexibility, while a large quantity decreases them.

It is impossible to obtain average figures of any practical value as regards flexibility and toughness. As the result of his investigations, Nördlinger found that—

According to the old saying, which is at any rate correct for Beech, Oak, and some other trees, a wet soil produces a brittle wood, and a dry or moderately moist soil a tough wood. Tough woods can usually be told by their great fibrosity and, among softwoods at least, by the "woolly" appearance of the cut part when they are sawn through. . . . The wood of both roots and butt is tougher than the stem-wood, while this is tougher than the top-end. The branchwood of Oak, Lime, Alder, and Pine is more brittle than the stem-wood ; but the opposite is said to be the case with Birch, and perhaps also with Spruce. The toughest wood is found in the young shoots of Osier-willows, Hazel, Birch, Elm, Hornbeam, Yew, Ash, Aspen.

With age and disease the toughness of stem-wood gradually decreases, so that in over-mature Oak and Walnut the sapwood is tougher than the heartwood. . . . The toughness of large Pine grown on suitable soil is increased by its great resinousness, while the more resinous outer portion of each annual ring is the tougher and more fibrous. Pine grown on poor soil and without proper heartwood is more like Spruce and Silver Fir, and has the tougher wood towards the circumference, where the annual rings are narrower and relatively more resinous.

The relative toughness of sapwood and heartwood can often even be noticed in the difference in fibrosity on stumps of felled trees. But it must be recollected that the sapwood is moister, and therefore must when green have the tougher wood. . . . Wood exposed to weathering, and even that used in construction in dry places, gradually loses in toughness.

3. **Fissibility** in wood is the ease with which a wedge can be driven into it parallel to the run of its fibres, so as to split it up into separate portions. Two directions of splitting may be distinguished—(1) that in which the force is applied radially from above, so as to split the wood in the direction of the medullary rays, and (2) that applied tangentially at right angles to the above. The latter requires the greater force, but the former is the more important. The greater the resistance offered to the splitting force, the less is the fissibility of any kind of wood. The different kinds of wood may be classified as follows as regards their fissibility generally :—

Easy to split: Spruce, Silver Fir, Weymouth and Scots Pine, Larch, Alder, Lime.
Less easy to split: Oak, Beech, Ash, Sweet-Chestnut, Austrian Pine.
Hard to split: Hornbeam, Elm, Sallow, Birch, Maple and Sycamore, Poplar.

Fissibility is of importance as a technical property with regard to such wood-consuming industries as cooperage, making wooden-boxes, sieves, split-rails, sounding-boards for musical instruments, making matches, trenails, toys, &c., where the radial surface is to form the exterior superficies. Fissibility is greatest in long and straight-fibred woods, while short and strongly-lignified fibres decrease it considerably and make the split surface rough and uneven. The outer portions of the stem are usually easier to split than the inner parts, partly because of the greater tension existing the nearer one approaches to the circumference. The fissibility of any wood is closely connected with its elasticity, because the more elastic the wood, the easier it is for the cleft made by the wedge to enlarge. As moistness decreases the elasticity of wood, so too does it diminish its fissibility ; but as moistness enables the wedge to obtain its first hold more easily and diminishes the sideward cohesiveness of the fibres, this advantage may sometimes outweigh the disadvantage caused by loss of elasticity. This explains why the softwoods—Aspen, Poplar, Alder, and Sallow—are harder to split when moist than dry, while nearly all the hardwoods are more difficult to split when dry than when green. Frost reduces the elasticity of wood considerably, and therefore makes it much harder to split, while during frosty weather the wedge will not hold, and is apt to spring back. Great resinousness diminishes fissibility, and stumps of Scots Pine are therefore harder to split when very full of resin. Long clean stems with straight, smooth fibres and few branches, such as are produced in tree-crops grown in close canopy on a good soil, are the easiest class of wood to split. The more fissible the wood, the less easy it is to obtain a fine smooth surface when it is being planed, owing to the tendency of the fibres to split in advance of the cutting-edge.

4. **Hardness** in wood is the resistance offered to the penetration of another body into its substance. Judged from a technical point of view, hardness in a wood is rather an indefinite term, because the hardness manifests itself differently when such different kinds of instruments are applied to the wood as axe, knife, plane, saw, rasp, nail, &c., some of which work parallel to the fibres, and others at right angles to them. Considered generally, Nördlinger's classification of wood as to hardness was as follows : [1]—

Very hard: Barberry, Boxwood, Privet, Lilac, Dogwood, Hawthorn, Blackthorn.
Hard : Robinia, Maple and Sycamore, Hornbeam, Wild Cherry, Yew, Pedunculate Oak.
Moderately hard: Ash, Holly, Plane, Plum, Turkey Oak, Elm, Beech, Sessile Oak.
Soft : Spruce, Silver Fir, Horse-Chestnut, Alder, Birch, Hazel, Juniper, Larch, Austrian Pine, Scots Pine, Sallow.
Very soft : Weymouth Pine, all Poplars, most Willows, and Lime.

Heavy kinds of wood are usually hard, and the hardness increases with its strength and with the cohesiveness of the woody fibres. Considerable resinousness increases the hardness of coniferous wood, especially when the annual rings are narrow. Older wood is harder than younger wood in trees. Dry wood is harder than green in general, though not always ; but heavy, hard woods, like Oak, Beech, Maple, and Sycamore, can be worked easier when still moist than when dry. Tough woods, like Black Poplar, Aspen, and Willow, are very hard when operated on with an instrument acting at right angles to the run of the fibres (as in sawing).

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[1] It would be exceedingly difficult, however, to tabulate exactly the hardness of wood, because each kind of wood shows great variations in its different parts as to hardness. Not only the difference between the spring and the summer zone of each annual ring, but also the difference between young and old wood in the same stem, and the variations in hardness shown according as the wood is operated on in the run of the fibres or at right angles to them, as well as many other influences, all of which cause variations of one sort or another, make it impossible that any one instrument can be invented which could be used in making satisfactory scientific tests regarding the hardness of wood. And a further complication arises from the fact that the hardness is almost always influenced by the fissibility, or, as it might be better to say, that the influence of fissibility introduces a disturbing and obscuring factor into the investigation of the hardness (Exner, *op. cit.*, p. 175).

With regard to resistance offered to the saw, Gayer found that woods are classifiable as follows :—

Hardest to saw : Poplar, Willow, Lime ; Birch, Aspen, Sallow.
Medium : Oak ; Alder, Larch, Maple and Sycamore.
Easy to saw : Scots Pine, Spruce, Silver Fir.

In felling with the axe, the more obliquely the stroke is given, the less resistance the fibres offer, because the cutting then takes partly the form of splitting, and this combined effect appears to overcome the resistance better.

5. **Heating-Power** in wood depends mainly on the amount of carbon contained in the woody tissue, and in the different substances (resin, oil, &c.) contained within it. But as the sp. gr. of the actual woody tissue is practically the same for all kinds of trees, it therefore follows that the density of the tissue and the nature of its contents determine the heating-power of any wood. Though light woods are more inflammable and give out a brighter flame, yet common everyday experience shows that for ordinary domestic purposes close-grained heavy wood gives out the greatest amount of heat, and that the drier the wood is, the greater is its inflammability and its heating-power. But as the sp. gr. of different kinds of wood is not dependent solely on the density of their woody tissue, it is therefore clear that sp. gr. alone will not indicate the relative heating-power of different kinds of wood,—although for one and the same kind of wood the heavier samples will, other things being equal (*e.g.*, as to soundness, percentage of moisture contained, resinousness, wood taken from same part of tree—root, stem, or branches, &c.), give out the greater heat in proportion to its greater specific gravity. The general heating-power is estimated theoretically at 3500-4000 heat-units for well-seasoned wood (see table on p. 593).

Gayer's classification of the usual warmth obtained from different kinds of wood when burned in closed stoves is as follows :—

Having greatest heating-power : Hornbeam, Beech, Birch, Turkey Oak, Mountain Pine from high elevations, Robinia, resinous old Scots Pine, Austrian Pine.
Having considerable heating-power : Maple and Sycamore, Ash, English Elm, resinous Larch, ordinary Scots Pine, Oak.
Having fair heating-power : Scots Elm, Spruce, Silver Fir, Sweet-Chestnut, Cembran Pine.
Having little heating-power : Weymouth Pine, Lime, Alder, unsound Oak, Aspen, Poplar, Willow.

Until the use of coal for iron-smelting had been discovered and had become general during the sixteenth century, large quantities of wood were used as fuel throughout England, and special legislation was effected to protect woods and coppices, and timber-trees of Oak, Beech, and Ash, and to prevent their being used as fuel (see vol. i., *Introduction*, pp. 18, 19). But for ordinary purposes, wood as fuel can only compete with coal where the former is cheap and abundant, and the latter is scarce and dear. Except for kindling purposes, the use of wood as household fuel in the British Isles is usually a luxury, as the heating-power is in general only about one-fifth of that of coal ; and for those who indulge in this luxury the favourite woods are Oak, Beech, Elm, Birch, and Ash—the latter chiefly on account of its burning evenly without crackling. It is certainly cleaner and less smoky than coal. Wood is still, however, largely used for charcoal-making and for miscellaneous fuel, though the faggots of course chiefly consist of the branchwood and any unsound parts of trees which find no other market.

6. **Durability** in wood means the length of time during which it continues sound and serviceable. It is the sum and substance of all the technical qualities of wood, because it is the best and the only practical standard for estimating its use for any given purpose. And of course it will be at once apparent that there

can be no absolute standard of durability, because the length of time any wood can remain sound and serviceable must vary greatly with the particular technical use to which it is put.

The **durability of timber** depends mainly on the extent to which the wood is exposed to alternating changes from moisture to dryness, more especially during the warmer seasons of the year. It is under such special circumstances that the saprophytic fungi (mostly species of *Polyporus*, and *Agaricus melleus*), which are the primary cause of the decomposition of the tissues and the ligneous matter, find the conditions most favourable to their development and regeneration. Wood, however, which contains any comparatively large proportion of albuminoid substances will be more quickly attacked than that having a less proportion in its structure; and **in the case of one and the same wood**, the heavier specimen will at the same time be the more durable, owing to the relatively larger proportion of lignin and of preservative matters contained per unit of volume,—though the mere specific gravity gives no sure indication as to the durability of any two different kinds of wood. And when once the saprophytic fungi have begun the work of decomposition, or often before then (as in the case of bark-beetles or *Scolytidæ*), insects attack the wood in order to deposit their ova or to feed on the starch, dextrin, &c., contained by the water still in the wood. But even long after the wood has become thoroughly seasoned, it is still exposed to the attacks of fungi and of beetles like *Anobium*, *Ptilinus*, *Lymexylon*, &c. Experience shows that while growing crops of coniferous species of trees are most of all exposed to injury from insect enemies and parasitic fungi, yet seasoned timber of broad-leaved trees is more liable than coniferous wood to be attacked by saprophytic fungi and timber-boring insects—and more particularly if the timber has been felled during the summer, instead of during the autumn or winter.

When utilised entirely under water, Oak, Larch, Scots Pine, and Alder are far more durable than any other species of timber; but when exposed to changes of moisture, dryness, warmth and cold, Oak, Larch, and Pines last longest.

With regard to **general durability**, the different kinds of home-grown wood may be roughly classified as follows:—

Most durable: Pedunculate Oak, and resinous Larch with large compact heartwood; Scots Pine from Strathspey and vicinity; then Sessile Oak, Douglas Fir, and resinous Scots Pine; Robinia, Sweet-Chestnut.

Durable: Ash, Elm, steamed Beech; Weymouth, Austrian, and Corsican Pine of good quality; Larch, Douglas Fir, and Scots Pine, not of best quality.

Least durable: Silver Fir, Spruce; Beech, Hornbeam, Maple and Sycamore; Alder, Birch, Aspen, Lime, Poplar, Willow, Horse-Chestnut.

Where short length, durability, weight, density, and toughness are required, the trees grown under conditions recently practised in this country will yield more suitable timber [than that grown in close canopy]. That is, the trees grown in our more open woods and in our hedgerows are, although shorter in the bole and rougher in the top, more durable, of greater density, and greater strength than timber grown closely together, as it is in the well-managed Continental and in the primæval virgin forests. To take a few concrete examples:—

It seems almost superfluous to compare British Oak with foreign. Very few countries grow Oak timber equal to our own in size, strength, wearing and lasting qualities combined. Some imported Oaks are equal to ours in size, and (speaking broadly) they are superior in ease of working and freedom from coarseness and some other defects. But this freedom from defects is largely due to selection, I believe, and, judging from what we see in our old buildings, and in occasional woods of comparatively unthinned trees, our country can grow Oak equal to foreign in these respects, and superior in the special good qualities of the species. The comparative coarseness of some of our Oak is due to the system under which it has for some time been grown. British Oak will withstand much greater torsional or twisting strains than almost any other. Hence its preferential selection for purposes where this strain occurs. . . . For the framework of railway waggons it is eminently suitable. One of my customers simultaneously built as an experiment six railway waggons with the framework of English and six with a framework of foreign Oak, for exactly the same purposes, and they were used in that way. By the time the waggons built on English timber foundations came in for repair, he tells me, the others were quite worn out. As nearly the same labour had been expended in building the latter as the former, it was true economy to use the somewhat higher-priced British than *vice versâ*. . . . For general wheelwright work, where the implements are often exposed to sudden strains (as in the spokes) and to long exposure to the weather, it is found that by far the most serviceable timber for construction is British and not foreign Oak.

For pit props, where heavy and non-cohesive roofs occur, it is found that Oak props, although priced 60 per cent more in first cost, are cheaper than the best foreign Pine and Fir props, because, besides bearing a heavier crushing strain in the first place, they can be withdrawn when no longer required, and by slightly shortening them they can be used again and again in other positions. Similar commendation can be made of our native larch. . . .

To take another species: German Beech is grown in much heavier crops per acre than is our own, and no doubt it is very useful for some purposes. At the same time there are uses to which Beech is put in this country, in large quantities, for which the German Beech is utterly unsuitable, because of its lack of density and weight. For mallets, shuttles, spools, wheel-cogs, rollers, and similar products, it is much inferior to our own hard-grown and comparatively rough Beech. Weight and resistance to repeated blows (resistance to indentation) are of more importance and value for these purposes than is the growing of large crops. A customer, a very large user, to whom I referred the question for confirmation, puts it in these words: "Such German Beech as we have had was much inferior to our English Beech, being light in weight, too free and open, and had not that solidity about it that ours had." . . .

Where really rough wear is experienced, even British Spruce is sometimes preferred to foreign, but as a rule the Firs and Pines generally are of a better quality in imported timber than in our own. This, nevertheless, is more a result of the system of sylviculture than of any inherent fault of our climate and soil. Take scaffold-poles, flag-poles, boat-stowers, and similar long, nearly parallel poles, for instance. The foreign Spruce trees, having been grown in close proximity, have made longer annual growths, with, consequently, longer spaces between the knots, than ours do. Besides, these knots are smaller because their crowding in the plantation has destroyed the branches before they got to any size, the leaves being borne on the top-most branches only. There is also less liability to "cross-grained" timber from the same causes. The annual accretions to the tree are not laid on from youth to age in even layers from the root to the top of a 60 ft. central pith, but are added, so to speak, "cone-on-cone." The longer we can get the annual cone, the less cross-grained will be the pole or tree, and at the same time the fewer the knots.—(Margerson, *Relative Merits of British and Foreign Timber* in *Report of Departmental Committee on British Forestry*, 1903, App. iii., p. 163.)

The conditions exacted in order to try and obtain durability in Oak scantling required for Post-Office telegraphs will be seen from the following specification (see *Report of Departl. Com. on Brit. Forestry*, App. xviii., p. 195) :—

(1) The scantling shall be sawn from good strong English or Irish Oak of large size.

The person tendering shall here name the district, or districts, in which the Oak he will supply has been grown..........................

(2) The timber shall be winter-felled, unless otherwise agreed.

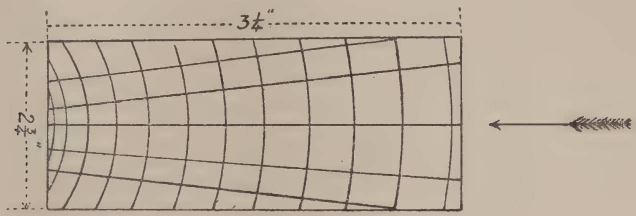
The person tendering shall here state when the timber he will supply was, or will be, felled..........................

(3) The timber shall be planked and open-stacked, for seasoning, at least three months before being sawn into scantling.

(4) The scantling shall be cut with the grain of the timber running parallel with the length, and shall be of sound timbers, free from deadwood, sapwood, the centre pith of the tree, sun-shakes, seasoning shakes, and from such knots as would impair its strength. It shall not be bent or warped.

In the case of scantling 3¼ in. by 2¾ in. section, it is preferred that it should be cut with the medullary rays running through the timber parallel with the sides of greatest width, *vide* sketch :—

Fig. 211.



(5) Samples of the Oak tendered for, showing the character of the scantling as regards the quality of the wood and its freedom from defects, will be required before an order is issued; and, if approved, these samples will be taken as the standard, for comparison with the supply.

(6) The scantling shall be of one of the sizes shown in the schedule attached to the form of tender, and shall not leave the saw more than $\frac{1}{16}$ in. under those sizes. Scantling more than $\frac{1}{16}$ in. under the specified size will be rejected, or will be accepted as, and at the price quoted for, the next smaller size, if any smaller size be due under the order.

(7) On no account shall the ends of scantling be painted. The person tendering shall stamp (not paint) the end of each piece of scantling either with the initials of his firm, or with some other identifying mark.

Heartwood is more durable than sapwood, and the dense summer zone of each annual ring is more durable than the looser spring zone. Winter-felled wood is better than summer-felled; dry, well-seasoned wood lasts better than moist, unseasoned wood; and timber used in dry places is more durable than when exposed to changes from dry to wet. The durability of wood can be very considerably increased by artificial means, as will be subsequently considered (see Chap. IV.).

The **Practical Uses** to which wood is put are almost innumerable, even though iron, steel, and other substitutes are now used to a large extent in place of wood for constructive purposes. The abstract given below of the technical uses to which timber is mainly put has therefore no pretensions to be anything like exhaustive, because demand, supply, past custom, &c., all come into play concerning the use of wood in different localities. All wood which is used for technical purposes, such as shipbuilding, carpentry, furniture, &c., is called **Timber**, in contradistinction to the wood which is merely consumed as **firewood** without being subjected to any technical process or used for any really technical purpose. All the larger parts of trees are in Britain usually sold as timber, including the trunk and the branches down to 6 in. diameter (free of bark) for broad-leaved trees, and down to 3 in. for Conifers. The rest of the tree, consisting of branchwood and ends, forms the "lop and top" often faggotted for fuel.

In Britain timber is either sold as **standing trees**, or is felled and then sold in **log** or **in the round**, and usually with the bark still on, to timber merchants, who, after removing it, convert it to a greater or less extent in order to prepare it as a marketable product for various technical uses. Thus it may be merely **dubbed** here and there with the axe to hasten the process of seasoning and remove part of the watery sapwood, or it may be **rough-hewn** with axes or **sawn** on all four sides to form **squares** or **balks**, with or without **wanes** or parts of the original circumference of the log showing at the four corners. If squared with the saw, the **slabs** or side-pieces removed give place to the smooth **panes** forming the four flat sides of the balk, or extending between the waney corners, as the case may be. A log or balk when halved lengthways forms two **half-balks**; and a log divided lengthways into four equal pieces is **quartered**, and forms four **quarter-balks**. When converted in the saw-mill to smaller dimensions, but in the full length of the log or of the section of the log, timber is known by the various trade terms, applied according to the dimensions of the pieces, of **scantlings**, **planks**, **deals**, and **battens**, which are always obtainable of standard sizes from timber-yards.

Scantlings are at least 4 in. thick, and more than that in depth.[1]
Planks are at least 10 in. wide, and from 2 to 4 in. thick.
Deals are 9 in. wide, and from 2 to 4 in. thick.
Battens are 7 inches wide, and from 2 to 4 in. thick.

These standard sizes are further reduced to **boards** of more or less fixed sizes, varying from 6 to 12 in. wide and ½ to 1 in. thick, and **laths**, varying from 1 to 4 in. broad and ½ to 2 in. thick.

According to the custom of the trade, 120 **deals** = 100; 1 **square of flooring** = 100 superficial ft.; 1 **load of timber** = 40 cub. ft. *in the rough* and 50 cub. ft. *squared* or *converted* into planks, although in Bucks a load of Beech is locally 25 cub. ft.; a **ton** is sometimes 40 cub. ft. (*hardwoods*), sometimes 50 cub. ft. (*softwoods*), for railway carriage (see rates, on p. 511), and sometimes deadweight avoirdupois (as timber is usually sold in Ireland); and a **Cord of wood** is 2½ tons, or 125 cub. ft., or it may be a cubic fathom ($6 \times 6 \times 6 = 216$ cub. ft.), or other size according to local custom—*e.g.*, the *stack* of 117 cub. ft. (12 ft. × 3 ft. × 3¼ ft.) in parts of Hants (see Part V. p. 291).

There are of course various ways of converting logs into planks and smaller material. The commonest way of all is the **bastard** method of conversion, which takes place when a log is run through a frame-saw set with parallel saws, which gives the largest out-turn, with the least wastage. But for ornamental work the best effect is produced by first of all quartering large timber of 8 ft. or more in girth, and then converting it as much as possible **on the quarter**—*i.e.*, in the direction of the medullary rays—so as to obtain the best flowering and display of grain, as in the so-called "silver grain" of Oak. There are several methods of converting on the quarter, but two of the simplest are shown in Fig. 212, where the various alternate and successive saw-cuts can be easily seen, as well as the final remnants that can be used as fence-posts, &c. Conversion may also, however, take place by cleaving or splitting the wood along the fibre of clean, straight-grained sections of logs, and such **cleft timber** is the best for oars, cask-staves, wheel-spokes, paling-wood, gate-rails, ladder-rungs, trenails or wooden pins, &c.

Fig. 212.

[1] In scantlings, the greatest resistance to transverse pressure obtainable for any given superficies of transverse section is when this assumes a decidedly rectangular or oblong form. From any round log of wood the strongest scantling obtainable for a beam is when the sides of the section are in the proportion of $1 : \sqrt{2}$, or in round numbers about 5 : 7, as this ratio gives the maximum product of breadth × height.

British timber, as well as the similar wood imported from our Colonies and from foreign countries, is put to the following uses:[1]—

1. **Hardwoods**—

Oak: Ship-building, house-building, bridge-building, and similar kinds of construction; interior decoration, wainscotting, panelling, parquet-flooring, cabinet- and furniture-making; waggon-making, carriage-building, wheel-naves; railway-sleepers; arms of telegraph posts; posts and rails, paling-wood, cask-staves, ladder-rungs, trenails, railway-keys, &c. Poles and branchwood below 6 in. diameter give good pit-wood, spoke-wood, and are much used in the ground and in water. Pedunculate Oak is harder, stronger, and more durable than Sessile Oak, which is softer and easier to work. Home-grown Oak is harder and superior in quality to imported Oak, which is freer from knots, softer, and easier to work.

Ash: Coach-building, wheelwrights' work, shaft-wood; furniture; agricultural implements and tool-handles (axe, spade, &c.), oars, and wherever toughness and elasticity are desired. British Ash is superior to any imported kind, and the finest quality is produced in Northamptonshire. There is such a dearth of first-class Ash in Britain, that in 1901 the Coachmakers' Association memorialised the President of the Board of Agriculture to try and induce landowners to grow more of this very valuable wood (see *Journal of Board of Agriculture* for January 1902). Ash is now our most valuable wood, being marketable from the very smallest size upwards (walking-sticks, pea-sticks, hop-poles, shaft-wood, &c.).

Beech: Chair-making, and bent-wood furniture (Bucks and adjoining counties); benches; piano-making; calico mill-rollers; handles of planes, chisels, and similar tools; lasts and boot-trees, brush-backs. The wood produced in southern England is also of better quality than that imported from the Continent.

Elm: Boards for coffins; coach- and waggon-building, and wheelwrights' work; furniture; tin-plate boxes. The finest quality of Elm is produced in Gloucestershire and other southern English counties. English Elm lasts well under water (keels of boats, &c.). It is redder than the whiter and tougher Scots or Wych Elm, the best quality of which is produced in the North, where its wood has often to be used in place of Ash.

Maple and **Sycamore**: Furniture-making; box-making; churns and other dairy-utensils; bread-platters and wooden spoons; turnery, reels, bobbins, &c.; clog-soles; blocks of pulleys. Sycamore is specially in demand for calico mill-rollers.

Hornbeam: Cogged wheels and other wood-work in machinery; jacks and pulley-blocks; benches; plane-boxes; handles of tools; boot-lasts, turnery, and all small articles where great toughness is desirable.

Sweet-Chestnut: Furniture; flooring and interior work; posts and rails for fences.

Robinia: Wooden ships'-nails; spoke-wood; gate- and fence-posts; turnery.

Mountain Ash: Spoke- and shaft-wood.

Service-tree, **Apple**, **Pear**, and **Wild Cherry**: Cabinet-making, turnery, carving, printers' blocks, &c.

2. **Softwoods**—

Birch: Cabinet-making and furniture; turnery, reels and bobbins; barrel-staves and crates; waggon-making; clog-soles; heads and handles of brooms. Birch and Alder were formerly much used as charcoal for gunpowder.

Alder: Clog-soles; barrel-staves; cigar-boxes; is well suited for use underground and in water.

Poplars: Packing-cases; framework for veneered furniture; bottoms and sides of carts; brake-blocks for railway carriages, &c.; clog-soles; interior boarding;

[1] See also remarks concerning small waste wood on page 605.

turnery and carving. Aspen is preferred for making matches and match-boxes, and for wood-pulp for paper.

Willows: Same uses as Poplars; also bread-platters, knife-boards, and cricket-bats (Red Willow).

Horse-Chestnut: Sides and bottoms of carts; cabinet-making; turnery, reels and bobbins.

Lime: Turnery and carving; framework for veneered furniture; packing-cases.

Walnut: Cabinet-making, gun-stocks, turnery, and carving.

3. **Conifers**—

Larch: Railway sleepers; boat- and bridge-building; cart-making; masts and posts of all sorts; posts and rails for gates and fences; pitwood. Wood of small size is used in hop-poles, pea- and bean-sticks, &c. Like the Ash among broad-leaved trees, Larch can be used of all sizes, and it is one of the most durable of all our woods, and the most useful for general estate work.

Douglas Fir: Used for similar purposes as the Larch, but only ranking in quality between it and Scots Pine.

Scots Pine or "**red deal**": used for similar purposes as Larch, but not so durable; also for masts and spars of ships, telegraph poles, and scaffolding.

Weymouth or "**Yellow Pine**": Packing-cases and miscellaneous work. Poles are very tough and durable. Imported wood from America is largely used in house-building and for other constructive purposes.

Austrian and Corsican Pine: Used for similar purposes as Scots Pine, but the wood of both is coarser and less durable.

Spruce or "**white deal**": Boarding, planking, and scantling for interior work of all sorts; rough furniture; masts and spars of ships; scaffolding and ladders; packing-cases; boxes; toys; cask-staves; sounding-boards for musical instruments; pitwood; wood-pulp; is less durable than Scots Pine.

Silver Fir or "**White Pine**": Put to much the same uses as Spruce. It is almost equal in quality with the Spruce grown in Britain, though in some localities the Spruce produced is considered the better, and in others the Silver Fir.

Different demands on the technical qualities of timber are of course made according as it is to be used for superstructures above ground (*e.g.*, bridge-building, carpentry), or on the ground level (*e.g.*, railway-sleepers), or for substructures below ground (*e.g.*, pitwood),—or whether it is to be kept always dry, or always wet, or subjected to frequent changes from wet to dry. If, however, timber and other wood be classified according to the manner in which they satisfy the ordinary requirements of the more important wood-consuming trades and industries, one will find the chief uses of British wood to be as follows:—

1. **Ship-building.**—Oak of best quality, for framework and side-planking of wooden coasting-vessels and sailing-ships, barges and boats; also Elm and impregnated Beech sometimes as keels; Scots Pine, Larch, Spruce, and Silver Fir for masts and spars, and for deck-planking and inner lining. Home-grown Oak is better than foreign Oak for ship-building, and the Pedunculate Oak is usually preferable to the Sessile Oak.

Most of a ship's framework consists of **crooks** or **knees**, and **curved pieces** or **compass timber**; and when these cannot be had in one piece of the required size, they have to be formed by splicing two or more pieces together. The base of a wooden ship is formed by the **keel**, a four-sided oblong balk or beam, which has to be spliced to obtain the whole length and strength required. The **prow** is formed of curved timber, and the heel of the **stern** is made of a knee-piece. The **ribs** forming the side-framework are generally spliced in two or three or more places, each opposite pair of ribs being strengthened and kept in position by beams.

The **deck-beams** extend crossways between each corresponding pair of ribs, and are slightly curved to let water flow off readily to each side. The ribs are then planked outside and inside, good Oak being used (steamed, if necessary, to make it more pliable) for the outer planking, and coniferous wood for the inner lining. Knee-pieces are used as supports for the deck-beams (though iron has now to a great extent replaced these, even in small wooden ships), upon which the deck-planks are fastened with trenails or wooden pins of tough wood, such as Robinia. For **masts, spars,** and **yards,** the best quality of Pine, Larch, and Fir is used; they have to be carefully jointed or spliced, and bound with iron in the case of large vessels.

The curved timber which fetches the highest price is that having the greatest curvature at one-third up from the thicker end; but as so many dimensions of curves and crooks come into consideration about ship-building timber, it is not advisable for the forester to try and work up his Oak-trees into what he thinks the best sorts and sizes of pieces. Where there is any good market for this class of wood, it is best to log even crooked trees in as large dimensions as possible, and to leave it to the purchasing wood-merchant, whose special business it is, to determine how the logs can be most advantageously converted. For **barges, or river and canal boats,** however, which have, in place of a keel, a broad, horizontal bottom formed by knee-pieces of comparatively small diameter, the rough conversion of Oak and Elm crooks at time of felling can often prove profitable.

2. **House-building and Carpentry.**—Very little home-grown timber is now used for house-building in the United Kingdom. On account of its lightness, coniferous timber is almost entirely used, and practically nearly all of this consists of imports of long, straight, clean-grown and large Scots Pine ("red deal"), Weymouth Pine ("Yellow Pine"), Spruce ("white deal"), Silver Fir ("White Pine," or "Swiss Pine"), and *Pinus palustris* ("Pitch Pine"). Home-grown **Larch** is not much used in building in Britain, because it is neither obtainable of the same large dimensions nor at the same price as foreign imports of Pine and Fir. Wherever the strain is great, so that specially strong timber is required, such as Oak beams formerly, iron is now generally used; and other substitutes, such as cement, are also employed as largely as possible in all high-class buildings, because of their greater durability and of their decreasing the risk of fire. In country districts, however, and especially for ornamental residences there, home-grown Oak is still used for the framework of half-timbered houses and for beams; while Oak and Sweet-Chestnut are used for ornamental flooring, staircases, balustrading, wainscotting, and panelling, to a greater extent than any of the other ornamental hardwoods. Much of this latter Oak is also, however, imported, as it is softer and easier to work. Even as early as the sixteenth century most of the Oak then largely used in England for wainscotting was imported from the Continent (as is stated in the Holinshed *Chronicles*).

3. **Bridge-building.**—Only the best Oak, Larch, and Scots Pine prove desirable for this class of work, which is, however, now almost entirely carried out with iron or stone.

4. **Pitwood.**—Larch and small Oak are the best and most durable timber in mines, whether used as sleepers (3 to 5 ft. long × 4 to 6 in. × 2 to 4 in. in collieries) or as pit-props of various lengths. But Scots Pine, Spruce, and Silver Fir are all used as propwood down to 2½ in. top-diameter free of bark, as well as the branchwood of all kinds of hardwoods; and in most parts of Great Britain and Ireland this forms the chief use to which the Conifers are put. After Larch, Douglas Fir and Scots Pine are best, because of their greater resinousness and durability. Our home-grown supplies are, however, nothing like sufficient for the needs of the mining industries, and our yearly imports of pit-props amount to close on 2,000,000 loads, or 80,000,000 cub. ft., valued at considerably over £2,000,000.

This demand is constant, because the average life of pitwood is only four to six years at most, and less than that for Pine, Spruce, and Silver Fir.

For the coal and lignite mines throughout Germany, whose total output was 128,000,000 tons in 1898, about 384,500,000 cub. ft. of wood were used, which represents the entire yield that is obtainable continuously from about 4,000,000 acres of well-managed woodlands (Stoetzer, *Forstbenutzung*, in Lorey's *Handbuch*, vol. ii., 1903, p. 186). As the British output of coal is about the double of that of the German Empire, our total requirements for colliery wood alone must be about 769,000,000 cub. ft. annually, the continuous supply of which would absorb the total yield from about 8,000,000 acres of woodland, or over 2½ times our existing total area under woods (see vol. i. p. 43). And large quantities of timber are of course also used in other mines and underground work of a similar nature.

Rough estimates of this sort may vary considerably. In the above it works out at 3 cub. ft. per ton of coal; but another estimate, at 4 cub. ft. per ton, puts it thus for British mines—

Putting the coal-production at 250,000,000 tons, we find that 25,000,000 tons of wood are used annually in this industry, one-half of which may be put down as small thinnings and branchwood, leaving 12,000,000 tons, or about 500,000,000 ft., of poles and timber, or the annual produce of at least 5,000,000 acres of forest land (A. C. Forbes, in *Journal of the Farmers' Club*, May 1904, p. 109).

The Fife Coal-Mines, from which are raised annually about 5,000,000 tons of coal, consume a yearly average of approximately the following amount of pitwood, viz.:—

	Linear feet.	Equivalent in solid cubic feet (quarter-girth measurement).
Imported wood, almost entirely Spruce and Scots Fir, coming chiefly from Baltic ports . . .	23,750,000	1,484,375
Home-grown wood, chiefly Scots Fir and Spruce from the north of Scotland	1,250,000	78,125
Totals	25,000,000	1,562,500

The description of wood preferred for the mines consists of:—

Round Fir "props," which run from 2½ ft. to 6 ft. in length; the most suitable diameter being 3 in. at the smaller end.

Round Fir "bars," which vary in length from 6 ft. to 9 ft.; they should have a diameter of from 4 in. to 6 in. at the smaller end.

Sleepers, which measure from 2 ft. 6 in. to 2 ft. 9 in. in length, with a cross-section of 5 in. by 2½ in., and are sawn from butt-ends which are too thick for props or bars. By far the larger quantity of timber used is in the form of "props."

The wood delivered to the mines from the Raith Estate is, for the most part, Beech, Elm, and other hardwoods of rough quality, sawn out of tops and branches into pieces from 2½ ft. to 4 ft. in length, and 3 in. by 3 in. in cross-section. The miners do not much like this class of wood, as it is comparatively heavy, and is difficult to handle on account of splinters. They prefer the imported wood, because, being better seasoned, it is lighter, it has a smoother surface and a more uniform thickness, it is more free from knots, and it is also stronger, on account of the narrowness of its annual rings. They prefer Spruce, because that species excels Scots Fir in most of the above qualities. For imported round Spruce and Scots Fir props and bars, delivered at the mines, the average rate now paid amounts to 4s. 1½d. per hundred linear feet, which is equivalent to 8d. per (quarter-girth) cub. ft. Wood of the same species, brought for the most part from the north of Scotland by sea, in the form of pit-lengths cut from round poles, and partially squared with the axe, to reduce bulk and weight during transport, is paid for at an average rate of 3s. per hundred linear feet, delivered at the mines; this rate amounts to about 6d. per (quarter-girth) cub. ft., which would represent a price of 5d. in the Raith woods. This timber is not so well seasoned as that which is imported from abroad, and it is therefore heavier; it is also of a much rougher quality. For the rough sawn wood from the Raith Estate, the price now paid at the pit's mouth amounts to about 2s. 7d. per hundred linear feet, or about 5d. per (quarter-girth) cub. ft., which represents from 3d. to 3½d. in the forest. A few years ago, the prices paid were higher than this (Bailey, in the *Trans. Roy. Scot. Arbor. Socy.*, vol. xv. part iii., 1898, p. 232).

As a rule, coniferous pitwood is sold to the merchant in whole lengths of stem, and he converts and sorts it according to the usual trade dimensions. Besides thinnings, whole crops of coniferous timber are disposed of for this purpose, as well as the branchwood of broad-leaved trees.

5. **Railway-Sleepers.**—Oak and Larch are by far the most durable woods, if the timber be used in its original condition, without antiseptic treatment; but even these are now treated antiseptically. As various methods of treatment make foreign Scots Pine sleepers also durable, the latter are now largely used, because they can be delivered from abroad in the railway companies' yards at a considerably lower cost than well-seasoned home-grown Larch sleepers. Wooden sleepers are always preferable to iron ones, as they are more elastic, and therefore less apt to wear out the rolling-stock.

With the standard gauge of 4 ft. 8½ in. between the rails, the standard size of sleepers in Britain is now 9 ft. × 10 in. × 5 in., so that each contains 3⅛ cub. ft. For each mile of railway 1936 sleepers, or 6050 cub. ft. of converted wood, are thus used; and as there are in round numbers about 25,000 miles of railway in the United Kingdom, this means altogether 48,400,000 sleepers, or about 151,250,000 cub. ft. of converted wood. Assuming the average life of a sleeper to be 20 years—a very long durability, only attained by the best class of Larch, Oak, and Scots Pine (antiseptically treated)—this means the annual replacement of not less than 2,420,000, sleepers, or 7,562,500 cub. ft. of converted wood, representing at least 10,000,000 to 12,000,000 cub. ft. in the round. If to this be added the annual requirement for the replacement of telegraph poles and wooden fencing along the lines, the total annual demand is probably something between 12,000,000 to 15,000,000 cub. ft. of converted wood, representing at the very least 18,000,000 to 20,000,000 cub. ft. in the log, and absorbing the entire yield obtainable continuously from 240,000 to 250,000 acres of good Scots Pine woods worked with a 50-year rotation and yielding 4000 cub. ft. (actual cubic contents) per acre when felled at 50 years of age.

For conversion into sleepers, fairly large timber is necessary. The sleeper-section being 10 in. × 5 in., the small end of a log, or of any sleeper-length of a log, must be *over 10 in.* in top-diameter before it can yield 1 sleeper; *over 14 in.* in diameter before it can yield 2 sleepers (the 2-sleeper-square being then 10 in., and the consequent diameter $= \sqrt{200} = 14{\cdot}1$ in.); *over 18 in.* ($\sqrt{10^2 \times 15^2} = \sqrt{325} = 18{\cdot}0$) before it will give 3 full-sized sleepers (although the 2 large side-slabs could give other 2 sleepers of smaller size with waney edges); while a log of 22⅓ in. diameter will give 6 good sleepers in all—viz., 4 from the centre beam ($\sqrt{10^2 \times 20^2} = \sqrt{500} = 22{\cdot}3$) and 1 from each of the two large side-slabs. The out-turn of sleepers varies from 64 to 77 per cent of the total cubic contents in the round, as from 24 to 36 per cent go into slabs and sawdust. Log-sections of 22⅓ in. diameter give the largest out-turn in sleepers (viz., 6 with 300 sq. in. of superficies out of a total log superficies of 390 sq. in., or 76·9 per cent sleepers and 23·1 per cent slabs and wastage in sawdust); while sections of 14 to 15 in. top-diameter give 2 sleepers with 100 sq. in. out of a superficies of 157 sq. in., or a yield of 63½ per cent, with 36½ per cent of good-sized slabs and but little actual wastage in sawdust. And it is of course necessary that only good round wood should be used, free from holes caused by branch-knots.

In Germany, in 1898, there were 32,500 miles of railway, on which there were 72,100,000 wooden and 22,600,000 iron sleepers (also 277 miles with stone sleepers). Of the wooden sleepers, 41,000,000, or 56 per cent, were of coniferous wood, 28,000,000, or 39 per cent, Oak, and 3,000,000, or 5 per cent, Beech. Of the total, 88 per cent were impregnated, and 12 per cent not treated antiseptically. The use of Oak is steadily decreasing, and that of Conifers and Beech increasing; but there is also a greater increase in the use of iron sleepers than of wooden ones. From 1887 to 1897 there was an increase of 20 per cent in the number of wooden sleepers used, but the increase in iron sleepers was 129 per cent. As the mean life of a sleeper is only estimated at 10 to 12 years, the annual requirements are about 6,500,000 sleepers; and as each sleeper (slightly larger than the British standard size) requires nearly 6 ft. of wood in the log for its conversion, over 38,850,000 cub. ft. of wood in the log are needed for sleepers alone. Estimating the average yield of timber per acre per annum as giving 50 cub. ft. (*i.e.*, 2500 cub. ft. actual contents fit for sleeper-timber in Scots Pine felled at 50 years of age), this will continuously absorb the yield from 777,000 acres of woodland, or about one-fortieth of the total forest area in the German Empire. Under a Public Works order, dated 6th July 1885, only wood felled between 1st November to 1st March is to be converted into sleepers (Stoetzer, *op. cit.*, p. 187). In Germany, Oak is the chief wood used; then Scots Pine and Larch in the Alpine districts; then creosoted Beech in much smaller number.

On the Alsace and Lorraine railways, Beech sleepers impregnated with carbolised oil of tar have been found to last 20 years, as compared with 18 years for Oak; and this is explained by the fact that Beech absorbs more of the oil than Oak does.

In France, creosoted Beech and Sweet-Chestnut are largely used, and it is even claimed that the Beech sleepers last for 30 years (see also Chap. IV. p. 544).

6. **Telegraph and Telephone Poles.**—Of home-grown timber, Larch and Scots Pine are best, but "Norway red Fir" (Scots Pine) is mostly used, as they are lighter to handle, easier and cheaper to dress, and stronger. Home-grown Larch is only used to a very limited extent, as creosote cannot be injected into it. Spruce takes creosote even worse than Larch, otherwise well-creosoted Spruce would be in every way suitable for telegraph posts (see Chap. IV. p. 554). Telegraph poles are classified as under—

Description.	Length.	Top-diameter, without bark.		Minimum diameter, at 5 feet from butt.
		Minimum.	Maximum.	
	Feet.	Inches.	Inches.	Inches.
Light . .	28	5	6	7
Medium .	30	6	7¾	8¾
Stout . .	30	7½	9½	10¾

The experiments made by the Postal Department to test the comparative strength of home-grown and Scandinavian Pine for posts gave the following results (*Report of Deptl. Com. on Brit. Forestry*, 1903, Appendix xviii. p. 190:—

Description of Scots Pine.	Relative strength.
Norwegian, creosoted . . .	100
Scottish, creosoted, 1894 . .	88·4
" " 1895 . .	71·3
" " 1897 . .	91·5
Norwegian, uncreosoted . .	100
Scottish, " . .	81·0

In Germany, Spruce, Scots Pine, and Larch are chiefly used; and as they are always impregnated before use, the summer-felled wood is preferred to the winter-felled.

7. **Scaffolding**, &c.—Scots Pine, Spruce, and Silver Fir are chiefly employed; but comparatively little home-grown wood is thus used, as the foreign imports are longer, lighter, easier to handle, and cheaper at all trade centres.

8. **Cabinet-making and Furniture.**—These trades absorb a very large proportion of our home-grown timber, as British wood is mostly superior to foreign in colour and figure. Oak, Ash, Elm, Maple, Sycamore, Walnut, and Birch are all largely used for the better classes of furniture, for which the home-supply is nothing like sufficient. The Beech chair-making industry of Bucks and neighbourhood, which supports 50,000 families, or about 250,000 souls, though based originally on local supplies, has now to import about 90 per cent of the wood required. For rough furniture any kind of soft or coniferous wood is used, most of it being imported.

Coach-building.—Ash is chiefly used, also Oak and Elm.

Cart and Waggon-building and Wheelwrights' Work.—Ash, Oak, and Elm are used for framework and wheels; Birch, Willow, Poplar, Horse-Chestnut, and Lime for bottoms and sides of waggons. The best **naves** of wheels are made from Oak, Elm, Hornbeam, and Ash, and the best **spokes** and **felloes** of Ash, Oak, Mountain-Ash, and Robinia, young tough wood being best for spokes.

Agricultural Implements.—Ash is chiefly used, also Oak, and Wych Elm in Scotland where Ash is scarce.

Cooperage.—Most of the timber used for staves is imported ready for use, though home-grown Oak, Sweet-Chestnut, Birch, and Elm are also used for the staves of herring-barrels, which are bound with withes of Hazel, Sweet-Chestnut, Oak, Birch, or Willow. For staves, the wood is split radially in the direction of the medullary rays, to prevent leakage.

Clog-making.—Alder is chiefly used, but also Birch, and to some extent also Willow and Poplar. The clog-makers usually work up the raw material by hand in the woods, so that this industry (as also the cleaving of wood for coopers) cannot be encouraged during the late spring and early summer in woods where game is preserved.

In Central France, clogs are shaped by vertical spindle machinery and finished by hand (piece-work). Boys are chiefly employed, and earn about 1s. 8d. a day, as men's wages would amount to about the double of that. The clogs cost about 3½d. a pair, of which 2½d. is for wood and 1d. for labour. Some of the clog-mills turn out 400,000 pairs a year.

For **Estate work** all kinds of home-grown wood are used, Larch, Oak, and Ash being those most suitable for general purposes. From the coppices the larger sizes of stems give hop- and fence-poles, and the smaller ones hurdle-stakes, bean- and pea-sticks, bobbin-wood and coopers' ware (of hardwoods chiefly), charcoal-wood (of softwoods chiefly), thatching-sprays, bavins, and various other small material, while the refuse is only fit for faggoting as firewood.

Note.—For **repairs to banks of streams**, a branch of estate work usually carried out by the forester, the best woods (if employed without creosoting) for general use between wind and water are Oak, Larch, and good Scots Pine, while Alder, Elm and green summer-felled Beech are specially durable when used entirely under water.

Where the stream-banks have been damaged by floods, the breach should be repaired by driving in a row of strong upright wooden posts from 2½ to 3 ft. into the ground along the water-line and level with the bank. A strong rail should then be nailed along or close to their tops to keep them in position, and another close to the water-level. **Fascines** or long bundles of brushwood from coppices, or Spruce or Silver Fir plantations, are then firmly packed in behind up to the water-level, and earth is thrown on the top and firmly trodden down and covered with turf sods. Well packed, such fascine repairs hold good for years. Where stones are plentiful, the broken parts of the bank can be faced with **rubble** after being levelled, smoothed, and sloped. The bank is then faced with large stones set edgeways, the largest being placed below, and the whole built up to above flood-level. A row of posts firmed by a couple of rails adds to the stability, and prevents the rubble being undermined and displaced (Fig. 213). Or damaged parts of a bank may be **faced with wood** (Fig. 214), by driving in posts (*a*) at an angle, and supporting them by other piles (*b*) and cross-pieces (*c*) nailed to keep both firm, then facing the posts (*a*) with strong planks, and packing the whole firmly behind with earth to make it secure. This method is, however, expensive.

Fig. 213.

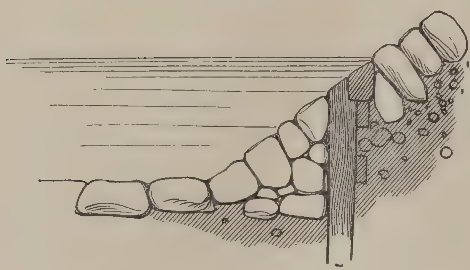
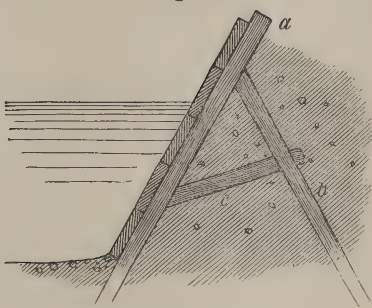


Fig. 214.



In such bank-repairs the tops and ends of the repaired parts should be well turfed, otherwise the next flood may wash out the soft earth. If large trees are allowed to grow near a river-bank, their roots are likely to cause erosion. Wherever there is danger of undermining, it is best to plant the banks with osiers and coppice them annually, when their roots help to bind the soil. The erosive force at river-bends can be broken by diverting the course of the current with breakwaters made of stones, or of fascines of brushwood held in place by posts.

The Market Value of British Timber varies greatly in different localities throughout the United Kingdom. Owing to the enormous imports, wood for constructive purposes can usually be bought cheaper in all great trading centres than in many inland places not well served by rail or river; while the local selling-price is often regulated mainly by the distance of, and cost of delivery at, the nearest port or large town (see remarks in vol. i., *Introduction*, p. 87). It is hardly possible to give any useful and reliable table of average selling-prices in different parts of the kingdom. The evidence put before the *Departmental Forestry Committee*, 1903, with regard to local prices in England, has already been given (see Part I. p. 89). To it may be added the tabular abstract given on pp. 464–465 compiled by Mr. D. F. Mackenzie, and published in the *Trans. Roy. Scot. Arbor. Socy.* (vol. xvi. Part iii., 1901, pp. 494-506), along with the following note :—

Note.—That these figures will be found useful to many cannot be doubted. The number of returns received is, however, disappointingly few. England sends eight, Scotland fourteen, and Ireland only two. These are sufficient, however, to indicate the direction in which the timber trade is drifting. It is stated in several of them that the supply is unequal to the demand.

In analysing the figures, it may be observed that they vary considerably ; but it is quite evident that a great improvement in values has taken place, and that the demand is good throughout. In districts adjacent to boat-building stations, prices rule higher for most kinds of wood. It is evident that a good deal of the timber sold has been of second and even third quality. This may be accounted for in several ways—(1) Hardwoods, or broad-leaved trees, are seldom put upon the market in quantity and in proper condition. They are either so old as to be decayed in the heart, branchy, and brittle, or are of such small dimensions as to be useless for the best markets. Timber merchants say that a good sound lot of hardwood of large size rarely finds its way into the market. This is to a great extent the explanation of the variation in prices for the same article. Take Plane, for example; the returns range from 1s. to 5s. per cubic foot. Distance from market is not accountable for this difference. (2) The quality of Pine and other timber of small sizes is inferior, owing to the large quantities of immature timber thrust upon the market through the bad effect of gales; and also, generally speaking, to the fact that parts of our woods are grown on the clump-and-belt system, where sylvicultural principles cannot be observed, and which produce an inferior, coarse-grained, and brittle class of timber. (3) The felling of timber which is immature, and is cut at all seasons of the year. These facts, taken together, account to a large extent for the amount of inferior timber one finds in the market. Notwithstanding all defects and faults, our home timber in the manufactured state fetches, class for class, a higher price than is paid for the imported article.

Locality.	Class.	Ash. Per cubic foot.	Ash. Per ton.	Beech. Per cubic foot.	Beech. Per ton.	Elm. Per cubic foot.	Elm. Per ton.	Oak. Per cubic foot.	Oak. Per ton.	Plane. Per cubic foot.	Plane. Per ton.
		s. d.	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*	*s. d.*
ENGLAND.											
County—											
Derby	1	1 6	...	0 8	...	1 0	...	1 4	...	0 9	...
Durham	1	1 0	...	0 6	...	0 6	...	1 0	...	...	...
Gloucester (near Bristol)	Average	1 11	...	0 11	...	1 1	...	1 6	...	...	...
Hants	,,	2 1	...	1 0	...	...	...	2 6	...	...	...
Hants, North	1	3 0	...	1 0	...	1 0	...	2 3	...	...	...
,, ,,	2	2 0	...	0 10	...	...	...	2 0	...	...	...
,, ,,	3	1 6	...	0 9	...	...	...	1 7	...	...	...
Hertford	1	2 2	...	...	...	...	...	2 3	...	3 6	...
Kent (Canterbury District)	Average	...	...	0 8	...	1 8	...	2 6	...	...	...
Leicester	1	1 8	...	...	...	0 11	...	1 6	...	...	...
SCOTLAND.											
County—											
Ayr	1	1 2	...	0 11	...	1 0	...	1 2	...	1 3	...
,,	1	1 1	25 0	0 6	12 0	1 0	...	1 2	26 0	1 4	26 0
,,	2	0 6	12 0	...	7 6	0 6	10 0	0 8	13 0	0 8	14 0
,,	3	...	7 6	...	...	...	...	...	...	...	...
,,	...	1 2	...	1 2	...	...	...	1 4	...	...	...
Dumbarton	2	1 0	12 0	0 10	10 0	1 0	10 0	1 0	10 0	5 0	50 0
Fife	Average	...	...	1 2½	10 0	1 2	...	1 3	...	1 6	...
,,	,,	1 9	...	1 1	...	0 11	...	1 7	...	2/- to 3/6	...
,,	,,	...	...	1 3	...	1 3	...	1 8	...	...	...
Forfar	1	2 0	...	2 3	...	1 9	...	2 0	...	4 0	30/- to 40/-
,,	2	1 3	...	1 0	...	1 3	...	1 3	...	1 3	
,,	...	1 4	12 0	1 0	12 0	1 4	12 0	1 3	...	3 6	20 0
,,	...	...	...	...	...	...	...	...	...	...	...
Forres	Average	...	...	...	...	...	...	...	...	...	...
Peebles	1	1 4	...	0 8	...	...	...	1 4	...	3 6	...
,,	...	1 2	...	0 6	...	...	...	1 0	...	1 6	...
,,	...	0 10	...	0 4	...	...	...	0 10	...	1 0	...
Ross	Average	1 6	...	0 8	...	1 6	...	1 6	...	1 0	...
Roxburgh	1	1 6	...	0 10	...	0 8	...	1 4	...	2 0	...
,,	2	0 9	...	0 8	...	0 6	...	1 0	...	1 4	...
Sutherland	1	1 6	...	1 0	...	1 6	...	1 6	...	...	...
,,	2	0 8	...	0 6	...	0 8	...	0 9	...	...	...
IRELAND.											
County—											
Armagh	1	1 0	...	...	8 0	0 9	...	0 10	...	2 0	...
,,	2	0 9	...	...	6 0	...	7 0	...	10 0	...	10 0
Kilkenny	...	1 0	20 0	...	10 0	0 9	15 0	1 0	20 0	...	...

Larch. Per cubic foot.	Larch. Per 100 lineal feet.	Scots Fir. Per cubic foot.	Scots Fir. Per 100 lineal feet.	Spruce. Per cubic foot.	Spruce. Per 100 lineal feet.	Various. Per cubic foot.	Various. Per 100 lineal feet.	Various. Per ton.	Remarks.
s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	
1 1	...	0 9	...	0 7	...	Cord	wood,	5 0	There is a good demand for all sorts of timber in this district.
...	...	...	...	...	...	...	...	...	Sold by private tender.
...	...	...	...	...	...	...	...	...	Softwoods used for estate purposes. All wood fair quality. Good demand for home-grown timber of fair quality.
...	...	...	...	...	...	...	...	...	
1 0	...	0 8	...	0 8	...	...	...	...	These prices range lower than formerly.
...	...	0 6	...	0 6	...	...	...	...	
...	...	...	...	...	...	...	...	...	
1 0	...	0 8	...	0 6	...	...	...	...	These prices are 2d. under those ruling last year.
...	...	...	...	...	...	Spanish Chestnut,		...	Oak ranges from 2s. to 3s. per cubic foot.
1 4	...	0 11	...	0 6	...	1 10	...	...	Silver Fir sold at 10d. These are the average prices of a considerable quantity of timber.
1 1	5 0	0 7	3 0	0 5	3 0	...	...	...	These are the prices paid for timber of good quality.
1 4	9 6	0 6	...	0 6	...	0 6	3 4	...	
1 0	5 0	...	3 4	...	...	...	...	...	
...	...	...	...	...	...	...	...	...	
...	...	...	...	...	...	...	Birch,	9 3	The Beech was of superior quality.
1 0	8 4	0 8	4 0	0 8	4 0	0 9 {	Salix	} 8 0	Not a very good timber-growing district.
1 1	...	0 6	...	0 5	...	...	...	...	Small Plane for Rollers at 41s. 8d. to 50s. per 100 lineal feet.
1 1	...	0 7	3 6	0 4½	3 0	...	3 0	8 0	Ash ranges from 1s. 6d.
1 3	...	0 6	...	0 3½	...	...	...	...	
1 6	...	0 6	Stack Props,	0 4	Stack Props,	1 2	} Poplar.		Wood of all kinds getting scarce, and still rising in price. Birch and Elder in demand at 10s. to 15s. per ton. Beech limbs for turning 10s. to 15s.
1 0	...	0 4	8 4	0 3	6 4	0 10			
1 0	17 0	0 6	3 6	0 5	3 6	...	...	...	Plane trees 7 ins. to 9 ins. diameter, and limbs same size, 6d. to 10d. per lineal foot. This is for timber in the woods. Heavy larch gives 1s. 4d. to 1s. 6d. Markets—boat-building, stations, &c.
...	...	...	...	...	...	...	Alder,	12 0	Three miles from railway station.
1 0	12 0	0 5	5 6	...	...	...	...	...	Sold in lots lying cut in wood.
1 0	...	0 6	...	0 4	...	...	...	...	Grown at 700 to 1320 ft. above sea-level, easterly exposure. These prices are for root cuts.
0 11	...	0 5	...	0 3	...	...	...	...	
0 9	...	0 3	...	...	...	...	...	...	
1 0	...	0 4½	...	0 4	...	...	10 0	...	Pine timber excepted, manufactured wood sells at double these figures.
...	...	...	...	...	...	...	...	...	Most of this was blown timber.
...	...	...	...	...	...	...	...	...	
1 0	...	0 6	...	0 5	...	...	Alder,	5 0	All sold by private tender. Wood situated 3 to 8 miles from railway and shipping port.
0 8	...	0 4	...	0 3½	...	...	...	...	
0 8	...	0 4	...	0 4	...	...	...	10 0	Used for general purposes locally, and exported. Branches 1s. to 1s. 6d. per load. Lime and Horse-Chestnut 7s. per ton. Spanish Chestnut not in demand.
0 6	...	...	...	...	...	...	...	...	
0 9	15 0	...	...	0 4	6 0	...	...	...	The prices per ton are for mining timber and firewood.

CHAPTER II.

THE HARVESTING AND SALE OF WOODLAND PRODUCE.

THE marketable products obtainable from woodland crops may be divided into **main produce**, including timber and smaller wood, also rods and withes from osier-holts, and **minor produce**, consisting of tanning-bark, tree-seeds, resin, and similar material. The former kinds of raw material are those for the express purpose of producing which the woods are worked, except perhaps in the case of Oak-bark coppices; while the latter are, with the same exception, merely casual products that can usually be harvested either along with the main crop, or without diminishing its productivity or value as timber.

1. **The harvesting of Timber and smaller wood**, whether grown as **highwood**, **copse**, or **coppice**, can only take place by **felling** or **cutting**. Falls of timber or of wood of smaller dimensions may, however, be made either when the crop has attained the full age of maturity desired (in which case it is either clear-felled for replantation, or falls are made to the extent necessary for natural regeneration), or else, to some greater or less extent, before the crop is mature,—these latter falls being **thinnings** or **intermediate yield**, while the former constitute the **mature yield** or **timber-crop**.

Fellings in coppice, copse, and highwood crops are ordinarily made with **handbills** or **billhooks**, **axes**, and **saws**,[1] according to the size of the material to be felled; and when the stumps are removed, either along with the bole or separately, **lever appliances** of one sort or another have to be made use of to give the extra power required.

1. The produce of osier-holts and of coppices worked in the ordinary short rotation, and the thinnings in young plantations, can be easily cut with **bills**, the stool-shoots being severed with a clean, sharp cut. There are various forms of bill, most of which have more or less of a curved shape; and their cutting-power depends mainly upon their weight and balance, in addition to the sharpness of their cutting-edge. The most effective instrument of this class, and one of the handiest, is a heavy, well-balanced bill with a slightly-curved blade about 16 to 20 in. long, and about ¼ to ⅓ in. thick along the very slightly concave back, the cutting-edge having a slight convex bend, set in a handle about 9 to 10 in. long, and bulging somewhat towards the middle to give a firm grip.

As it is always important to make a clean cut, this can be better secured by bending down the young stem or shoot slightly with the left hand when delivering the blow with the right. Poles that cannot be severed at one stroke should, to

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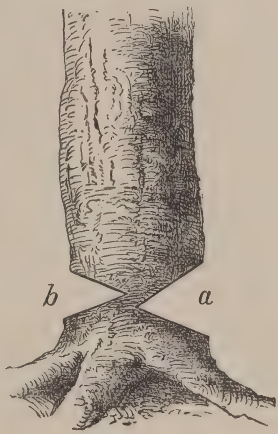
[1] Illustrations of the best kinds of implements of these three classes will be found in all the catalogues issued by good firms.

prevent tearing of the bark and splitting of the stool, be laid into on one side and then cut from the other, as in felling with the axe; and in coppices particular care should be taken to make the cut surface of the stool smooth and sloping to prevent lodgment of water.

2. At time of cutting, coppices in England are generally marked off with sticks into strips 33 ft. broad, known locally as *hags* and *lands*, and the different kinds of material are assorted on each hag as it is cleared. In felling large poles or trees with the **axe** alone, the tree is either laid in deeply all round the base, close to the ground, with the grubbing-axe, and then pulled over by rope or chain, or else (Fig. 215) the stem is first **laid in** by making out a wedged-shaped cleft at *a*, on the side to which the stem is desired to be thrown. This first cut should be made as low down as possible, and should penetrate as far as, or slightly beyond, the heart or central point of the trunk. The second cleft, *b*, must be made on the opposite side of the stem, and should be so laid in that the apex of the angle formed by it should, if completed, just about come above the apex of that formed by *a*. When there is likely to be any difficulty about the stem falling in the exact direction desired, a round branch or billet may be inserted into *b*, and then a wedge or wedges below it, and as these are driven home the stem is forced over. It is astonishing how exactly skilled woodmen can make stems fall in almost any desired position. In felling large valuable timber trees with the axe alone, the roots may be cut through, and the earth cleared away, in order to allow the workmen to fell as low down as possible.

Fig. 215.



Felling by the Axe alone.

There are various kinds of axes, specially used for felling, lopping, splitting, grubbing, and trimming. These differ as to their shape and weight; but they all consist of two pieces, viz., the steel-faced **head** and the tough **shaft** or **handle**, and of course their cutting-power depends, *cæteris paribus*, on the weight of the head and the length of the shaft, while it is very distinctly increased by the face of the blade having a slightly convex edge. In the **felling axe** the head is comparatively light (about 3 lbs.), and with a convex cutting-edge, while the shaft, made of Ash, Mountain-Ash, or other tough wood, is usually about 30 in. long, and slightly curved to give freer play to the right hand when making the stroke. The most effective of such axes is the well-known *Kenebeck or Pennsylvanian Axe*, with bulging cheeks (to prevent jamming), which is imported in large numbers from America, and is made in two sizes ($5\frac{1}{2}$ and 7 lbs. total weight). The **Collins** axe, somewhat lighter ($3\frac{1}{3}$ to 5 lbs., and costing 3s. and 4s. without shaft), is also largely used. For felling large trees in Australia, axes having three broad parallel grooves running from the edge to the back of the blade, are said to cut more easily into the wood, and to be least liable to get jammed. The **lopping axe** is rather heavier in the head, straighter in the face, and shorter in the shaft than the felling axe; but the special shape, &c., vary more or less locally. The **splitting axe** is still heavier in the head (5 to 8 lbs.), and more wedge-shaped. Sometimes it has a flat cutting-edge, at other times it is slightly convex. The **grubbing axe** is also heavy in the head for rough work. The **trimming axe**, used for rough-hewing balks, has a broad blade, like a headsman's axe, and the head (weighing up to 6 or 8 lbs.) is set at an angle to the shaft to enable the woodman to use it. The shaft varies from about 18 or 20 in. up to 4 or $4\frac{1}{2}$ ft. long, according to the manner of its use.

The long-shafted and heaviest-headed axes are used by woodmen standing upright on the log, the sides of which they are rough-hewing.

3. Felling with the **saw** alone is only convenient in the case of small stems. These are simply sawn through from the opposite side to which the fall is desired, and then pushed over. But with larger trunks a cut should be made first of all on the side to which the fall is desired, and to a depth of 4 to 6 in., or more if the saw work freely, and then a second cut on the side directly opposite to that. When the saw has penetrated to some depth, it will be sure to get so jammed as to hinder it working freely, and then wedges must be made use of to keep the slot or cut open. These wedges, which may require to be driven home occasionally, at the same time act directly in forcing the stem slightly over to the side on which the fall is desired; and by means of these the tree is finally thrown.

The action of a saw is twofold, because it combines cutting with tearing.[1] The harder and the shorter the fibre of the wood, the more does the cutting action come into play (as in sawing hardwoods); while the longer and the tougher the fibres, the more is a tearing action necessary (as in softwoods and most Conifers). The softer the wood, therefore, the more force requires to be exerted in sawing it, and the greater is the wastage in sawdust.

For petty work, such as pruning, **one-handed saws** are used. These are generally only about 1½ to 2 ft. long, and the teeth are all arranged so as to act with the forward stroke only, and not with the backward pull (which mostly clears out the sawdust). For cross-cutting of large poles or small logs however, a one-handed American saw, 3 ft. long, is in use, which has a slightly convex blade and teeth arranged for cutting both ways. For any heavier class of work in felling or in cross-cutting, **two-handed saws**, usually from 4 to 6 ft. long, and worked by two men, are in use. The efficacy of any saw depends, however, greatly on a convenient shape and position of the handle or handles.

As also in the case of axes, so too there are many local kinds of saws; but those now usually considered the most effective are the two American forms known as the *Nonpareil* and the *Great American Saws*, which have patent adjustable handles.

The main points common to all good saws are—(1) that they should be made of the best steel, (2) that the cutting-edge should be slightly convex, (3) that the teeth (Fig. 216) should be more or less triangular (formerly they were often M-shaped), (4) that they should provide ample space for removing the sawdust (which is of about six times the bulk of the wood it represents), (5) that the saw should weigh between 5 and 6 lbs., (6) that the teeth should be well *set* to alternate sides, and (7) that the back of the blade should be somewhat thinner than the face. This difference in thickness between the front and the back of the saw tends to reduce friction, which is further diminished by greasing the saw. To prevent the jamming of the blade, wedges have of course to be used. It has never been settled theoreti-

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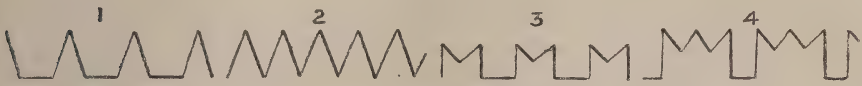
[1] The oldest and commonest, with the widest range of adaptability, is the straight saw, with reciprocating rectilinear blade. In this class is included the ordinary hand-saw, with its varying range of uses, from fine to coarse and from rip to cross-cut, and with teeth of forms as various as are the different duties which it is calculated to perform. The teeth are long or short, cutting one way or both ways, according to the "pitch" or "set" which may be given, and which should be adapted to both the kind and character of the timber to be sawn. The "pitch" of a saw-tooth is the angle of the point with reference to the blade, and is found by subtracting the back angle from the front, 60° being the generic angle of saw-teeth, which, however, may be variously placed. From the smallest hand-saw to the largest "mill-saw" the same general rule applies. In the largest saws of this class may be named the "pit-saw," used in the earliest manufactures of lumber or timber, and worked by one person standing over the log and drawing upward, while another in the pit below follows with the downward or cutting thrust (G. W. Hotchkiss, article on *Saws* in *Encyc. Brit.*, 9th edit., 1886, vol. xxi. p. 343; see also p. 567 in Chap. V. below).

cally what is the best convexity to give to the face of the blade of a saw; but practically it has been found that the convexity given by a radius of about 5 ft. is best for general purposes, though a saw with a higher convexity than that is easier to work and more effective for sawing Conifers and softwoods, while saws with a straighter edge and lower convexity than the above are more effective in sawing

Fig. 216.



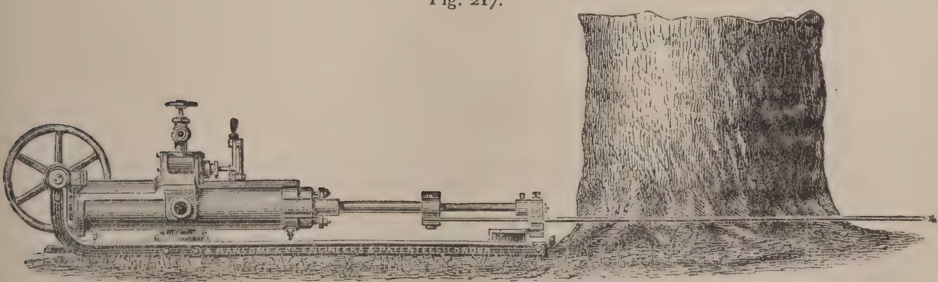
Teeth of Two-handed Saws.

hardwoods, especially logs of large size. Saws with upright triangular cutting-teeth, interrupted at regular intervals by somewhat shorter, single spaced-teeth for holding the sawdust, are usually found the best to work with. Of course, the greater the convexity, the less of the cutting-edge forming the face of the saw comes in contact with the hard wood; the greater, therefore, must be the cutting and tearing power of the parts in actual contact, while the sawdust is also more easily expelled and prevented from interfering with the teeth of the saw. In the *Nonpareil* and the *Great American Saws* three or four teeth are grouped together, and are then followed either by a deep, hollow space (*Great American*) or by one single tooth with a good deep space on each side of it (*Nonpareil*), which provides plenty of room for sawdust. They have somewhat low convexity, but are on the whole the best of saws for large hardwoods.

Good two-handed saws, with movable handles and crown-shaped teeth, now cost from 6s. to 10s., according to length (4 ft. to 5 ft. 8 in.).

In all saws it is necessary to **set** the teeth alternately to right and left in order to prevent the buckling of the blade when being drawn to and fro by the two woodmen. The set has to be greater for Conifers and softwoods than is necessary for hardwoods. With use the teeth lose their set to some extent, and have to be equally re-set with a **setting-key**, worked with or without a screw. Some American saws are so constructed that the teeth are thicker than the blade behind

Fig. 217.



them, and the effect of this is to make them work more easily then if the teeth were set alternately sidewards, as is usual. In time, too, the teeth get blunt and worn away, when they have to be sharpened with a file; and in the best American and other modern saws there are perforations in the blade to admit of the sharpening of the saw taking place more easily. Saws are now made of the best cast-steel. The blade must not be so hard as to prevent the teeth being set, nor so soft as to allow them to become soon blunted or to lose their set.

If one wishes to test and compare the working-power of saws, this can be done by ascertaining the time required to saw through a given superficies, or by measuring the superficies sawn through in a given time. But in all such tests, it is necessary that the kind of tree, dimensions, and other conditions of the logs operated on, the woodmen employed, and their acquaintance with the saws used, &c., should be as nearly as possible alike in all the tests.

Trees can also be sawn by steam-power (Fig. 217), but this method is nowhere largely used in Britain. Ransome's machine can also, however, cross-cut logs.

Fig. 218.

Felling with the Axe and Saw.

4. **Felling with Axe and Saw** is practically the best method for all large trees. The operation is performed in the manner represented in Fig. 218. A cleft, *ab*, which should penetrate to about $\frac{1}{5}$ to $\frac{1}{4}$ of the diameter of the stem, is first of all laid in with the axe on the side to which the fall is desired, and in the form shown in the illustration —*i.e.*, as nearly horizontal as possible in the base— and then the saw is applied at *c* on the opposite side. Here again wedges will be required in order to enable the saw to work freely, and to assist in ultimately throwing the stem. If metal wedges are used, their sides can be slightly toothed to prevent their slipping back. Ordinary wooden wedges are apt to recoil in frosty weather, and this can best be prevented by sprinkling sand or ashes along their sides. The **universal wedge**, made of the best steel, is sometimes used (costing 30s.). It can be screwed up as required (Fig. 219). It is said to be safer to use than ordinary wedges, as there is no risk of it springing back.

The first requirement to be made in felling timber is that it should allow the stem to be thrown in any particular direction, whilst at the same time enabling the largest possible quantity of timber to be removed in the log. These objects are combined better by felling with axe and saw than by using either of these implements alone; but it is often not practicable on very steep hillsides, or for stems of very large dimensions that must be cut in all round about, even although a good deal of wood is thereby wasted; and, of course, in thick crops of young pole-forest, the axe must be employed where there is not sufficient space for a free use of the long two-handed timber-saws. The best method is to chop through the buttress-like run of the roots near the ground-level with a grubbing-axe before laying in with the axe and cross-cutting with a two-handed saw. It is only thus that the trees can be felled so as to leave merely a small stump or *moot* sticking out of the ground.

Fig. 219.

According to Gayer, there is a loss of only 1 to $1\frac{1}{2}$ per cent of timber felled by axe and saw; whereas the wastage of wood amounts in large trees to from 4 to 7 per cent, and in poles to from 2 to 2½ per cent of the total out-turn, when the axe alone is used. The wastage is of course least where the turf and earth around the roots are laid bare, and the neck of the root-stock is trimmed for the use of axe or saw.

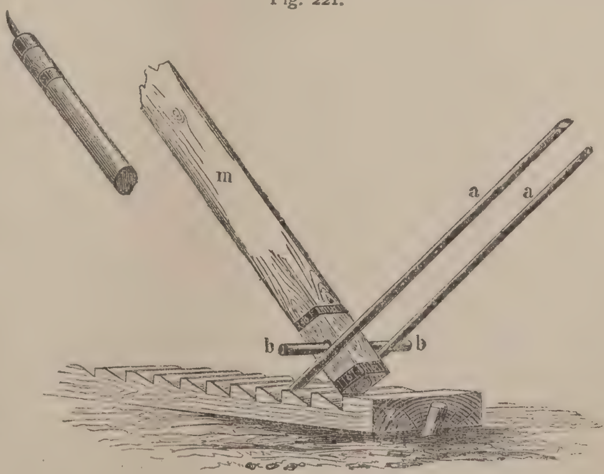
Fig. 220.

Black Forest Method of Throwing Conifers in Felling with the Axe alone.

As regards the **bark-allowance** that may be reckoned to the different classes of wood, Gayer makes the following remarks as to actual quantity :—

"*The loss of bark* in working up the different kinds of wood amounts to 4 per cent of the quantity of timber worked up in the case of Beech and other smooth-barked, broad-leaved trees; 7 per cent in Oak and other rough-barked, broad-leaved trees; 8 to 11 per cent in Pine, Spruce, and Silver Fir; and 15 to 18 per cent in Larch and Black Pine."

Fig. 221.



In Britain, the bark-allowance varies locally and for different kinds of trees; but the usual deduction of 1 in. per foot of girth comes to about 16 per cent of the whole actual contents of any log (see Part V. p. 291).

To obtain leverage for throwing the stems and thus facilitating felling operations, various arrangements exist. Fig. 220 exhibits a method largely practised in the Black Forest, where felling takes place with the axe alone, in order to secure the fall of the stem in a particular direction. After two wedge-shaped cuts have been laid in on opposite sides of the base of the stem, wooden wedges are inserted into the second cleft, and leverage is then applied by means of a stout pole, *m*, with which another pole, *ab*, has been connected by means of notches at *a* in the stem and *b* in the pole.

Fig. 222.

Wohmann's Felling-machine.

Wohmann's Felling-Machine (Figs. 221 and 222) is simply a development of the above. After the roots have been cut or the stem has been laid in all round, force is applied by the levers *aa*, acting on the pole *m*, whose base works along a sort of rack-base *z*, and whose apex consists of a metal tooth fixed at some firm and convenient part of the stem where it cannot easily slip. The practical effect of this contrivance is said to be from eight to ten times greater than that of the above more primitive Black Forest method.

In other parts of the Black Forest the common **timber-jack** is also used for throwing stems, as shown in Fig. 223, which requires no description.

One of the most powerful means of pulling down trees that have been laid in at the base with axe or saw consists, however, of the **Chain-Lever,** a very ancient Swiss instrument known as the **Waldteufel** or **"Wood-demon"** (Fig. 224), which was formerly used chiefly for hauling stumps out of the ground. It consists of two strong iron chains, *mm*, attached to a stout tough pole, *c*, which is fastened to some stable, holdfast object (like a large tree) by a mooring chain, A, and which acts in connection with the main chain, B, attached to the upper portion of the stem to be pulled over—as, for example, around some lofty branch. By moving the pole or lever C alternately backwards and forwards, the hooks *mm* can gradually be moved upwards link by link along B; and this, with a rigid iron

Fig. 223.

chain, of course, means that the top of the tree is very gradually, to the distance of one link each time, being dragged over. When this contrivance is brought into play simultaneously with the use of axe or saw, it very effectually assists the felling operations. Both in this and in Wohmann's machine the leverage is only very gradual, though very effective; and of course the higher up the stem either of these arrangements, or even a rope and a hook, or a rope alone, can be brought into play, the greater the leverage, and consequently the more effective is the result obtained.

This implement is in regular use on the Morton Hall Estate, Norwich, but, to the best of my belief, it is not in general use. Still, it has many qualities to recommend it. It is very simple in construction; it is comparatively inexpensive; it can be moved about and manipulated by four or five men; it can be fixed and applied in places inaccessible to horse- or steam-power; and, what is of most importance, it is very powerful, being much more so than the best rope-and-pulley tackle, and even approaching the traction-engine in this respect.

For steadying or swinging round leaning trees during the process of felling, for pulling down trees whose tops have fallen into the crowns of neighbouring ones, for pulling up roots, for turning heavy trees over, and such like work, it is simply invaluable, and, in my opinion, it should be included in the equipment of every timber-growing estate.

Fig. 224.

The Chain-Lever.

The "Chain-Lever," as it is locally termed, is made up of a stout Larch pole 14 ft. long, a bar of iron 4 ft. 6 in. by 3 in. by 1 in., and a sufficient supply of suitable chains or steel ropes, in lengths of from 10 to 20 ft. By clasps and wedges the iron bar is fixed to the butt end of the pole in such a manner that about two-thirds of its length project beyond the wood, and along the centre of this projecting portion a row of ⅝-inch holes, about 6 inches apart, is made; a stout coupling and pin is made and fitted into the centre hole, while two strong chains, 2 ft. long, are fitted with a similar coupling and pin at one end and a short pointed hook at the other; these chains are attached by their couplings to holes in the bar, one at each side of the centre coupling.

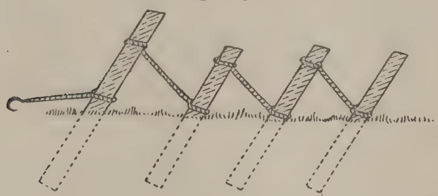
When a tree or other object is to be moved, a standing tree is selected, or a strong post is fixed into the ground, to act as a holdfast or fulcrum; round this a chain is passed, and the lever is attached by its coupling about 3 ft. from the holdfast. From 10 to 20 yards from the object to be hauled is a good distance at which to fix the lever, but a longer distance will answer the purpose, provided it is not longer than the supply of ropes and chains will admit of, and a shorter distance may be adopted if sufficient room is left for the working of the lever, which describes a semicircle in its movement. It is, perhaps, needless to mention that it is worked horizontally.

The lever being fixed, the next operation is to lay down a line of chains to the object to be moved, one end being made fast thereto, and the other, after the whole has been pulled as tight as possible by hand, being coupled to the lever. This being done, everything is ready for pulling.

To accomplish this, one man attends to the hooks, while three or four others go as near as possible to the free end of the lever, and push it round into position, when one hook will have pulled in the chain a little way, while the other can be put into another link a little farther up. The lever is then brought back to its previous position, during which movement the one hook is always pulling in the chain, while the other is released and put still farther up. And so the pulling goes on, hand-over-hand style, every movement showing one hook pulling and one hook being released for a fresh hold; and it is astonishing what weights can be thus moved.

This estate is bounded on the east by a river about 15 yards wide, and on the west bank there are a number of heavy poplars, growing very close to the edge of the bank, and about 8 ft. above the summer-level of the water. These trees are over-ripe, and have the heavy eastward list so common to this species, so much so that a perpendicular line from some of their tops would touch the water about 8 yards from their butts. They average 100 ft. in height, and this appliance has been of very great service in bringing them round clear of the water during the process of felling, and also in pulling out of the water a number of them which had been blown down. Last spring I was asked to take down a few of those standing closest to the river and leaning the most; and of thirteen trees selected, twelve were safely landed well on to the meadow without touching the water. The thirteenth one, through the breaking of a chain, fell into the river at right angles to its course, most of its branches resting on the meadow on the other side. Five men set to work, the tree was cross-cut on the opposite bank close to the water's edge, the lever was attached, and in four hours the main part of the bole was laid high and dry on the spot where it was meant to fall. The log measured 45 ft. long by 22 in. quarter-girth, equal to 151 cub. ft.

Fig. 225.



Five years ago a westerly gale uprooted a good many of these poplars, which all fell into the river, many feet of their tops lying on the opposite meadows. The lever was brought into action, and they were hauled to land at the rate of about one tree per day.

General Remarks.—When it becomes necessary to fix a post into the ground for a holdfast, it is, especially on marshy ground, sometimes a matter of considerable difficulty to make it firm enough to withstand the very great strain brought on it when the lever is at work. A plan I found to work admirably is that shown in the accompanying sketch (Fig. 225). The lever chains may be of any pattern, provided they are strong enough and have got a hook at one end and a ring or big link at the other, so that they may be easily coupled; but it is imperative to have, next the lever, a length of chain with equal sized links, such that the pulling hooks may fit into any of them. The chains we use are made of ½-inch and ⅝-inch iron, with links about 3 inches long; we have also a wire rope, 25 yards long, which is lighter and more easily hoisted into the top of a tree than the chains. For very heavy pulling I have found it advisable to put coupling C into the second hole from the wood instead of into the central hole, and to put the pulling chains into the first or nearest hole on each side.

I can recommend the lever with the greatest confidence as being an instrument of great power and real practical value in forest work (J. Rodger, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvi. part ii. pp. 189-192).

The Extraction of Tree-Stumps from the ground can take place by various instruments more or less like the Chain-lever in their action, such as those shown in Figs. 226 and 227, which hardly require any explanation. On the Continent, where firewood is high in price, this operation pays well, and is usual in the case of the high stumps left by felling with the saw alone. The **Hawkeye Machine** for extracting tree-stumps is merely a more powerful application of similar leverage worked by horse-power. Large stumps can also be blasted with gunpowder or dynamite when necessary, though this is not always cheaper than the methods above referred to.

The best Season for Felling depends to a great extent on the nature of the timber-crop and on local circumstances. In Britain there is no practical reason why, except as regards stripping bark when the flow of sap is most active, the greater part of the felling operations should not be conducted during late autumn, winter, and early spring, when, even in purely agricultural districts, labour is only too often in want of employment, and when the preservation of game is least interfered with. In some of the Continental forest-tracts heavy snowfall prevents work in the higher-lying coniferous woodlands during winter, and practically restricts forest operations of all sorts

Fig. 226.

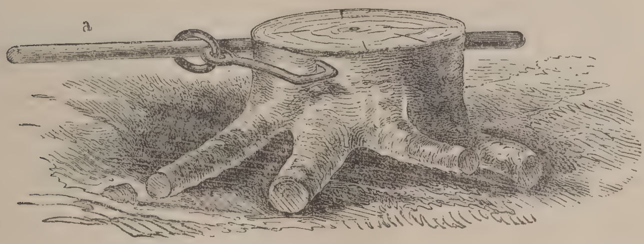
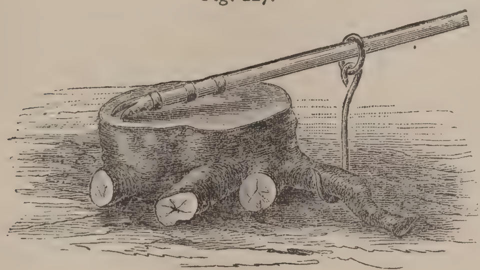


Fig. 227.



to the milder seasons of the year; but in no part of Britain can such climatic conditions be said to prevail. And it is a well-known fact that not only is the quality of the mature wood better, but also that less damage is done to young seedling growth and to neighbouring trees when the fall of timber takes place during the winter period of non-active vegetation.

Theoretically, felling in late autumn, just after the fall of the leaf, must, for most kinds of trees and for general purposes, be the best time so far as the technical quality of the wood is concerned. There are, however, exceptions to any such general rule. Thus Beech can be best steamed (for bent-wood furniture) or impregnated (for sleepers) if felled in sap and treated at once; and summer-felled wood is easier to cleave and split than winter-felled. Again, summer-felled Conifers are both less durable, and also more likely to be attacked by fungi and turned bluish in colour, than winter-felled wood; yet if large falls have to be protected against bark-beetles, it is best to fell in spring or summer, because it is only then that the bark will strip easily. This also helps to season the wood quickly, and makes it lighter for floating, while the bark can often be profitably disposed of (on the Continent, at any rate; see Fig. 136, p. 66). To prevent splitting and cracking, rings of bark are often left at the ends and in the middle. During winter and early spring the cambial layers of the stem gradually get filled with water, which rises from the soil by capillary attraction, until, with growing atmospheric temperature in spring, the flushing of the buds and the movement of the sap indicate the re-awakening of active vegetation. The minimum of moisture in the tree must therefore naturally be contained immediately after the fall of the leaf; hence from then till the time at which there is the maximum of moisture in the stem—*i.e.*, generally during the month of July (but see table on p. 429), when the summer flush of shoots and foliage appears—the technical quality of the wood will gradually decline, whereas from that same time till the minimum point is again reached it will gradually improve. Other considerations also require to be taken into account; for in wood felled in summer when containing a maximum of moisture, and exposed to the highest temperature of the year, the shrinkage both diametrally and tangentially will be considerably greater than at any other time of the year—*i.e.*, there will be more surface-cracks and star-like flaws formed at the ends of the log. In autumn-felled wood evaporation and shrinkage will of course be least, as above indicated.

There can, however, be no hard-and-fast dictum about such matters. Thus Bavarian investigations showed that winter-felled Pine and Spruce, tested within two to three months after the fall, had about 25 per cent more strength and elasticity than summer-felled wood; whereas Saxon investigations failed to discover any regularity about the variations, and seemed to indicate that the greater or less durability of the wood was less likely to be determined by the time of felling than by other external influences.

In practice, felling in Britain is mainly regulated by the time of the year when labour can easiest be obtained without interfering with other estate work and with game-preservation. In **osier-holts** the cutting of the crop begins in January, unless the beds are then inundated; and if labour were always obtainable, late winter would also be the best time for felling other kinds of **coppices** (except Oak-bark hags, of course, or coppices of Alder, Hazel, and Mountain-Ash to be peeled for charcoal-making for powder factories, where the flow of sap must be awaited) and **underwoods**. There is then less danger of the stools being damaged by hard frost than when felled in autumn or early winter, while the coppice-shoots come much more freely and strongly than if cut in spring or summer when more or less in sap. In order to prevent damage to stools and shoots, **Copse Standards** should be felled as soon as possible after the coppice is cut; and even if they are Oak, which it is intended to bark, the felling and peeling should be done as early in spring as the bark is found to strip. When the bark will not strip easily, as sometimes happens, then the trees should be felled all the same, otherwise they will cause damage to coppice-shoots if felled one year later, or must remain for another rotation though they are not wanted as overwood. In either of the former cases, the lopping of the crown and branches diminishes the chance of damage to underwood on the tree being felled. In the Hildesheim district (Hanover) 150- to 200-year-old Oak standards are barked standing in May and June, and then felled along with the coppice in the following winter. In **Highwoods** the best time for felling depends on the given circumstances. **Clear-felling** can take place either in winter or summer, according to the given circumstances and the intention or interests of the owner (*i.e.*, in Ireland, where Larch, Pine, and Spruce pitwood is sold by the ton weight, spring- and summer-felling yield the heaviest wood), but winter-felling is the rule. In **natural regenerations** least damage is done to the seedling growth when snow is lying on the ground. **Thinnings** in young plantations and thickets should, however, usually be done in spring, as early as is convenient after the flush of the foliage, so that the young crop may have the full advantage of the operations throughout the summer season. In crowded plantations this minimises the risk of damage resulting by any heavy fall of snow during the following winter. In older and maturing woods, however, the falls should be made in winter, although the scribe-marking of the smaller poles and the blazing and hammer-marking of the larger poles and trees to be removed ought to take place in summer while the crowns are in full foliage.

The Felling of Timber.—The main points to be kept in view by foresters and wood-cutters when felling stems of timber-size are as follows:—

1. *All the trees to be felled should be plainly blazed and hammer-marked, both well above and well below the felling-place.* This should prevent mistakes being made; and it also makes it easy to find out such, if made.

2. *Trees should be felled so as to give the largest possible out-turn in timber.*—This point is very apt to be disregarded if the timber-merchant is permitted to fell with his own men any standing timber he may have purchased by the cubic foot measured after felling and logging; but he is less likely to waste wood, if he buys the whole tree at so much as it stands. All large trees should be felled by axe and saw.

3. *Trees should be felled so as to do the least damage*, whether to neighbouring trees, underwood, hedges or fences, &c., or to themselves. Lopping the branches is therefore, in most cases, desirable. On hillsides it is usually best to let the tree fall slantingly up the hill, because the crash is then least, and the log can generally be removed easier.

4. *Trees should be felled in the direction from which their removal is easiest*, subject of course to the proviso that unnecessary damage is not thereby done.

5. *Timber felled should be at once cross-cut by saw into the best size of logs, and removed to the nearest road or green lane, and more trees should not be at any time felled and left on the ground than can be conveniently dragged out within the next two or three days.*

6. *On reaching the road, the smaller classes of wood from thinnings (poles) should be at once assorted according to their size and class, for sale or other method of disposal.*

7. *Trees which have to be barked are of course stripped immediately after felling, and before the logs are dragged out to the road.*

8. *Felling operations should be temporarily suspended during high wind*, both on account of the greater risk of accidents, and of the uncertainty of being able to make the tree fall in the desired direction.

9. *Large trees and poles over about 9 in. diameter at base should, as a rule, be felled by axe and saw; while small poles and coppice growth should be cut by bill or by axe, according to their size.* To prevent water lodging and rotting the stools, and to stimulate the production of shoots, coppice-stools should be cut smooth and sloping.

In **Copsewoods** the saplings (called *stores*, *tellers*, or *heirs* locally) to be left as young standards should be ringed with whitewash to mark them; and more than are required should be marked at first, to allow for accidents in felling standards, &c.

Felling in any kind of wood—**highwood, copse,** or **coppice**—is usually best done by the proprietor's own men, wherever there is any permanent staff of woodmen. It is quite true that a timber-merchant's wood-cutters should be specially skilled in felling, logging, and removing timber, as they are constantly at work; but, on the other hand, they have not the same personal interest in doing the work in the way best for the landowner and the woods, and they can never be so amenable to the supervision and the orders of the forester as local labour employed by the latter. So, too, there is plenty of room for difference of opinion as to whether it is better to employ labour by contract or piecework at so much per tree or per ton or load, or on daily labour at a fixed wage; and really such matters can only be decided when one is fully cognisant of the precise state of affairs regarding labour on the estate in question. No general opinion is of the slightest practical use whatever. In general, however, so far as the well-being of the woods is concerned, it would seem best to have felling done by local men employed by the forester, and in every way directly under his control and orders; and this obviates any possibility of dispute arising owing to timber not being felled and moved out to the roads and green lanes before the crops break into leaf in spring.

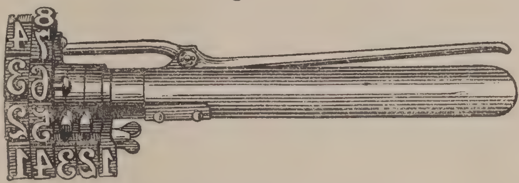
The Cost of Felling, Trimming, and Logging Timber of course varies locally, and with the size and the quantity of timber to be felled and logged; but it may be taken as averaging for Oak about 2s. 6d. to 3s. 6d., for other hardwoods 2s. to 3s., and for Conifers and softwoods 1s. 6d. to 2s. 6d. per load of 50 cub. ft. (square-of-quarter-girth measurement). The **coppicing** of underwood of about twelve to sixteen years' rotation usually costs from about 10s. to 12s. 6d., and even 15s. or more, per acre, according to the density of the crop.

The cost of felling the **coppice** will of course vary with its age and size, and also with the quantity on the ground, since where much overhead timber prevails there will be proportionately less room for underwood. Small stuff, cut in a ten-years' rotation, may cost about 14s. an acre, and, where the rotation is twenty years, 20s.; but these are only rough average prices. **Timber-trees** are generally felled at so much per foot, or per hundred feet, or "load," according to locality. The price also varies according to the value of labour in the district, and the description and habit of the tree. For the broad-leafed trees, from 5s. to 8s. per hundred feet is paid, according to circumstances, to include throwing the tree and trimming it out ready for the carriage. For Larch and Spruce Fir having smaller branches and entailing less labour, about 4s. per hundred is a usual price (R. Anderson, in *Jour. Roy. Agric. Socy., England*, vol. lxiv., 1903).

Assortment of Timber, Branchwood, Poles, &c.—After being logged into the largest convenient lengths and removed from the falls to the nearest roads and drives, the logs should, if not already disposed of, be assorted by arranging them according to kind of wood, class, quality, and size of timber. It is then easier for the forester to form them into convenient lots for sale. Except as regards hedgerow and field trees, it is best not to have mixed lots of different sorts and sizes of timber. The "lop-and-top" from the branchwood below timber-size (6 ins. top-diameter for hardwoods, and 3 ins. for Conifers) is then assorted in pitwood or other lengths and sizes, and the smaller stuff worked up into cordwood for fuel. Fuel-faggots should be cross-cut into the required length by hand-saw; if the axe be used, about 7 per cent of the wood becomes wasted in chips. The poles from thinnings and coppice-woods should also be assorted according to dimensions, so as best to meet the local requirements for posts sold by the dozen or 100, and for bavins, hop-poles, lugs, sprays, or brick-kiln bavins, bush-bavins, broom-handles, &c., which are all usually sold by the 100; while the smaller material left on the felling-area is then gone over and faggoted and assorted, according to local custom, into bundles of hedging-rods, bean-, pea-, and flower-sticks, &c. The fall should always be cleared of all the timber, branches, and brush-wood as soon as convenient, so as not to interfere with the growth when vegetation re-awakens in spring.

The Marking of Timber for Sale.—When timber is to be sold standing, it is best in the case of valuable trees like Oak, Ash, Elm, and other hard-woods to make a blaze on each tree about 5 ft. up with a hatchet or hand-bill, and to mark the serial number with good, rain-proof red keel or with red-lead paint at the time of valuing it; and in the case of park, field, and hedgerow trees, they can be the more easily distinguished by prospective buyers if the stems are ringed with a narrow band of paint or whitewash. When the timber is logged, the logs may either have serial numbers, or all those comprised within one lot may bear the same number, or the different logs may have such distinctive numbers as, say, $\frac{20}{1}$, $\frac{20}{2}$ . . . $\frac{20}{19}$, $\frac{20}{20}$ respectively on logs 1, 2 . . . 19 and 20 of lot No. 20. This can hardly be done on very large falls of coniferous timber, where it is perhaps most practical to hammer-mark the serial number of the lot on the ends of the logs with a patent revolving numbering-hammer.[1] In the case of smaller wood (posts, piles, &c.) sold by the hundred, it is sufficient merely to indicate the number for each lot on one pole drawn out from the rest to show the number prominently.

Fig. 228.



Göhler's Revolving Numbering-Hammer.

Storage of Timber.—If not already sold before the fall, felled timber should be disposed of as soon as is convenient and profitable. It is of course not always possible to avoid having large quantities of unsold timber on hand, as in the case of windfall, where a clearing sale might only be made at a low price. But in general it is well to get the timber out of the woods as soon as possible, and let the timber-merchants convert, store, and season

[1] In Germany, that known as *Göhler's Revolving Numbering-Hammer* (Fig. 228) is considered the best. By a simple lever action the number is changed after each stroke of the hammer; and the number stamped is made plainer by the numbers being pressed on a felt pad soaked with oil and printers' ink each time the hammer is going to be used. Hammers for numbering up to 10,999 cost 22s., and those for marking up to 19,996 cost 32s. 6d. each.

it in their own yards. When Scots Pine logs are stored in water, the wood is much less apt to assume the bluish discolouration (see p. 444) often appearing when it is stored on land, and which affects its market-value when converted. All kinds of wood, however, when stored on land, whether piled in heaps or lying in single logs, should be well raised above the ground-level on supports, and in the case of Conifers, the stems should be barked to season quickly and to prevent attacks of bark-beetles (see Fig. 136, p. 66).

The Sale of Timber.—In Britain, timber is usually sold either by **public auction**, called **public roup** in Scotland, or by **tender**, or by **private contract.** Sometimes the trees are **felled, logged, and assorted** into convenient lots before the sale is advertised, and at other times the trees are sold **standing**; and in this latter case, the **conditions of sale** or **articles of roup** determine whether, and under what conditions, the trees are to be felled by the seller or by the purchaser.

Sales of **standing timber** should be made as early as possible in autumn, so as to enable the wood to be felled and removed during the winter; while sales of **felled timber** should take place as soon as is convenient after the felling, logging, assorting, and lotting have been completed. The earlier one gets the timber sold and removed, the better for the woods and for the other work on the estate; and damage to roads should be at once repaired.

All of the above three methods of sale, as well as the two different ways of arranging for felling, have specific advantages and disadvantages inherent to them; and it is therefore absolutely impossible to say that any one is better than the other. From the very nature of such business transactions no general rule can be held to apply. In most districts sales by public auction are the commonest way of disposing of large falls of timber; and at such sales held at some rural centre the catalogue of lots usually includes timber on two or more estates in the vicinity.

For large quantities of timber, sales by public auction are no doubt in most instances best. Theoretically, they should be better than any other method of disposal, if the competition be *boná fide* and free. But, practically, there is always a certain amount of danger that the timber-merchants who habitually attend such auction sales may form a *ring* to prevent anything but nominal competition, and then afterwards hold a *knock-out* or supplementary trade-auction, at which is divided among themselves an additional sum representing the true value of the timber of which the landowner has really been deprived by means of a combination of buyers whose action goes very near being a fraudulent conspiracy. Such rings absorb casual outside buyers, and are very difficult to break up unless some of the buyers quarrel among themselves, and then even one resentful bidder may raise prices—at any rate for such lots as suit his requirements—to near their true level.

It is often difficult to find out whether a *ring* is formed or not, because it generally operates over an extensive area, and consequently reduces the average price of wood throughout the whole of that, and there are always specious, plausible explanations for such low prices (*e.g.*, labour scarce and dear, transport heavy, very difficult wood to handle, trade bad, and market for timber poor, &c.). Certainly, if there happen to be saw-mills in the vicinity of the woods, the owners of which are willing to give a fair price for timber, it is then best to sell by private contract, and thereby to establish a permanent connection in which the sawyer will look to the local woods for at any rate part of his yearly requirements in timber in the log, and the landowner will find a fairly assured market close at hand. The more such local conditions of supply and demand are developed, the better for the seller and the buyer, and for the neighbourhood supplied by the local saw-mills.

When, however, there are specially fine falls of Oak, Elm, or Ash suitable for particular purposes (*e.g.*, railway workshop requirements, carriage-builders, butts and burrs for cabinet-making, &c.), then it may often be advantageous to advertise for tenders; and if no suitable offers are received, the timber can still be sold by public auction or private contract; and, as a matter of fact, calls for tenders often result in a subsequent sale by private contract.

In sales by private contract there are no extraneous expenses, such as commission and advertising; and in calling for tenders, there are only the expenses of advertisement; whereas in sales by public auction there is the auctioneer's commission (10 per cent ordinarily, but this includes lotting, cataloguing, and valuation, and also the collection of the money from the buyers), advertising, refreshments at sale, &c. A public auction can of course be held by the landowner, or his agent, bailiff, or forester, after taking out an auctioneer's license (fee £10), but this is probably very seldom ever done.

When timber is marked for sale, whether standing or felled, it is valued by the forester; and if an auctioneer be employed, the forester's valuation is compared with the valuation made by the auctioneer, when any very marked differences can be inquired into before the latter valuation is approved by the landlord or his agent as a sort of *upset price* or basis for the amount anticipated.

Even when an auctioneer is employed, the forester should attend the sale and make his own notes in some such form as the following:—

AUCTION SALE OF TIMBER HELD AT D——, on 15th November 1904.

No. of lot.	Kind of wood.	No. of logs in lot.	Contents.	Forester's valuation.	Purchaser.		Selling price.	Remarks.
					Name.	Residence.		
			Cub. ft.	£			£ s. d.	

In France, Belgium, and Holland the usual method of sale is that known as a **Dutch auction.** The lots are successively put up at an **upset price** considerably above the true

reserve price, and the sum asked is gradually reduced till some buyer calls out that he will take the lot at that price, when it is knocked down to him.

In Britain, the custom varies both locally, and on different estates in the same locality, as to felling timber while **standing** or **after felling and logging**. The only real advantage in offering standing trees for sale is that if the prices offered are not considered satisfactory, the bids (whether made privately, or by tender, or at a public auction) need not be accepted, and the trees may be left growing for some time longer. Once the timber is felled and logged, however, the wood-merchants know that it must be sold sooner or later, and that the landowner will generally be glad to dispose of it as soon as he can get anything like a reasonable price for it. But in standing timber one can never tell whether, or to what extent, there may be unsound wood in the trees; and it is only after they have been felled and logged that either the seller or the buyer can form a correct idea of the true quality and condition of the wood.

In disposing of **standing timber** the conditions of sale sometimes stipulate for felling by the seller, and sometimes for felling by the buyer, subject to the supervision of the forester; but, on the whole, it is usually preferable to have this work done by the landowner's employees (see also remarks on p. 478). If the buyer desires to have the trees logged in special lengths, or to special top-diameters to suit his particular requirements, he can easily send a man to chalk-mark the cross-cutting places where the stems are to be logged. When standing timber is sold, it is customary for the buyer to have all the "lop-and-top," or branchwood below timber-size, for nothing, as a set-off against the cost of felling and logging—on much the same principle as that on which the customary British square-of-quarter-girth measurement is based.

In France, it is usual to sell the timber standing, which is then felled, logged, and removed by the buyer; while in Germany it is usually felled and assorted previous to the sale. But it is now generally admitted that the latter is the more satisfactory practice from a sylvicultural point of view.

At sales by **public auction** the bids are made for each lot, irrespective of its entire contents. Even when these are perhaps roughly indicated (and then always only with the saving clause "more or less"), the conditions of sale provide for the buyer having informed himself of the quality and contents of each lot, and no subsequent representation about either can be entertained. But in sales by **tender** or by **private contract** the price agreed to is often per cubic foot (square-of-quarter-girth measurement) for the different kinds, qualities, and dimensions of timber; and this often gives rise to differences of opinion and disputes in fixing the total amount actually payable. In such cases it is therefore well to make (besides the other customary business stipulations) special conditions as to (1) what is to be measured as timber, (2) what is to be I. and II. or III. class timber, (3) what deduction in girth-measurement is to be allowed in each case for bark (unless the timber is already stripped), and (4) how the "lop-and-top" below timber-size is to be disposed of. Disputes about such matters are of course always most likely to occur when the trees are sold standing. Such causes of dispute are obviated when the timber is sold at so much per tree, or per ton weight.

General Conditions of Sale.—Every timber-auctioneer has his own special and concise **Conditions of Sale** or **Articles of Roup** printed at the end of each of his catalogues; and these conditions are always either read, or agreed to be taken as read, before the first lot is put up for auction. And on all estates where extensive sales of timber take place, whether by private contract or by tender, printed forms are in use which have been drawn up by the agent or factor and revised by the solicitor or law-agent of the estate. There is therefore no necessity for here giving specimens of any such documents, because for anything beyond a mere petty sale the forester should not act, and should not be permitted to act, except under the direct and explicit instructions of the landowner, or of his responsible agent or factor.

In all such documents, however, the conditions of sale should provide for the following matters:—

1. *The mode of payment of the purchase money.* At public auctions, in most parts of Britain, it is customary to accept 10 per cent cash down, and a bill for the balance at three months' date, or to allow a total discount of 2½ per cent for cash in full at once. But of course special terms are given for large transactions made by private contract.
2. *No timber to be removed till payment in full has been made in cash or by deposit and bill; but the timber to be at the risk of the buyer from the time it is knocked down to his bid.*
3. *The date by which the timber must be removed*—usually the 31st May at latest, except in the case of very large sales of woods to be clear-felled, when the time allowed for felling and removal may perhaps extend to 1, 1½, or 2 years.
4. *The roads by which it should be taken off the estate, and the minimum breadth of the wheels of the timber-carts* (wheels less than 4 in. flange cut up soft roads badly when the loads are heavy).
5. *The buyers to be responsible for any damage done by their men, horses, or traction-engines to trees, plantations, coppices, fences, and gates, &c.*
6. *The right to make one bid for each lot is often reserved to the seller, and also the right to stop the sale if the bidding proves unsatisfactory.*
7. *If a buyer fails to complete the purchase, the lot may be re-exposed and re-sold, and the original buyer shall be responsible for any deficit thereby accruing.*
8. *In the case of standing timber, it should be stipulated whether felling and logging should be done by the seller or the buyer.* In the former case, arrangements must be made for payment of all charges incurred; and in the latter, it must be precisely stated how and at what height above the ground the trees are to be felled.[1]

As soon as a sale by public auction has been held, the buyer should be made to pay his deposit and give his bill for the balance, unless he prefers to pay cash down and obtain the usual discount. This can easily be shown as follows in

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[1] If any contract be made for felling timber such details must of course also be fixed, all large trees being felled by axe and saw as close above the ground as may be possible under the given circumstances (a limit being fixed).

a **Sale Register** or **Roup Roll**, or the form given on page 481 can easily be arranged to include the extra details, thus :—

Register of Auction Sale of Timber held at D——, on 15th November 1904.

No. of lot.	Kind of wood.	No. of logs in lot.	Purchaser.		Price.	How paid for.		Remarks.
			Name	Residence.		Cash.	Bill at 3 months.	
					£ s. d.	£ s. d.	£ s. d.	

Coppices are usually sold standing, either privately or by public auction, at so much per rood, lug, or acre, and with the proviso that they are to be cut and cleared by a certain date. Ordinary coppices should be cleared by the end of March, but in Oak-bark coppices one must allow till the middle or end of May even in the mild climate of England, and up to about a month later in the north of Britain, so as to enable the bark to be stripped.

The material cut on the coppices is generally fashioned on the spot. The largest and straightest poles are trimmed as **hop-poles**, wherever a fair market still exists for these. They are simply cut into the proper lengths, classed according to size, and sold at about 8s. per 100 poles, 12 ft. × 1-1½ in. top-diameter, and 10s. per 100 for 14 ft. poles, the rates often applying equally to hard and soft woods, and also to Conifer thinnings from neighbouring plantations.

In most parts of the country hurdles are still used, though rapidly being displaced, and a large quantity of small Hazel, Oak, Ash, and Chestnut is used for **hurdle-making, crate-wood,** and **barrel-hoops,** as well as for **bean-sticks** about 8-10 ft. long, **stakes** from about 5-8 ft. long for fences and hedges, and **pea-sticks** about 3-5 ft. long, also stakes for **fishing-nets** for salmon fisheries (*e.g.*, in Severn valley), and for supplying local requirements of various sorts (flower-sticks, broom-handles, brickyard-stakes, brick-kiln bavins, bush-bavins, shores, headers for thatching, &c.), and **clog-making** near Alder-groves.

Hurdle-making is still practised, just as when it was, down to about thirty years ago, of more importance in our rural economy. The upright stakes, sharp-pointed and a little over 3 ft. long, are stuck in line about 8-9 in. apart in a stout block of wood on the ground, with holes bored of the required size and depth, and the pliant withe formed by the split rod is woven alternately in-and-out around these uprights from the base upwards. The ends of each withe are spliced in so as not to damage the fleece of the sheep penned, and care is taken to avoid leaving sharp snags at either end of the hurdle. When this rough wooden woof reaches the proper height of about 3 ft., the snag-ends of the uprights are trimmed, and the hurdles ranged in dozens ready for removal. It takes about three-quarters of an hour to make one hurdle, and one dozen is a good day's work. At present they only fetch from about 4s. 6d. to 5s. 6d. a dozen, and it is often difficult to dispose of them in any quantity.

Osier-holts are carefully coppiced to provide withes or "*rods*" for basket-making and other wicker-work. The shoots go by the various trade names of (1) *green rods*, when fresh cut and unpeeled; (2) *brown rods*, when they are left to dry in their skins; (3) *white rods*, when they have the bark peeled; and (4) *buff rods*, which are brown rods boiled and then peeled, but the colour thus produced can be imitated by dyeing.

In the Fen country, under very favourable circumstances, the newly planted holts can be first cut over at three years; but, in general, four or five years must elapse before the first crop is mature. Well-managed holts remain from ten to fifteen years in good bearing, their duration depending mainly on the kinds of Osiers planted, and on the degree of attention paid to cleaning, filling up, coppicing low down, &c. For strong uprights some of the coarser kinds are specially grown, or else part of the holt is left growing for two or three years to produce the stouter rods wanted. The holts are usually along river-banks, to reduce the carriage of so heavy and bulky a crop.

Throughout the Fen country the Osiers are full-grown by the middle of September, with shoots from 8 or 9 even up to 12 or 13 ft. long during the season, while the harvesting of the rods commences in January if the holts are not inundated or too marshy. But the harvesting should take place at any rate before the sap begins to rise, in order to prevent "bleeding" of the stools, which prejudices the development of the following crop.

The rods are cut as close as possible to the stool with a sharp hook, like a strong reaping-hook, a clean cut being made without splitting the rod. As soon as cut, the rods are tied up with willow bands into bundles or "bunches" girthing 45 in. (an English ell) at 1 ft. from the butt end. This *ell band* is held in place by being joined to the *breech band* round the butt end, and a third band is tied higher up.

If the rods are to be peeled to increase their value, they are taken to the peeling yard and placed with their butt end in water, until its rise makes the bark strip easily. To prevent the rods drying from exposure to the air, they are *couched* or put in a heap, watered, covered up, and sweated. If the rods thus pitted flush too far into leaf before being stripped, peeling is difficult, and the rods are easily damaged. Peeling begins as soon as any of the rods are fit to strip. It is chiefly done by women, who draw the rods through a *break* or *cleave*, which divides the bark into strips, which are easily removed by the hand. In this latter operation the children of the peelers assist. No use seems to be made of the bark (see p. 489).

The peeled rods are at once sorted into three grades (*large*, *Middlesboro*, and *small*), according to thickness and length. They are then aired for a short time, either on racks or against hedges or walls. When dry they are *bunched* in bundles of the same dimensions as before, and then stored in sheds.

Rods suitable for the purpose are *skeined* or divided lengthways into three equal parts. The thick end of the rod having been notched with a knife so as to divide it into three sectors, a triple wedge is inserted, and the rod is then drawn rapidly through the hand. To reduce each of the three parts of the split rod to a flat thin strip of equal thickness, it is drawn twice under a knife fixed to a gauge, which removes the outer ring and the inner angle. These flat *skeins* are used for weaving bottoms of sieves and riddles, and for making basket-handles, &c. Green rods are similarly *skeined* for making eel-grigs, bee-hives, &c.

It is customary, however, for most growers to sell the green rods as they are cut, and to leave it to the buyer to peel, sort, and store them.

An average crop will yield about 150 bunches of rods, having a girth of 45 in. (an English ell) at 1 ft. from the thick end of the bunch, whilst a heavy crop may reach 250 bunches, weighing about 6 stones each; the weight of rods may vary thus from about 5 to 10 tons per acre. The harvesting of the rods is paid for at about 2s. 6d. per score of bunches, or about 1½d. per bunch on the average. The selling price ranges from 1s. 6d. to 2s. 6d., and averages about 2s. per bunch.

If the green rods are peeled so as to command a better price and to store well, then there is a loss of fully 50 per cent in bulk, as three bunches of green rods yield only two bunches of clean or peeled rods.

Osier-holts in the Fen districts yield about £15 an acre, taking 150 bunches of green rods as the average crop; this, of course, is subject to deduction of all the cost of planting, tending, harvesting, ground-rent, taxes, supervision, &c. The cost of peeling, sorting, and handling the same so as to transform the crop into clean white rods amounts to about 8d. per bunch, or £5 per acre. Thus a crop of 150 bunches of green rods, when peeled, yields 100 bunches of white rods, having a market value of nearly £35 (see Agricultural Leaflet No. 36—*Osiers*).

2. **The Harvesting of Bark.**—The stripping and drying of Oak-bark for tanning was formerly an important part of British forestry; but it does not pay to grow bark-coppices now, and even the barking of large Oak-trees is hardly profitable.

Vast quantities of tanning materials are annually used in Britain, the imports amounting to close on £1,000,000 in value, while the quantity of tanning-bark produced of home growth still probably exceeds 200,000 tons, though it is no longer so large as it once was.

Although many kinds of bark are suitable for tanning, only Oak, Larch, and Birch have ever been very largely used in Britain for this purpose. Other barks formerly used include Willow, Mountain-Ash, Spanish Chestnut, and Alder; but these were only substitutes to eke out the supplies of Oak-bark; and when large quantities of Oak-bark were imported into this country free of duty from the Continent, tanners could then get plenty of good Oak-bark at a moderate price, and were no longer compelled to use inferior tanning-barks. Consequently the price of bark fell heavily, and this once important branch of British forestry received its death-blow. The market for tanning-bark for many years has been very depressed in England, owing not only to large Continental imports of bark, and of Oak-galls and Sumach from the Mediterranean, but also to increasing imports of Cutch, Gambier, and Myrobalans from India, and of Quebracho wood from the Argentine, of Dividivi seed-pods from Brazil, of Wattle-, Mimosa-, and other Acacia-barks from Australia, &c., and likewise in no small degree to the introduction on a large scale of chemical preparations for tanning purposes. This last was particularly the case about twenty to twenty-five years ago, when such chemical processes as Knapp's (with iron) and Heinzerling's (with chromic acid) tried to displace tanning with bark. But such processes of tanning with metals have been far from proving successful in producing the better classes of leather, and especially of sole-leather, for which the raw skins seem to require a longer soaking in the tanning-pit than is permissible when metals are used. For sole-leather the chief rival of Oak-bark is the Quebracho wood (*Schinopsis balance*), which, either rasped or after being formed into an extract, tans very quickly and cheaply. Sweet-Chestnut wood is similarly treated in Savoy and Würtemberg for producing a tanning extract. Of recent years considerable quantities of Oak-branchwood have in similar manner been used in Slavonia for making bark-extract. In Hungary a tanning-extract is also made from Spruce-bark.

The export of Quebracho wood from the Argentine, either in stem-sections (*rollizos*), or ground-down like meal (*asserin*), and of the wood-extract, is a trade that has sprung up entirely within the last twenty years. In 1902 it amounted to 245,000 tons of *rollizos* and 9099 tons of extract, while but little *asserin* was exported. From Paraguay the export in 1902 was 11,359 tons of *rollizos*, and 5000-6000 tons of extract.

The chemical composition of bark is very complex, and is not yet thoroughly investigated. But at any rate the bark of certain kinds of trees has a special commercial value by reason of the **tannin** or **tannic acid** contained in it. Tannins form a series of weak acids widely dispersed throughout the vegetable kingdom, but usually mainly to be found in the bark and in certain pathological or abnormal conditions, such as galls on Oak-leaves and knoppern-galls on acorns, both of which are produced by gall-wasps (**Cynipidæ**), and contain, when dried, about 60 per cent of tannin. The tannin or tannic acid of Oak-bark ($C_{14}H_{10}O_9$) may be taken as typical of the others generally. It is a yellowish, grey-white, amorphous powder, easily soluble in water, difficult of solution in alcohol, and insoluble in æther. It has a bitter taste, which causes the skin of the mouth to contract, and gives a bluish-black or greenish precipitation when mixed with ferric salts. When brought into contact with animal skins it transforms them into *leather*, characterised by pliancy and great power of resisting decomposing influences.

Tannic Acid can be transformed into **Gallic Acid** by the addition of water (when $C_{14}H_{10}O_9 + H_2O = 2C_7H_6O_5$), so that the latter is practically a hydrate of the former; and a retransformation can take place by withdrawing the additional water. Gallic acid crystallises in fine rods, is easily soluble in water, and produces a brown colour in combination with iron-vitriol. Exposed to air, this combination with iron quickly oxidises and becomes a deep black. Gallic acid is largely contained in galls, and these are therefore of special use for making ink. Gallic acid is contained, as well as tannic acid, in the bark of Oak, Sweet-Chestnut, Horse-Chestnut, and other trees.[1]

The amount of tannin contained in bark varies greatly for different kinds of trees, and also for different parts of the same tree. The European barks used for

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[1] Besides tannic and gallic acids, the other constituents of technical value which may be found in different kinds of bark include the following (Schwackhöfer, in Lorey's *Handbuch, &c.*, 1903, vol. ii. p. 296) :—

(1) Other **Organic acids**, such as *Oxalic acid* and *Pectinic acid*. The former is often to be found in the form of crystals (mostly oxalate of lime) in the bark.

(2) **Glycosides**, such as *Quercitrin*, ($C_{21}H_{22}O_{12}$), in the bark of *Quercus tinctoria*, a yellow dye-stuff of considerable commercial importance ; *Salicin* ($C_{13}H_{18}O_7$), in the bark of Willows and Poplars ; *Æsculin* ($C_{15}H_{16}O_9$), in the bark of Horse-Chestnut ; *Saponin* ($C_{19}H_{30}O_{10}$), in Quillaja-bark, which is boiled and used for cleansing wool and different textures ; *Populin* ($C_{20}H_{22}O_8 + 2H_2O$), in Poplar-bark ; *Phloridzin* ($C_{21}H_{24}O_{10} + 2H_2O$), in the bark of fruit-trees ; and a few more, including *Coniferin*, from which *Vanillin* (closely resembling vanilla in its appearance and flavouring properties) is extracted on a commercial scale in the Saxe-Weimar forests.

(3) **Starch, Sugar, Gum.** A certain amount of starch is desirable in tanning-bark.

(4) **Ætherial Oils, Resins, Balsams,** such as in the pockets of aromatic resin in the Douglas Fir, or in Cinnamon-bark, &c.

(5) **Bitters and Alkaloids,** such as in *Cinchona*-bark, from which quinine is produced.

(6) In addition to the above, bark of course also contains cellulose, lignin, suberin, colouring matters, nitrogenous substances, mineral constituents, and water. There is more nitrogen in bark than in wood, and more in young bark (0·6 to 0·8 per cent) than in old tree-bark (0·4 to 0·6 per cent). The mineral constituents vary from 1·5 to over 7 per cent ; while the water contained averages from 50 to 60 per cent, and sometimes even exceeds 70 per cent. A large percentage of water depreciates the value of tanning-bark, as damp bark soon becomes overgrown by mould-fungi (especially by *Pennicillium glaucum*), which rapidly oxidise the tannin. Hence the necessity for seasoning and drying bark as soon as possible.

tanning contain on the average from 5 to 15 per cent of tannin, while several of the tropical and subtropical barks have from 20 to over 35 per cent.

The **tannin** or **tannic acid** is contained in the cambial layer of the bark, but decreases by about 3 to 5 per cent from the root towards the crown. This difference is occasioned, however, mainly by the changes that take place as the bark grows older on the tree; the fleshy part of old bark contains much about the same percentage of tannin as that of young bark—viz., from about 12 to 16 per cent; but the old, hard bark contains less than the half of that, so that the whole proportion of tannin is considerably less in old, hard, rough bark than in young and smooth bark. According to its exterior smoothness or roughness, Oak-bark is therefore assorted into three classes:—

(1) **Smooth** or **silver bark**, from coppice-shoots up to 14 or 16 years old, of which the best sorts contain when seasoned (air-dried) from 15 to 20 per cent of tannin;

(2) **Seconds** or **medium quality**, stripped from poles and branches, the bark of which has begun to fissure, and containing from 10 to 15 per cent of tannin;

(3) **Cleaned tree-bark**, from the stems of older trees, which contains 8 to 10 per cent of tannin; and

(4) **Coarse, rough tree-bark**, as stripped from Oaks of large size, which contains 5 to 8 per cent of tannin.

The bark of the Sessile Oak is usually thicker and richer in tannin than that of the Pedunculate Oak; but the quality of the bark depends far more on the soil, situation, and climate than on the species grown for bark-production. A good strong mineral soil and a warm sunny situation are the two chief factors in any given locality; while districts with a warm summer climate produce the best bark. As intensity of light is favourable to good bark-production, it follows that pure Oak-coppices will give more and better bark per unit of area than coppice under standard trees of any kind whatever, no matter how light the shade they cast on the underwood. Thinning of Oak-coppices also increases bark-production, and Gayer estimates that proper thinning increases the quantity of wood produced by about 27 per cent, and of bark by about 20 per cent, while the quality of the latter is at the same time improved.

Although many other barks contain a much greater percentage of tannin, **Spruce-bark** is, after Oak-bark, that used in largest quantities for tanning; indeed, throughout Northern and Eastern Germany, Poland, and Western Austria, more Spruce-bark is now used than Oak-bark. But as the better kinds of bark, peeled from 50- to 80-year-old trees in high mountainous regions, only contain from 7 to 9 per cent of tannin on the average, Spruce-bark can only be used by itself in the preparatory stages of tanning, or for calf and other small skins, and not for preparing the better classes of sole-leather, for which at least a fair proportion of Oak-bark is necessary in admixture with the Spruce. The bark of trees below about 50 years old contains less tannin, while that of above 80 years, though not containing less tannin than 50- to 80-year-old bark, has at the same time so large a proportion of red colouring-matter that it darkens the leather. Spruce-bark is peeled wherever the falls take place during late spring or summer, the measure being in any case necessary as a protection against bark-beetles when large areas are being clear-felled (see Fig. 136, p. 66).

Larch-bark contains from 10 to about 15 per cent of tannin, and is used, wherever it can be had in fair quantity, for tanning sheep-skins. In the Alps and Carpathians it is preferred to Spruce-bark.

Silver Fir-bark contains only about 5 or 6 per cent of tannin, and is nowhere largely used for tanning. In the Silver Fir districts of Central Europe the bark is worth more as fuel than for tanning.

Alder-bark contains from 16 to 20 per cent of tannin, or fully as much as the best Oak-bark; but at the same time it contains so much colouring matter, that little use can be made of it for tanning.

Birch-bark contains only about 3 per cent of tannin, but is extensively used wherever there are large Birch-woods throughout Northern Europe. As it gives a pale colour to the skins, it is used for the preliminary and the final stages of tanning. **Birch-oil** is extracted from the white epidermis of Birch-bark.

Willow-bark contains about 5 to 7 per cent of tannin, and is very largely used in Russia for tanning. The distinctive aroma of "*Russia leather*" is obtained by steeping it in Birch-oil (see Chap. V. p. 603), after it has been tanned with Willow-bark. **Osier-bark** grown in Russia has been found to contain up to 8 to 13 per cent of tannin, and is there used to prepare "*Danish kid*" and "*doe-skin*" for glove-makers, as also in preparing salicin, and for fodder. The larger the rods, the more tannin does their bark usually contain.

In no part of Europe is much use made of the bark of Beech, Walnut, Italian Poplar, Elm, or Horse-Chestnut for tanning, though these all contain from a slight to a fair percentage of tannin.

In tanning 1 cwt. of leather about $\frac{1}{2}$ cwt. of tannin is needed, which is about the average amount contained in $6\frac{1}{2}$ cwt. of the best smooth Oak-bark, in about 8 cwt. of medium quality, and in about 14 cwt. of coarse Oak-bark, while other kinds of bark are required in quantities varying according to the average percentage of tannin they contain.

(1) **The Harvesting of Oak-bark.**—The best season for bark-stripping is when the young leaves are just beginning to flush. The bark will generally peel freely throughout May, June, and even in July; but this depends on the part of the country, and on the season. In the south of England, barking operations may begin about the middle of April and be completed by the middle of May; in the central and northern parts of Scotland, it only begins in May, and can continue till July; while in Ireland, peeling is generally done from about the end of April to the middle of June. The Pedunculate Oak will strip about eight to twelve days earlier than the Sessile Oak; and in either case the bark peels best during warm damp weather, and better in the morning and evening than during the daytime. It is best to cut and strip coppices as early as possible, because this not only lets the stools shoot again sooner, but it has also been found that the earlier the bark can be harvested, the heavier it usually is.

The method of stripping adopted for coppice-woods of course differs considerably from that for trees of large size.

In **coppice-woods**, any other kind of wood than Oak should first of all be cut out and removed. Then the Oak-shoots should be cut by men and thrown into small heaps to be stripped at once by women and boys, each of whom should have a separate heap, as the work is then generally done better and more quickly. Each should be provided with a large, flat, smooth stone, or a big billet of wood, and a wooden mallet, the stripper sitting in front of the stone or block of wood, and keeping the heap of wood to be stripped upon the left-hand side. A branch being taken in the left hand, and laid upon the stone or billet, the branch is firmly beaten with the flat part of the mallet till the bark parts from the wood along all its length, when it will peel off easily with the hand. In peeling, the bark should be kept in as long lengths as possible, and laid in a heap on the stripper's right-hand side, till it is collected and carried to the drying-stages for seasoning.

From Oak-trees of large size the bark may either be stripped while they are standing, or after they are felled. The stripping of standing trees is still practised in the Forest of Dean, but elsewhere it is now comparatively rare in Britain, though at one time it was not uncommon in the case of trees in hedgerows or near corn-fields. And this method has the additional advantage that the timber is of better quality when cut in autumn than when the sap is rising in spring. When trees to be stripped have moss growing on them, this should first of all be removed with a **scraper**, or piece of iron about 6 in. broad in the face and made semicircular to fit round the stem. A handle 2 ft. long is fitted to this, and fixed at right angles for scraping easily. Unless scraped off, the moss hinders the bark from drying. The branches should also then be lopped off. Beginning at the top of the tree, a man

Fig. 229.

Fig. 230.

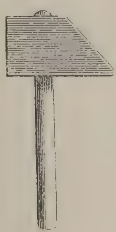
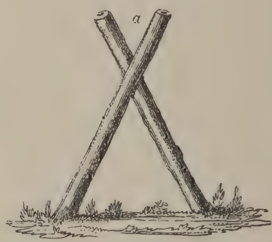


Fig. 231.

Fig. 232.



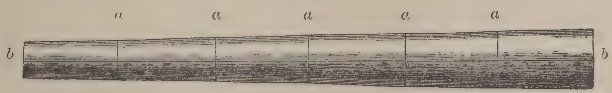
with a ladder strips off the bark with a barking-iron. He also cuts off the branches with a small axe, and these are stripped on the ground, the branches and bark being taken away, and the trees left standing till autumn or winter. Large Oaks are now, however, usually felled and barked in spring, as soon as it is found that the bark will strip.

The **Tools required for Bark-peeling** consist, in addition to **axe** and **saw**, of a curved **handbill** or **billhook** (Fig. 229), the edges of which are kept sharp both on the curved side and along the straight face ; a **wooden mallet**, made of Ash, with a flat face about 4 in. square, tailing off for about 6 in. to a sharp point behind, and a 9 or 10 in. handle of Pine or other softwood (Fig. 230) ; a small spud-like **barking-iron, peeling-iron**, or **stripping-chisel**, with an iron or steel face about $2\frac{1}{2}$ by 2 in., and a wooden handle about 8 in. long (Fig. 231). For barking poles and branches a pair of **forked stakes** (Fig. 232) is also rigged up, and placed slantingly in the ground for resting one end of the pole in a convenient position for barking.

Before the trees are felled they are usually ringed for 3 ft. round the butt, close to the ground, to prevent wastage of bark, and to allow axe and saw to be easily applied. If the trees are not too old, and it be intended to let them have a fair chance of shooting from the stool, care must be taken not to tear away any of the bark from the stump left. To protect the stump, the stem should be notched all round through to the wood with a light hatchet or handbill close to the ground, and also about 3 ft. up. The broad band of bark between these two notched rings should then be stripped with the **barking-iron** in as large pieces as possible, for use as a covering for the smaller bark when drying. The tree is then felled with axe and saw, and the larger branches are removed by cross-cutting with the saw, while the smaller ones are also either sawn or lopped off with light hatchets or hand-bills, care being taken to injure the bark as little as possible. The branches are then cleared of twigs, cut up into lengths of about 4 ft., and piled in heaps, and carried to the barking-place.

In stripping the bark from large poles and trees, two men usually work together. If not too heavy, one end of the pole is raised and rested on the forked stakes stuck slantingly in the ground. One of the men with a handbill cuts through the bark right round the stem at intervals of about $2\frac{1}{2}$ ft. apart, beginning at the thick end, and with the same implement then cuts it longitudinally right along the pole, from one end to the other (Fig. 233). As this is done, the other man strips off the bark with his peeling-iron, and using the

Fig. 233.



a. Transverse cuts $2\frac{1}{2}$ ft. apart; b. longitudinal cut all along pole.

flat end of the mallet to tap the bark firmly and loosen it; but this should only be done at places where the bark refuses to strip with the iron alone, as tapping means bruising, and the less the bark is bruised, the better its quality is. In warm parts of England the bark usually strips readily, without beating; but in Scotland the mallet has generally to be used to some extent. Some trees strip freely, while others growing close to them may be difficult to peel. If the mallet must be used, it should be applied lightly, otherwise this will injure the colour and quality of the bark when dried. The thinner the bark, the less beating will be required; but thick strong bark is often more difficult to peel. The men should be cautioned, however, not to make any unnecessary use of the mallet.

As soon as each length of bark is stripped, it is placed in a heap as pole after pole is raised on the forked stakes and stripped. When the stems are too large to raise thus, the bark is first removed from the upper side, and then the log is turned over, and the rest of the bark peeled. The branchwood is cut into lengths and peeled by beating in the same way as the bark of coppice-shoots.

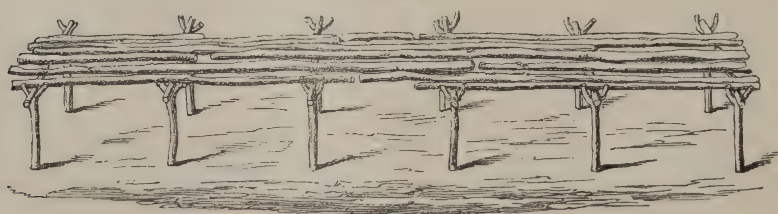
The Drying of Bark.—The drying-stages for seasoning the bark should be in charge of a careful and experienced man, because in wet or showery weather it is often difficult to season the bark properly. The drying-stages should be formed on some dry, open, airy, sunny spot, for if they are erected in a close, damp situation, or under the drip of trees, the bark will take long to dry, and may perhaps not season properly. The "ranges" or drying-stages consist of a number of forked stakes (Fig. 234), formed of branchwood about $2\frac{1}{2}$ to $3\frac{1}{2}$ ft. long and $2\frac{1}{2}$ to 3 in. diameter, driven into the ground in opposite pairs to form a double row about 2 ft. broad and $1\frac{1}{2}$ to $2\frac{1}{2}$ ft. high. Upon this framework cross-pieces are laid, and then upon these a very loose flooring of small poles about 2 or 3 in. diameter is placed lengthways, for supporting the bark, but with plenty of space between each two longitudinals to allow a free circulation of air (Fig. 235). The level of the upper row of forked stakes should be about 4 in. higher than that of the lower row, to allow rain to run off the bark after any shower. As soon as the bark is brought, it should be placed loosely on the stages in regular lines, all lying one way, and not pressed together, but kept open, to allow a free circulation of air. The layer of bark thus spread over the stage should not exceed about 6 in. deep, and should always have the white inner side downwards. The smaller branchwood-bark should be laid on first of all; while the larger pieces of trunk-bark should be put on the top as "cappers," with the rough outside uppermost, to keep off rain from the finer bark below.

Fig. 234.

After standing for a few days on the stages, the bark should be turned. The freshest or greenest pieces should be placed at the top, and all the bark should be properly mixed, but care being always taken to keep the coarse outer side of the bark uppermost, and to place the larger pieces on the top. If the smooth inner side of the bark be exposed to the sunshine, the weight and the quality of the bark are decreased.

During fine weather the bark may season in eight or ten days, while it may take fourteen days or more during dull and cloudy weather; and wet or showery weather of course always retards the process of curing or seasoning, which is greatly assisted by repeated turning during fine weather. In wet weather it ought not be handled, as it is then apt to turn mouldy where touched, but it should be turned on the first fine day. The bark is not properly seasoned till it has lost all its sap, and has become so dry and hard that it will snap and break instead of bending. It should then be a cream-colour inside, because if it is dark-brown in colour, this shows injury by damp, and lowers its market-value. The more quickly it seasons, the better are its tanning qualities.

Fig. 235.



Drying-Stage formed of branchwood, for seasoning Oak-bark.

If wet weather threatens at a time when much bark is to be stripped in one district, it may be advisable to erect a temporary drying-shed of the required size in some open, airy place. The sides of the shed should be left open, to admit air freely, but the roof should be of deals overlapping and nailed on to prevent rain coming through, or wind from displacing the roof; and the roof should, to throw the rain well off, project about 1 ft. or more over the line of the side-posts erected about 6 to 8 ft. apart. In such an open-sided shed 3-, 4-, or 5-tiered stages, made of rough wood to any number required, can be erected for drying the bark. Seasoning in this way, however, of course takes longer than drying in the open; but it is the only way of treating the bark in wet weather—except where it would pay to dry large quantities of bark artificially by means of hot air. The seasoning of shed-dried bark is assisted if stages are erected outside all round the shed, to which the bark can be removed and laid during dry weather, and then taken inside again when rain is likely to come, the bark being kept in the shed only while the weather is damp. In shed-drying, there is always more chance of the bark getting mouldy than when it is dried in the open; and frequent turning is the only remedy against this. Mouldy pieces should either be scraped clean and the mouldy parts burned, or else, if badly damaged, picked out and burned so as to prevent the spread of the mould-fungi.

In Southern England, park or hedgerow Oaks yield about 10 cwt. of seasoned bark for every 50 cub. ft. of *timber* (square-of-quarter-girth measurement down to 6 in. diameter); while in some other parts only $6\frac{2}{3}$ cwt. can be reckoned on; and in drying, the bark loses on the average over one-third of its weight when green (see p. 498). Felling and stripping of Oaks is usually done by contract. Thus in a Hampshire copsewood the felling and stripping of ten Oak standards recently cost 10s. 6d. per tree, or 105s. in all, and the ten trees gave $33\frac{1}{2}$ cwt. of bark. The local price of bark there was only 40s. per ton in 1898; but it had risen to £3 a ton in 1903, at which latter price the amount received for the bark hardly quite clears the total cost of felling, stripping, and delivery. But contract-rates of course vary locally, and in many places large Oaks are cut down and stripped at the rate of about 30s. to 35s. per ton for the out-turn in bark, while from 40s. to 60s. per ton may have to be paid for cutting, stripping, and curing young Oak-coppice; but from 30s. to 40s. per ton may be taken as about an average contract-rate for piece-work. Larch, Spruce, and Birch should be stripped, chipped, and bagged for about one-third less than the above rates for Oak-bark.

In the Crown woodlands in Gloucestershire (Forest of Dean) large timber-trees are *felled* at 1s. each; *barking* costs 19s. per ton of bark for large Oak-trees, and 25s. per ton for small trees; *logging* large timber costs 3s. per load of 50 cub. ft.; and *preparing and stacking* pit-timber and cordwood 3s. 8d. per cord of 127 cub. ft. stacked. The work is done by direct agency (Hill, *High Meadow Woods Working-Plan*, 1897, p. 11).

The selling price of bark varies from year to year. Oak-bark now fetches about £3 to £4 a ton, while Larch and Birch are only worth about one-half of Oak.

The price of bark delivered at the tanyard has lately varied between £3 and £4 a ton (of 21 cwt.), and as stripping and delivery will generally cost about £2 and often more, it is possible that the work would be less frequently undertaken than it is, if it did not come at a time when the heavy part of the work in the woods is completed, and before the season when extra labour is required for turnip-hoeing, haymaking, and harvesting on adjacent farms (Anderson, in *Jour. Roy. Agri. Socy. Engl.*, vol. lxiv., 1903). In 1905, the prices ruling around Cirencester fell to only £2, 15s. to £3 a ton f. o. R.

Disposal of Oak-Bark.—When seasoned, the bark can either be sold as it lies on the stages, or it may be stacked and kept for some time. It is sometimes sold unchopped, but is more often chopped into small pieces and packed in bags. Stacks should be built in an open, dry, sunny, airy place, and laid on a good foundation formed by first laying down 6 in. poles, then placing others of suitable length crosswise above those, so as to keep the bark well off the ground and allow a free current of air to circulate below it. The openings in such a framework can be covered by branches to prevent the bark falling through. The stack may be of any suitable length, but should not be wider than 7 or 8 ft. at the bottom. To steady the stack, a few upright poles can be ranged along the sides and at the ends.

In building up the stack, the centre should be filled with small bark, and the middle portion thus kept higher than the sides, to prevent rain from getting into the heart of the stack. The height of the stack should be in proportion to the breadth, but not more than about 8 ft. up to the eave. The eaves should project sufficiently to carry off rain-water; while the roof of the stack should be as steep as possible, and thatched with the large flat pieces of bark, or with branches of trees, ferns, and broom. But large pieces of the bark laid on like slates make the best roof, because they admit air freely, yet keep out rain.

When bark is being stacked or chipped, strong waterproof covers, like those used for railway trucks, should be provided for throwing over the stack or the chipped bark when rain threatens; for, if the broken stack or the chipped bark get wet, the result will be a great deal of trouble, and probably a loss of some of the bark. If the bark is to be delivered direct to the tanner, it has to be chipped with any edged tool into small pieces about 3 in. square and sent off in large bags, each of which is weighed as it is filled, the sales being made by the ton weight. Chipping and bagging usually cost about 8s. or 9s. a ton.

The Continental Methods of Stripping Oak-Bark.[1]

Utilisation of Oak-Bark.—The cultivation of the Oak in the forests of Northern Germany, and in most other German woods, is principally with a view to the production of **timber,** to which are subordinated the advantages often also gained in firewood, bark, and acorns, and in grazing and litter on pasture-land. Throughout Northern Germany, Oak-coppices for tanning-bark occupy merely a minor position, while copse with standard Oak receives somewhat more consideration. But throughout Western Germany, Belgium, France, and Holland, Oak-coppices are cultivated very extensively for tanning-bark. The

[1] In France, the Le Maître and de Normaison's processes are often used for stripping the bark from Oak felled in Winter. The wood is placed in closed vessels and steamed, when the bark strips easily. There is said to be little loss of tannin by this process, but the bark is not quite so good as that stripped in spring. No such process has yet been adopted in Germany.

vast Oak-coppices in the Odenwald, on the Neckar, in the valley of the Maine, and in the hilly tracts of the Central Rhine district, together with its numerous great side-valleys, are rendered profitable by the utilisation of the bark; because the good but usually small wood yields only the minor part of the income from them. Worked mostly with a rotation of 14 to 18 years, such Oak-hags yield first-class smooth bark on favourable classes of soil and situation, and supply the raw material for a brisk trade, especially in the preparation of soling and glazed leathers. The bark is sometimes sold in the forest, and sometimes at special marts, according to samples, which latter method is finding imitation in other districts. Amongst the most celebrated of these bark-markets are Heilbronn, Hirschhorn, Bingen, and Alzey.

The tanning-bark most highly prized is that produced on rich mountain-soil, on sunny exposures, and in crops that are not too dense, and which is thick, fleshy, and still smooth and unfissured. When grown at high elevations, the bark of the Sessile Oak is better, both as regards quality and quantity, than that of the Pedunculate Oak (Burckhardt, *Säen und Pflanzen*, 1893, p. 38).

(*a*) **Coppice-Woods.**—The smooth-skinned and more valuable assortments of bark are only obtainable from young crops under about 25 years of age at most; but wherever Oak-coppice is grown for bark, the rotation ranges from 14 to 20 years, and it is only when a specially favourable market exists for the young poles that this is increased to 25 or 30 years. Where the soil and situation are favourable to the Oak, the coppices should consist purely of that. As Gayer remarks:—

From the rational standpoint as to bark-production, it must be the rule *to endeavour to have a pure crop of Oak-coppice as far as possible* on all tracts on which the Oak can thrive; for the net return from coppice-woods rises and falls with the less or greater admixture of other species. Neubrand is quite right in asserting that on good soil a mixed bark-coppice is a sign of negligent management.

And with regard to the number of stools per acre, of which the crop should consist, he says:—

A crop of 1600 to 1800 vigorous stools per acre is considered the most suitable density under average circumstances, and under the supposition that thinnings are to be rationally conducted. In forming new Oak-coppices, one should not plant at a greater distance than 5 ft. by 5 ft.

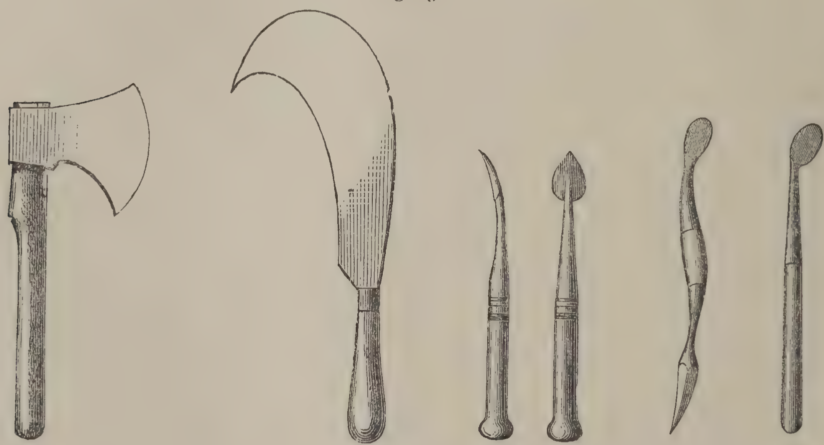
The thinnings for the removal of all the other kinds of trees as well as of the less vigorous Oak-shoots should be begun when the coppices are about 8 or 10 years of age. This operation is repeated a year before the fall, and the small epicormic or adventitious side-shoots are at the same time removed from the Oak-poles. Owing to the large amount of light and of growing-space thus obtained by the more vigorous shoots, they rapidly develop during the remaining 5 or 6 years of their growth into thick-barked small poles having a large proportion of fleshy cambium, containing tannin and other reserve supplies, and a relatively small proportion of the dry, corticeous epidermis; for on the general vigour of growth of the shoots depends the quantity of reserves stored up, and consequently the amount of tannin.

Wherever, as is usually the case practically, there are patches of other kinds of trees which could not be removed during the thinning without causing blanks in the crop, these are cut out during the winter or early spring before the harvesting of the Oak-bark begins. And at the same time in many districts the Oak-shoots are trimmed by removing all the little side-twigs as far up as a man can reach with a bill; while any young seedling stores or standels that are to be reserved to grow into timber-trees should also be marked. To grow standards, however (a first step towards the formation of copse), is distinctly at variance with the proper treatment of Oak-coppice, as good returns from bark-coppice can only be obtained when the crop has the full benefit of exposure to light and warmth.

The work of barking is proceeded with from May till about the middle of July; but the best time for peeling is just after the buds open, which may be from about the end of April to the middle of May, according to the local climate. In addition to the bark peeling most easily at that particular time, other important points are attained by accomplishing the work within that fortnight if possible, because (1) the tannin and other reserve supplies begin to be utilised in large quantity in other portions of the organism after the vegetative activity re-awakens, so that there is only a smaller percentage of tannin in the bark in summer; and (2) by an early fall the new coppice-shoots flush earlier and are better able to harden and season thoroughly before early frost comes in autumn.

Throughout Germany, poles and trees are mostly stripped after felling. The fall is made with the axe, and as low down and as smooth as possible; and only

Fig. 236.



a *b* *c* *d*

German bark-stripping tools—a, hatchet or small axe; *b*, curved bill-hook; *c* and *d*, barking-spoons, scalpels, or bark-slicers.

so many poles are felled at any time as may be completely stripped within an hour, so that one feller can keep 2 or 3 strippers busily employed. The bark only peels freely when stripped immediately after the fall. Poles that have lain on the ground for 24 hours require to be beaten all over with the mallet before the bark will come away, which not only involves the expenditure of more time, but also depreciātes the market-value of the bark. The use of the mallet is always a forcible proceeding, and must produce a loss of tannin, which has been assessed at 20 per cent (Gayer).

The barking-tools are of a very simple kind, and include (Fig. 236) a **hatchet or small axe** (*a*), a **curved bill-hook** (*b*), for felling small poles and for stripping bark from standing trees, and a **barking-spoon, scalpel, or bark-slicer** (*c* and *d*), formed of a curved piece of wood or bone, about 8 to 12 in. long, and flattened at the end. If made of bone, it requires to be fitted to a wooden handle to be of sufficient length to give a good purchase. Barking-spoons of wood or bone are much preferable to those with iron points, which discolour the bark and lower its value in the eyes of buyers, even though its ultimate quality may thereby only be very slightly affected. Different forms of the barking-spoon are preferred in different districts.

In many parts of the Upper Rhine districts it is customary to cut the poles more than half through, about 3 to $3\frac{1}{2}$ ft. above the ground, until the crown falls or can be easily bent down to the ground (Fig. 237). The pole (*b*) is stripped immediately on being cut through and bent over, and then afterwards the stump (*a*) is felled close to the ground and barked also. This is a very good method, because it has the great advantages that the use of the mallet would be inconvenient and ineffective, and that the bark is stripped without any possibility of the flow of sap being interfered with by evaporation or transpiration.

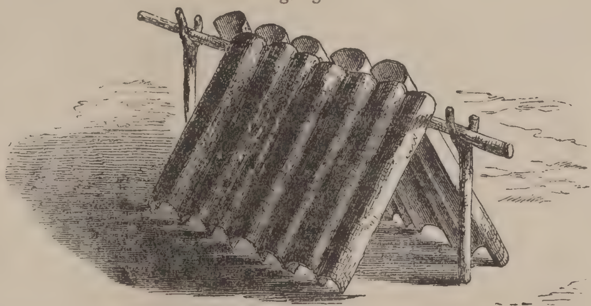
Bark-stripping from standing poles is a method largely practised in France, the Black Forest, and in Austria. The poles are first lopped of branches as high up

Fig. 237.

Upper Rhine method of notching and bending down poles for bark-stripping.

as can be reached, and then by means of the curved bill and the bark-slicer strips of bark about $1\frac{1}{2}$ to 2 in. broad are removed to as great a height as convenient, which are bound loosely into bundles and hung on the poles to dry. The upper portion of the bark, consisting of the greater part of the crop, is then stripped by means of the bark-slicer, ladders being usually employed in order to reach it. It is, however, not removed from the pole, but remains hanging there till it seasons, which it does quickly and easily. This method also prevents the use of the mallet, but does not utilise the bark of the small branchlets, which are very rich in tannin; and it is rather a tiresome process for the workmen.

Fig. 238.

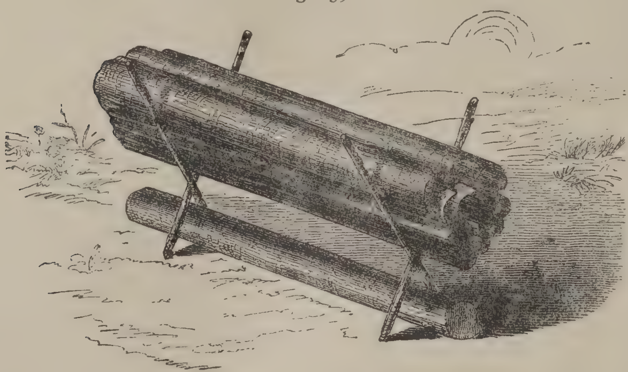


Another method common in France is to remove the bark, in two rolls of about 3 ft. each, up to a height of about 6 ft., then to fell the pole, and proceed as is usual for peeling felled stems. When bark is stripped without the use of the mallet being necessary, a workman can, according to Neubrand, peel from $2\frac{1}{4}$ to 4 cwt. of bark in one day; whereas, if the use of the mallet is necessary, he can only strip $1\frac{1}{2}$ cwt. per diem with difficulty.

In drying the bark, the same principles are of course kept in view as in Britain—viz., to accelerate the process of curing or seasoning by free exposure to dry air, and to prevent the bark from becoming mouldy by damp. The usual methods adopted in the open are shown in Figs. 238 and 239. The former needs no explanation; but as regards the latter, it may be remarked that the two pairs of cross-stakes when fixed in the ground are bound together at the top (which is not here shown), and a faggot or pole is also put in below to act as a support, while the bark is laid lengthways in the larger upper fork. Or drying-stages are made by erecting several parallel pairs of forked stakes, each with a cross-pole, as in Fig. 238, then laying other poles on these cross-poles, so as to form a long, broad drying-stage or platform, on which the bark is spread thinly.

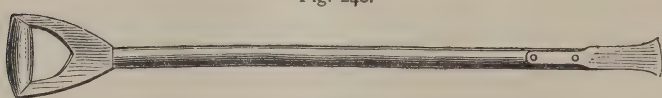
(*b*) **Timber-Trees.**—As in the case of coppice-woods, the bark-stripping of large trees also takes place in early spring; but this method is open to objections, which deserve consideration now that prices for bark are low. In the first place, if Oak be felled while the sap is rising, the quality is not so good as that of timber felled in autumn or winter; and, in the second place, if there be any young growth underneath these standard trees, it is more apt to be injured than if the fall take place during the leafless time of the year. In the large tracts of copse with Oak standards near Hildesheim (Hanover), the trees are barked in spring and felled in the following winter; while in other districts they are felled in January or February, and then peeled in spring. In the former case there is a loss of one year's growth of wood, and in the latter a loss in the quality of the bark owing to the use of the mallet; but in either case the damage to young growth is less than if the trees were felled while the leaves are flushing in spring.

Fig. 239.



As a rule, the barking takes place after the stems are felled, and only such number of trees should be cut as can be barked on the same day. The instrument used is a strong **barking-iron** (Fig. 240), with which a long slit is made in the bark, right down to the wood, at the butt end of the stem, and continued as far up as possible. It is then measured off in sections 40 in. (1 metre) long, and each of these is in turn peeled by means of the iron and the hands, very much in the manner previously described in connection with Fig. 233. The use of the mallet to a greater or less extent is in this case unavoidable. When the stems are peeled standing, ladders have to be used; but as the bark strips more easily at the time of the sap rising, the use of the mallet is then unnecessary. In Germany, a well-trained woodman can bark 4 to 5 large Oaks in one day during favourable weather. When the bark is rough and fissured, some cleaning is necessary, and this can best be done before peeling commences.

Fig. 240.



According to measurements made by Baur, the following loss in weight and volume takes place in the drying of Oak-bark:—

Shrinkage.	Smooth branch-bark.	Smooth pole-bark.	Smooth tree-bark.	Fissured tree-bark.
	Per cent.	Per cent.	Per cent.	Per cent.
Loss in weight . . .	49	45	42	32
Loss in volume . . .	41	36	34	21

That is to say, the younger and the more valuable the bark, the more it shrinks both in weight and in bulk during seasoning. If stacked for long, the bark continues to shrink after seasoning in the open, the further loss in weight being 4 to 5 per cent, and in volume from 11 to 20 per cent. Baur also found that the proportion of bark to the total volume of the unpeeled wood (actual cubic contents) was as follows: Smooth branch-bark, 35 per cent; pole-bark, 30 per cent; smooth tree-bark, 27 per cent; and rough tree-bark, 18 per cent. When seasoned and ready for the great bark-marts, the bark is at once assorted, then laid on trestles made of crossed stakes fixed in the ground, and firmly bound with withes into bundles measuring from about 3¼ to 6½ ft. long, and from about 2 to 3½ ft. in girth, according to local custom. Bundles of 3¼ ft. long and the same in girth usually average about 33 lb. in weight.

The loss of material when coppice-falls are stripped of their bark varies from about 17 to 30 per cent; but this is fully balanced by the better quality of the wood, even when sold merely as fuel. Hence, even if the market for tan-bark is not particularly remunerative, it will usually pay to bark Oak-coppices if there be any favourable outlet for firewood in the neighbourhood.

According to Bernhardt, the **average yield of Oak-coppices** in Germany, when worked with a rotation of 12 to 17 years, is as follows *per acre and per annum*:—

I. Climate very favourable, soil very good: 4 cwt. bark, and 100 cub. ft. wood (actual contents).
II. Climate favourable, soil good: 3⅓ cwt. bark, and 85 cub. ft. wood (actual contents).
III. Hill climate, W. Germany, soil medium: 2 cwt. bark, and 70 cub. ft. wood (actual contents).
IV. and V. Central, N. and N.W. Germany; good fresh loamy sand, and fresh sandy soil: 1 to 1½ cwt. bark, and about 56 cub. ft. wood (actual contents).

In the warmer localities of the Odenwald, however, the finest hags yield up to 6 cwt. of bark *per acre per annum*.

Larch.—Larch-bark is not now so often stripped as it used to be before cheap foreign Oak-bark became largely imported; nor does it possess such good tanning properties as Oak (see p. 488). Wood-merchants are apt to complain that if the Larch be left long after being peeled, it cracks and splits deeply, especially during hot, dry weather, though this danger can be to some extent obviated by leaving unpeeled bands of bark at each end and in the middle of the log. Undoubtedly by barking Larch, Pine, or Fir a great saving is effected in carriage, because Larch cut for pitwood loses about one-third of its weight soon after being peeled. But neither Larch- nor Spruce-bark is everywhere saleable in Britain, and it can no longer be said that—

> Larch, in the form of thinnings, and below thirty years old, should be peeled for the sake of the bark: the operation usually pays from 15 to 25 per cent, minus the cutting down and pruning (Michie, *The Larch*, 1885, p. 111).

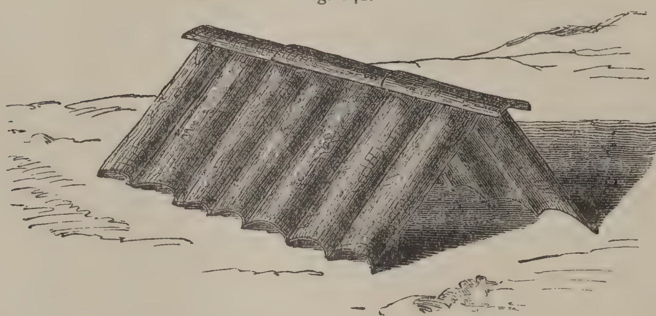
Larch will strip from about the middle or end of April till late in the season; but the best time for peeling is when the young leaves are expanding from the bud. The work of peeling is similar to the stripping of the Oak, except that Larch-bark is taken merely from the stem, and not from the branches. The mallet seldom needs to be used, as after the bark is cut into lengths it comes off easily with the stripping-chisel; hence Larch can be more quickly and cheaply barked than Oak.

The bark may either be dried on stages on forked-stakes, or by laying it on the Larch-trees on the ground. It usually dries sooner than Oak-bark, and is much less liable to mildew. In favourable weather it may even be stacked in four days after being stripped.

Instead of being chipped into small pieces like Oak-bark, seasoned Larch-bark, being very brittle when dry, is often threshed with flails on a tarpaulin laid on the ground. This is a very cheap method, as a man can break into pieces about a ton weight of bark in a day.

Even winter-felled Spruce can be stripped for a short time during the spring, when the sap moves. In Scotland a Larch-tree containing 36 cub. ft. of timber yields 16 stones (224 lb.) of green bark, equal to $9\frac{1}{2}$ stones (133 lb.) when dry; some stems yield 8 to 10 lb. of bark for every cubic foot of timber, or 6 to 7 cwt. of bark for every load of 50 cub. ft. of timber, and trees not over 40 years old may be calculated to yield 7 to 9 lb. of bark for every cubic foot of timber. In the Highlands of Scotland the Larch, Willow, and Birch usually begin to strip easily about the beginning of May, whereas the Oak is about a fortnight later in peeling readily. Stripping costs about 20s. per ton, and chipping and bagging other 7s. per ton. Scottish Larch-bark contains about 15 per cent of tannin, or rather less than the half of that contained in the best Oak-bark (Michie, *op. cit.*, p. 151).

Fig. 241.



Spruce-bark is harvested to a much greater extent than Larch-bark on the Continent, and more especially throughout Eastern and Southern Germany and Western Austria. The stripping takes place in much the same way as in the peeling of Oak and Larch, and is usually carried out during the summer months. The stems are barked in sections about 40 in. long, and then peeled with a hard, pointed, wooden bark-slicer. The pieces of bark are seasoned by being ranged in roof-shaped fashion (Fig. 241), or are simply laid on the stems lying on the ground. As they dry, the pieces of bark roll themselves up, and they are usually sold in such rolls (by the 100), or in stacked heaps (Fig. 136, p. 66), instead of by weight. In seasoning, Spruce-bark loses more than half its weight when green. The quantity of bark on Spruce has been found in Saxe-Meiningen to vary from $11\frac{1}{2}$ per cent of the total actual cubic contents in trees of 16 to 18 in. diameter (at breast-height) to 17 per cent in those of poles of 4 in. diameter (Stoetzer), while for Conifers generally it may be reckoned at from 10 to 15 per cent (Gayer).

Birch-bark was also formerly in much greater demand in Britain than is now the case, though in some places it is still used for tanning. Birch may be stripped nearly a month earlier than Oak; but the best time is when the buds are beginning to burst.

Birch-bark is peeled in much the same way as Oak. It is, however, much more easily dried if merely put upon a few sticks on the ground. Unless it has to be carted a long distance to the tanyard, Birch-bark is generally sent in bulk straight from the stages, unchipped and not in bags; because, owing to its small value, just as little time and labour are spent on it as will secure proper peeling and drying.

On the Continent, though Birch flushes into foliage earlier than Oak, barking is easiest about fourteen days after the Oak-bark strips most readily.

3. **The Harvesting of Tree-seeds** can only in Britain be said to assume anything like commercial proportions with regard to Scots Pine and Larch, and even with these only to a small extent; while as to Larch, it is perhaps better to obtain seed from Alpine districts rather than raise plants from that produced in the milder parts of this country. Details about the collection and storage of the seeds of broad-leaved trees will be found under the respective trees in vol. i., Part II., chap. i., and also in a summarised form in Part III., pp. 372–374, so that the following remarks can be confined to Pine and Larch.

Scots Pine.—The old and still customary Scottish method of dealing with the seed is thus described by Brown (abbreviated):—

After the cones ripen in autumn, the desired quantity is collected during December or January, and placed on a timber-kiln made for the purpose. They may be laid on from 6 to 8 in. deep, and the heat in the kiln raised to about 110° Fahr., and not exceeding 116° at most. Neither brick nor metal kilns should be used. Even when the cones are heated on wood, great care is necessary not to apply too much heat to them, as a very slight overheating destroys the vitality of a large portion of the seeds. They should be turned every two hours, and at each turning all the seeds that come out should be gathered. With a heat of 110° to 114°, the cones should be removed in about eleven or twelve hours, when all the cone-scales will be open, and the remaining seeds will come out on the cones being well shaken in a riddle. If only a small quantity of seed is wanted, this may easily be extracted by exposing the cones to the heat of the sun; this will open their scales, and the seeds will fall out by gentle threshing with a light flail. When the seed has been extracted, it should be stored in a dry, cool place till required for sowing.

German Method.—In some parts of Germany (Hesse, Bavaria, Saxon States, &c.) the collection and extraction of the seeds of coniferous trees forms a large industry, employing a considerable amount of labour. The extraction of Scots Pine seed, and of the seeds of coniferous trees generally, is thus described by Burckhardt (*Säen und Pflanzen*, 1893, p. 269):—

The collection of cones and the extraction of the seed are usually undertaken directly by the foresters and woodmen, although in some cases contracts are made with approved seedsmen for delivery of seed under certain stipulations as to quality, &c. In many districts the harvesting of the seeds of Conifers forms an important branch of trade and industry.

The worst quality of seed is delivered by peasants, who heat the cones in their baking-ovens, whilst the best quality is obtainable by exposing the cones to the sun's warmth; but care must in the latter case be taken to procure the seed only from trustworthy persons. When seed extracted by means of the sun's warmth is used, hardly two-thirds of the quantity of seed otherwise requisite are needed for the ordinary operations of sowing, and the most vigorous plants are produced; hence it can be strongly recommended for use in nurseries. Although dearer in price, seedsmen buy it eagerly, in order to mix it with older seed.

The construction of seed-kilns has been considerably improved of recent years. The warming of the cones takes place with heated air, and a special contrivance admits of the seed falling down into a cooling-chamber as soon as it drops out of the cone. Whether the use of perforated trays ranged as shelves (Fig. 242), or of wire cylinders that are kept turning round like coffee-roasting machines, deserves the preference, is a point not yet decided.

When the extraction of the seed is completed, the cones are used as fuel for the kiln. The warmth that should be applied varies according to the nature of the kiln, but is in general greater for Scots Pine than for Spruce cones; it is usually kept at or below 127° Fahr. for the latter, but may be somewhat higher for the former; and the Scots Pine seed is less likely to be damaged by the rapid change of temperature on falling into the cooling-space.

The cleaning of the seed from the seed-wings or bracts takes place either by threshing in half-filled sacks, or by moistening it slightly with water, an operation requiring caution; but in both cases it has to be cleaned subsequently in sieves or winnowing-machines.

Larch seed is extracted as follows in Scotland (Brown, abbreviated):—

The speediest way to extract seed from the cones is to subject them to heat on a timber-kiln in the same way as Scots Pine cones; but for Larch cones the heat should not on any account be raised above 105° Fahr. Even when the cones are subjected to this heat, the seed will not fall out so readily as that of Scots Pine, but will have to be threshed out with a flail, as on the kiln they merely become dry and brittle. The kiln-dried cones should, while still warm, be laid 8 or 10 in. thick on a stone or pavement floor and threshed into pieces with flails, the seeds being sifted through a sieve from time to time, until all are extracted.

Continental Notes.—In many parts of Germany the cones are no longer collected and the seed extracted in seed-kilns (*Samendarren*) by the foresters and woodmen for local requirements; but in the Prussian State forests this method is still followed for Pine and Spruce seed. Elsewhere, the cones are either collected by trustworthy workmen and sold in bulk to seed-merchants, or else the latter buy the right of collection and make their own arrangements for harvesting the cones and transporting them to the seed-mills (*Samenklenganstalten*), and the seed needed for sowing in the woods and nurseries is purchased from these. For acorns, Beech-mast, &c., the right of collection is usually sold, subject to the proviso that a certain quantity required is to be made over to the forester.

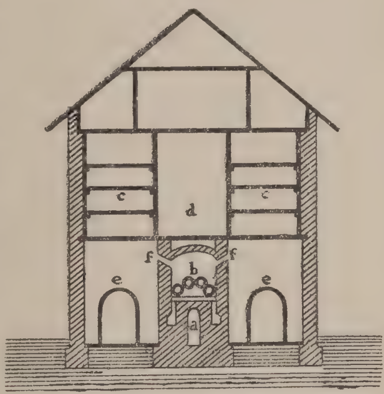
Special attention is given to see that only good, well-formed seed is collected from middle-aged trees, this being preferable to that produced either by young or by old trees. The seed is of course collected when it ripens—*i.e.*, Oak, Beech, Ash, Maple, Sycamore, Hornbeam, and Alder about the end of September or early in October; Elm in May or June; Birch in July and August; Silver Fir early in October; Spruce and Scots Pine from November till January; Larch, however, not until February, as the action of hard winter frost acts on the resin closing the cone-scales, and makes it easier to extract the seed; while Weymouth Pine cones are collected as early as September, owing to the scales soon opening and scattering the seed.

Heavy seeds, like acorns and Beech-nuts, are picked after falling to the ground, the fall of the seed being sometimes assisted by climbing the trees and shaking the branches, or beating them with the padded back of an axe, and making the seed fall on sheets spread below. Or the seed-twigs are broken off and thrown to the ground, as in Ash, Maple and Sycamore, Hornbeam, and Alder, while very light seeds like Birch and Elm are at once put into a sack slung over the back of the collector. In marshy localities Alder seed has often to be skimmed off the surface of the water on which it has fallen. Unless sufficient can be collected from Conifers felled in winter, cones are got by climbing the trees (with climbing-irons) and snipping the twigs with a sharp chisel-edged hook, and afterwards collecting them from the ground.

The extraction of the seed from the cones is easiest in Weymouth Pine, as the seeds fall out of themselves, especially if the cones are turned from time to time with a rake. Silver Fir cones soon fall to pieces if spread on an airy loft and raked over daily, when the scales and seed part from the spindles, and this pulling to pieces of the cones can easily be accelerated by warming them slightly, the seed being then separated from the scales by passing through a sieve, and rubbing and winnowing the seed to free it from the wings.

Scots Pine, Spruce, and Larch seed all require, however, more warmth than Weymouth Pine or Silver Fir before their seed can be extracted from the cone. The oldest method of all is extraction by means of the sun's warmth (*Sonnendarren*) in stages erected against a warm south wall. Loosely-woven, hurdle-like trays are filled with cones, and ranged in rows above each other, but so far apart in height that the sun's rays can reach right to the back of each lower trayful. The cones are turned frequently during bright sunshine, and the seed gradually comes out and falls down through the trays as the cones are turned, till it finally drops into drawers or boxes placed to receive it. The whole stage is roofed to protect the cones from rain, and the drawers for catching the seed below have a bottom of linen, in place of wood, so that the rain-water entering from the side may at once drain off and the seed be able to dry. When the bulk of the seed is thus won from the cones, these are put into barrel-like cylinders, and turned round and round till the rest of the seed falls out.

Fig. 242.



Seed-kiln for extracting Scots Pine seeds from the cones—

(a) *Furnace.*
(b) *Heating-pipes.*
(c) *Shelves with trays for cones.*
(d) *Passage.*
(e) *Cooling-chambers.*
(f) *Outlets for hot air.*

(After Stoetzer, in Lorey's *Handbuch*, vol. ii. p. 247.)

The above method is, however, not much in use nowadays, because it is rather slow, and is always more or less dependent on the weather. Hence seed-kilns (*Feuerdarren*) are mostly in use. The simplest form of seed-kiln is a framework of trays above the common oven used in heating houses throughout Germany, but in large seed-merchants' establishments special kilns are built on the following principles (Stoetzer, in Lorey's *Handbuch*, 1903, vol. ii. pp. 246-250):—

The kilns in use in the Prussian State forests are still of somewhat similar type to that erected by Eytelwein at Eberswalde (near Berlin) in 1837. This consisted (Fig. 242) in an arrangement of iron tubes (*b*) over a furnace (*a*) so as greatly to superheat the surrounding air, which is then conducted through openings (*f*, that can be closed at will) to loosely-woven wire trays (*c c*), ranged row above row along both sides of an upper storey (the extracting chamber), so that the hot air ascending at each side can pass upwards through the wire trays filled with the cones. The three or four stages of trays are closed in towards the passage between them (*d*) with wooden shutters along their front side, so that the hot air *must* ascend through the meshes of the trays and act on the cones in ascending. While the current of hot air flows upwards the cones are repeatedly turned and stirred about, and the trays shaken, when the seed falls out and drops from tray to tray, till it finally reaches the stone-flagged cooling-chambers (*e e*), into which cold air can be admitted as required.

There are various modifications of such seed-kilns, such as the use of drum-sieves worked by machinery, in place of the wire-trays on which the cones are turned by hand. In others, the trays are placed immediately above the current of hot air, and when the scales open, the cones are poured out on a floor and raked to make the seed fall out, after which the cones are put in wide-meshed drum-sieves and turned quickly till all the seed is obtained.

Another method, introduced in 1866 at Darmstadt, and still in use there, is extraction of seed by steam conducted below the seed-trays by iron pipes coming from a boiler outside. Steam-heating has the advantage over seed-kilns that there is less chance of the seed becoming over-heated, and that the cones can be more quickly warmed to the temperature required for extracting the seed, so that the germinative power is not likely to be so much affected by loss of essential oil.

It is of course desirable that the seed should be exposed to heat for as short a time as possible, and be cooled quickly. Exposure to a high temperature of 112° Fahr. for a short time, which soon makes the cone-scales open, is therefore less likely to damage the seed than a considerably longer exposure to about 100°; but in any case it is always necessary to have some arrangement by which the hot air can be led off, and fresh air obtained from outside to cool down the cones as soon as the scales have opened with the warmth.

Some seed-merchants consider that it is best to warm the cones by putting them for a short time above the heating-chamber before they are wanted in the latter, while others think that the cones open better if brought in straight from the storing-sheds to the kiln. If brought in damp during wet weather, they are (but only until the outside moisture is evaporated) exposed to rather greater warmth than would otherwise be the case; and as soon as the cones are dry, the temperature is reduced to the normal degree.

The measure of success in extracting the seeds mainly depends on the cones being collected during dry weather, and not too early in the season. The best cones, and those that open soonest, are those collected after hard frost has come several times, and has driven most of the moisture out of them. But if cone-collecting be delayed too long, it may of course happen that the best of the seed has already been shed naturally.

The empty cones are generally used for heating the furnaces of the seed-kilns, although the heat generated is not so even as that obtained from charcoal. The kilns work day and night, and the time taken in extracting the seed varies from 8 to 15 hours, Spruce taking less time than Scots Pine.

Seed-merchants remove the wings from the seeds for purposes of storage and transport, and also because the quality can then be seen better than before; but in small private establishments it is better to keep the seed with its wings attached, and to hang it up loosely packed in coarsely-woven sacks hung in a dry, cool, airy barn or granary, in the same way as seeds of broad-leaved trees are protected against mice and rats. Scots Pine, Larch, and Spruce seed retain their germinative power longest (up to two or three years), however, if kept in cone. After coming from the seed-kiln the seed can easily be detached from the wing (to which it is attached as if held by pincers in the Pine, and as if resting in a spoon-shaped hollow in the Spruce), either by a **dry process** of working them well up and down in a sieve by hand, or by filling it into sacks and threshing them with flails, whilst at the same time turning and shaking them often, or else by a **wet process** of spreading them to a depth of about 6 in. on a smooth even floor and moistening them with water poured from a watering-pan, then leaving them thus for a night before threshing them with leathern flails. The latter method is the speedier when large quantities of seed are being dealt with, and it usually brings the seed away cleaner from the wing than in either of the above dry processes. But in large establishments the seed can also be well parted from the wing by being put into large grooved revolving drums, which shake the seed well. Whatever method is employed, the seed has afterwards to be cleaned in winnowing machines to get rid of the wings and dust, while the clean seed falls into a bin ready for packing into sacks.

Larch-seed cannot be extracted merely by warmth, as the resin melts and closes up the cone-scales if too high a temperature be applied. The cones have therefore to be broken in pieces mechanically. In the Tyrol this is done by utilising the water-power of the mountain torrents. The cones are placed inside a cylindrical box set with nails and pins, and so attached to the axle of the water-wheels driven by the torrent that as the wheel revolves the cones are broken and rubbed violently against each other. In large seed-establishments, however, the cones are either broken up inside a rapidly revolving drum, driven by steam-power, the interior of which is ribbed to increase the friction between the cones, or else the drum is fixed, while four movable rake-like arms attached to the axle rotate and break up the cones. The sides of the drums have openings in the form of narrow slits, through which part of the cone-dust may be got rid of as the machinery revolves. When taken from the drum, the seed has to be either sieved or winnowed to free it from impurities (dust, pieces of scale or wood).

The average results of seed-extraction in Germany are as follows:—

Tree.	1 hectolitre (22 gallons = 2¾ bushels) of cones		Or reduced to British weight and measure, 1 bushel (= 8 gallons) of cones	
	Weighs,	Gives clean seed,	Weighs,	Gives clean seed,
	lb.	lb.	lb.	lb.
Scots Pine.	110-132	1·65-1·98 (and even 2·2)	40-48	0·60-0·72 (and even 0·8)
Larch .	about 77	4·4-6·6	about 28	1·60-2·40
Spruce .	55-66	2·64-4·18	20-24	0·96-1·52
Silver Fir .	55-66	4·4-6·6	20-24	1·60-2·40

Tree.	1 kilogramme (2·2 lb.) of clean seed		So that 1 lb. of clean seed		
	Contains seeds, about	Fills in litres (1·76 pint = 0·22 gallon), about	Contains seeds, about	Fills about	
				Pints.	Gallons.
Scots Pine.	150,000	2 litres	68,000	1·6	0·2
Larch .	120,000	2 ,,	54,500	1·6	0·2
Spruce .	120,000	2·15 ,,	54,500	1·72	0·215
Silver Fir .	24,000	3·5 ,,	10,800	2·8	0·35

Note.—10 lb. of Scots Pine seed with wings will give 7 lb. of clean wingless seed; and 5 lb. of Larch seed with wings will give 4 lb. of clean seed.

CHAPTER III.

THE TRANSPORT OF TIMBER BY LAND AND WATER.

Throughout the United Kingdom, the transport of timber in log is almost entirely by **cart** or **carriage**, by **traction-engine**, or by **railway**, special **timber-waggons** being in each case employed. Converted timber is also conveyed to some extent in canal-barges and river-boats, but there is no great amount of cheap transport by water, such as the **floating** so largely practised on the Continent, where fuel-billets and even logs are cast loose into the water and allowed to **drift** down-stream, or logs are lashed together, end to end, to form a large **raft** for conveyance to distant marts.

I. **Transport in Woodlands and on Roads.**—**Horses** are usually employed for dragging logs and large poles from the felling-area, while smaller poles are either lashed at the small ends into bundles and dragged out in the same way, or are carried out singly by men if the road or green lane to which they are to be taken lies near at hand. Oxen are not used for dragging purposes to anything like the extent customary on the Continent.

The transport of timber is in Britain a matter of very great importance, because, as already shown (see vol. i., *Introduction*, pp. 87-94), in the absence of local demand close at hand, the cost of conveyance from the woods to the nearest available market often determines whether wood can be disposed of profitably or not. On this point the evidence of Mr. Margerison, who represented the Timber Trades Federation of the United Kingdom before the Departmental Forestry Committee in 1903, is of particular interest:—

It costs, I take it, about 5d. to grow a cubic foot of Fir timber in this country. On the average, it costs at least another 5d. or 6d. to get it into the market, and it is sold (I speak from local experience) at 8d. or 9d. per cub. ft.—that is, less than cost price. This selling price is ruled by the selling price of foreign Fir. There is no reason why we cannot produce as cheap and good Fir as other countries ; but we cannot afford to sell it as cheaply (although we do so), because the cost of handling it and transporting it short distances is greater than the cost of the long distance traffic from abroad. Until some means of cheapening these handling charges is devised and adopted, the growing of cheap timber and transporting it in the round in this country will not pay, unless the "timber famine" which seems to be before us—owing to foreign supplies getting more and more remote—sends up prices. The relation of transport to value in the case of timber is of much greater proportionate importance than it is in the case of, say, corn. Where a ton of corn would cost 5 per cent of its selling value in transport, a ton of Fir timber would cost 60 per cent. A ton of Spruce from the Baltic, or even from Canada, would not cost any more than, if as much as, a ton of Spruce from the Yorkshire hills to the Yorkshire coal-mines. Differential railway rates are costing timber-growers as much as the rental value of much of the lands the timber is growing upon.

The fault of this is not all to be laid to the doors of the railway companies. Foreign timber imports are handled in larger quantities than ours, thus saving much cost in detail work. It is in handier forms than ours often is. Our timber is often in clumsy trees, crooked and knotty, forming comparatively light and dangerous loads per truck. But there is no indication that if any effort be made by our home producers and merchants to centralise their work, make their loads more compact, and arrange for regular and large consignments, that the railway companies would make their charges equal to those on imported timber. Straight and crooked, large lots and small, compact loads and light ones, are all charged at the same rate. There is a growing tendency to use road locomotives for moving timber in some districts, and it is said to have resulted in considerable saving where the roads are suitable. But good roads do not, as a rule, penetrate into the woods, and there are sometimes weak bridges and sharp corners to negotiate with long, heavy loads. So that this competition can only be partial. And in this country we have not the advantage of rivers and water-shoots, nor the certainty of frosts to harden swampy places, as is the lot of some timber countries.

The question of transport is perhaps the most important one for growers of timber to consider in connection with their forestry, because it is of little use to grow large and valuable crops unless there is an available market for them. At the same time, the life of a tree is a long one, and that of a forest longer, and if conditions of transport change as much for the better in the next eighty years as they have done in the past eighty, there will be no fear of being able to place the crop in an advantageous market (*Report of Deptl. Com. Brit. Forestry*, 1903, App. iii. p. 164).

Even in the handling of logs and their removal from the felling-areas to the nearest roads there is room for improvement in British methods, and some of the Continental implements for obtaining strong leverage might with advantage be introduced where the timber cannot be conveniently dragged or carted from the fall at once by horses or oxen.

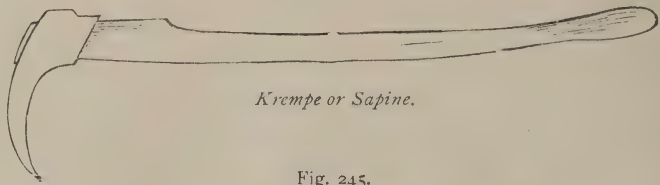
Some of the best and handiest of such implements for handling timber and bringing it out to the nearest roadway are the **pick-hook** (Fig. 244 ; Ger. *Krempe*, Fr. *Sapine*), by whose aid the woodman obtains remarkable purchase over any log into which the point is driven ; the long **boat-hook**, also of great use during rafting operations (Fig. 243) ; and the more powerful **pointed gripper and ring-hook lever** (Fig. 245), the method of employing which is also here shown (Fig. 246). The pick-hook is an extremely useful instrument when timber is being slid, butt end first, down a hillside to a roadway below. Other useful implements, when horses or oxen are used for extraction, consist of the **dragging-shears** or **grappling-irons**, mostly used for hardwoods (Fig. 247), and two small sledge-like contrivances, the **dragging-pin** (Fig. 248) and the **dragging-shoe** (Fig. 249), which are used chiefly for Conifers and softwoods. But any other sledge-like arrangement is of assistance, even if it only raises one end of the log or pole off the ground, because this decreases the friction between the surfaces of the log and the ground ; and the haulage is also facilitated if the thick end is that supported, leaving only the smaller end trailing.

Where the ground is open and hard it is customary in Britain to load timber at once on 2-wheeled timber-carts or 4-wheeled carriages (**timber-waggons, gills**) on the felling-area, without hauling it out to the road-ways. But where immediate loading is not practicable, it is first *tagged* or dragged off the fall by horses with chains attached to the butt-end of the log. In loading on 4-wheeled timber-carriages, of which there are several kinds, stout poles (called *leaders*) are generally placed at a suitable slope from the cart-frame down to the side on which the log to be raised lies ; and chains having been passed below this near each end, and then brought

Fig. 243.

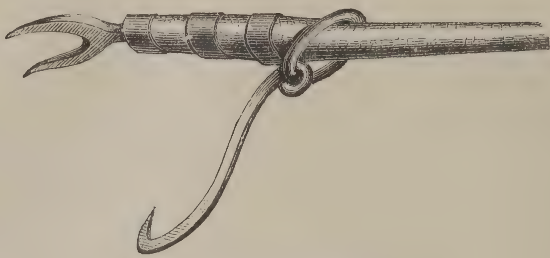
Rafting-Hook.

Fig. 244.



Krempe or Sapine.

Fig. 245.

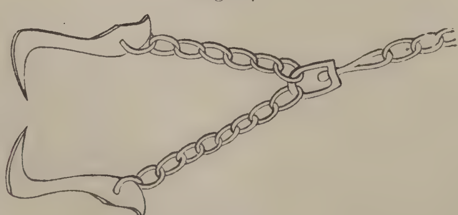


Pointed Gripper and Ring-Hook Lever.

Fig. 246.

Pointed Gripper and Ring-Hook Lever in Use.

Fig. 247.



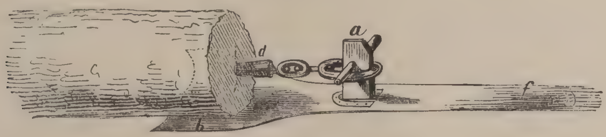
Dragging-Shears or Grappling-Irons.

back over the cart and hooked on to the horse-yokes, the horses are moved forward simultaneously till the log rolls up the leaders on to the cart-frame, and is there firmly secured.

But there are of course various methods of loading (*e.g.*, tilting the cart longways and windlassing the log up), which are all very much alike in principle, though they may vary in details as to applying leverage and fixing the log in position.

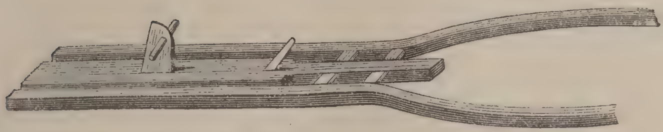
The common English **timber-carriage**, usually employed for heavy traffic on metalled roads, consists of four high and broad-tired wheels, the hind pair

Fig. 248.



Dragging-Pin.

Fig. 249.



Dragging-Shoe.

of which is adjustable to any given length desired by means of a long pole or beam forming the body of the cart. The front pair of wheels having been brought into proper position over the butt end of the log as it lies on the road, this butt end is lashed by chains to the strong hook on the thick lower end of the beam, which is raised perpendicularly aloft at the time. On bringing down the upper end of the beam and securing it to the axle of the hind pair of wheels, the great leverage thus brought into play lifts the chained butt end of the log clear up from the ground. The other end of the log is then raised by means of levers, or jacks, or a fixed windlass, and is securely fastened to the beam, when the whole log swings clear of the ground and is ready for transport. Broad-flanged wheels, though heavier than narrower ones, facilitate the work of haulage greatly, as they are much less likely to sink far into the ground under a heavy load.

One of the handiest of two-wheeled log-carts is that known as the **Timber Bob** or **Jim** in England, and the **Janker** in Scotland (Fig. 250). The log is slung under a bent iron axle, to which the iron-plated Oak or Ash shaft-pole (ending in a strong hook) is attached. The wheels are from 4 to 6 in. broad in the flange, and from 5 to 6 ft. in diameter ; the whole cart weighs from 9 to 11 cwts.

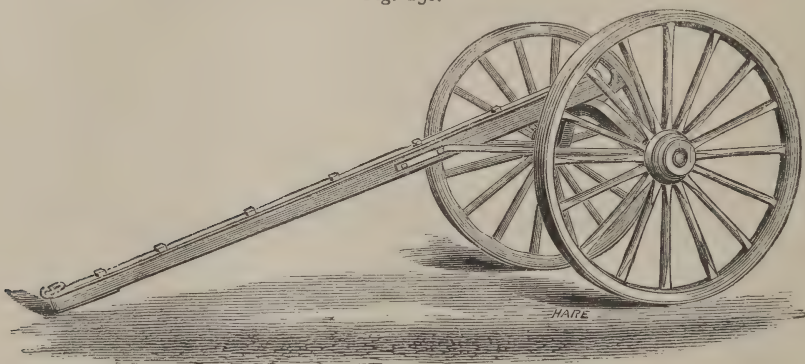
Roads.—In all extensive woodlands a well-projected network of good **roads** for facilitating the extraction of timber adds largely to the value of the produce as compared with that from woods whence extraction is difficult and expensive.

No large acreage of waste land should be planted without a well-considered network of roads having been first of all projected (see Part V. p. 250).

Where the quantity of timber required to be carted is not likely to be great at any given time, the roads in woodlands need not be wider than is necessary to allow one timber-cart to be driven, provided always that recesses or halting-stations be made within easy sight of each other. But otherwise, the roadways only need to be about 18 ft. broad, so as to allow empty carts to pass loaded ones at any place along the route.

It is by no means necessary that any considerable expense should be incurred until the roads are likely to be required for extracting timber. It is sufficient if the roadways or green lanes be aligned at the time of forming the plantations; and later on such preparation as may ultimately be required in the way of levelling, metalling, bridging, &c., can be carried out at the most opportune season

Fig. 250.



The Timber Bob, Timber Jim, or Janker.

before the roads are required for traffic. Except in the case of windfall and damage from snow or ice, insects, fire, &c., the time for preparing the roads can always be easily foretold in well-managed woods.

The Cost of Carting Timber may vary considerably according to the distance, the gradients of the roads, the general condition of the roadways, and the weather; and the variations are so great that average figures can have little more than local value. Under fair ordinary conditions in Central and Southern England the cost of loading, hauling, and unloading may vary from ½d. to 1½d. per cub. ft. per mile according to circumstances (R. Anderson); while the average of other experience (T. Bright) shows that for cartage on a fairly level road the cost per cubic foot (square-of-quarter-girth measurement) is from 1d. to 1½d. up to 2 miles, from 2d. to 3d. for 2 to 4 miles, about 4d. for 4 to 6 miles, and from ¼d. to ½d. per cub. ft. per mile beyond this distance.

Timber-merchants usually keep few or no horses, but contract locally for the felling and logging of the trees, for handling and loading, and for conveyance of timber from the woods at so much per tree, ton, or cubic foot.

In many parts of the United Kingdom home-grown timber can only compete with foreign imports when strict economy is exercised in transport and conversion; and the question of transport, first to saw-mills and then to the nearest railway or seaport, becomes of special importance in order to secure any margin of profit. At the present high cost of manual and horse labour, a traction-engine is usually the cheapest method of transport if the gradient and state of the roads make it practicable. If the distances are long and the quantity of timber is large, the saving in haulage may vary from 5 to 20 per cent as compared with cartage.

By means of a traction-engine and goods waggons, a forester can, on a small schooner's cargo of, say, 1800 or 2000 sleepers, even with a distance of five or six miles' carriage, effect a saving of some £16 as compared with the cost of horse labour. The wages of a staff sufficient to work the traction-engine and to load and discharge the waggons would be 16s. 2d. per day; coal, oil, &c., would cost 6s.; upkeep of traction and waggons, say, 5s.—amounting in all to 27s. 2d. per day. At this cost 500 sleepers can be carried the above distance in one day; whereas it would be necessary to employ 16 horses and carts at 7s. per day, which would amount to £5, 12s., to do the same amount of work. The above example applies to manufactured goods only; but by using the traction-engine during the summer season in the woods, an equal or even a greater saving can be effected in the transport of round timber (M'Pherson, *Note on Manufacturing Timber* in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvi., part iii., 1901, p. 448).

II. **Railway Transport.**—As most of the timber used throughout the United Kingdom is imported from abroad, it necessarily follows that far larger quantities of timber are conveyed by railway from the seaports to the interior than are transported in any other manner.

Logs are usually loaded on special timber-waggons strongly constructed of iron, while converted stuff is placed on trucks with iron stanchions at the sides. When large quantities of wood are being handled, the logs are raised to the waggons by strong grappling-irons worked by a movable steam-crane, but where only a few logs are being loaded at small country stations, they are either placed on the trucks by hand-cranes, or are pulled up on leaders (as in carting) by chain and windlass.

As has already been indicated (see p. 506), there is a strong feeling that the difference in charge made by British railway companies for the through conveyance of foreign timber from seaports into the interior amounts to an unfair preferential rate, although it cannot be denied that foreign timber is usually handled in larger quantities, and is easier to handle than our rougher home-grown produce. The charges for the conveyance of timber which can be grown in this climate (tropical timber has been here excluded from the railway list) are shown in the following extract from the *General Railway Classification of Goods*, 1902:—

1. The term "timber" embraces all descriptions of wood in an unmanufactured, or roughly hewn, or roughly sawn state; but (except when otherwise specifically stated) not any wood shaped, or prepared, or partially prepared, or any description of wood separately specified in the classification.

2. For square timber the divisor of 144 is used.

3. In the measurement of round timber, when carried at measurement weight, the divisor of 113 is applied, measurement being taken by string-under-bark (or by string-over-bark, with a reasonable allowance for the bark), except when such timber is consigned at tape-over-bark rates, or it is agreed that tape-over-bark rates shall apply.

4. The right is reserved to require payment for the carriage of bark upon round timber charged on the 113 divisor in addition to the rates charged for such timber.

5. When round timber is carried at tape-over-bark rates the divisor of 144 is applied, measurement being taken by tape-over-bark.

6. Round timber: (i) between stations on Scotch railways; (ii) from stations on Scotch railways to stations in England and Wales; (iii) from North-Eastern Railway Company's stations, charged at measurement weight, is carried at tape-over-bark measurement with the divisor of 144, the rates being exclusive of loading, for which service, when performed by the company, an additional charge is made.

7. When debenture, octagonal, waney-edged, or other timber of defective angle is measured by calliper (as square timber), the 144 divisor is used, but an allowance is made of 22½ per cent. When debenture, waney-edged, and defective angle timber is measured by tape or string, the 144 divisor is used, but in such case the allowance as when measured by calliper is not made. Logs practically square, not to be treated as waney-edged timber.

8.[1] Baltic sleepers and sleeper blocks are charged at measurement weight on the following basis: (i) sleepers 10 in. by 5 in. by 9 ft. rectangular, 16 creosoted and 17 not creosoted, to be taken as equal to 1 ton; (ii) other dimensions *pro rata*.

9.[1] Lathwood (not laths) is charged per square fathom, or 36 sq. ft., 9 cwts. per ft. in length.

10. When timber (other than round timber, and except sleepers, which are already provided for by clause 8) chargeable at measurement weight is creosoted, an addition of 5 per cent is made to the weight for the creosote.

11. When ascertaining the measurement weight of creosoted telegraph poles, telephone, ricker, and scaffold poles, 5 per cent is added thereto in respect of the creosote.

12. All timber in pieces of or over 6 tons measurement to be charged 25 per cent over usual rates.

13. The weights of the various descriptions of timber must be computed from the measurements upon the basis that, for Acacia, Ash, Beech, Boxwood, Holly, Hornbeam, Oak, or other heavy timber (including other timbers not producible in Britain), 40 cub. ft. are taken as equal to 1 ton; while for Alder, Birch, Cherry, Chestnut (Spanish and Horse), Elm,[2] Fir, Hemlock, Larch, Maple, Pine, Plane, Poplar, Spruce, Sycamore, Walnut, or other light timber, 50 cub. ft. are taken as equal to 1 ton.

14. Except as provided in clause 6, the rates for round timber, unless otherwise noted, include the ordinary service of loading from beneath the crane when the company perform that service, but are exclusive of haulage to the crane when the timber has been previously deposited at a distance therefrom. When the company do not perform the service of loading, a rebate is allowed.

15. The rates for round timber do not include unloading.

16. Round timber at measurement weight is charged at exceptional rates.

17. When timber is consigned by measurement weight, the number of cubic feet must be declared by senders when consigning the timber. If at request of senders the company ascertain the measurement, a separate charge is made for such service.

18. For pieces of timber weighing less than 4 tons each in weight, which on account of their length require more trucks than one for their conveyance, a minimum charge is made of 1 ton per truck for each truck used whether carrying part of the load or used as a safety waggon only.

19. Pitwood, for mining purposes, at measurement weight, is charged at tape-over-bark measurement, 144 divisor.

Not applicable to traffic between stations on Scotch railways:—

(1) The following are charged at exceptional rates noted for deals, battens, and boards, or, in the absence of exceptional rates, at Class C rates, in consignments of 2 tons and upwards: deals, battens and boards unprepared (not exceeding 4 in. in thickness) of Fir and Pine, deals, battens, and boards, *at* 66 *cub. ft. to the ton.* Any of the following

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[1] Not applicable to traffic between stations on Scotch railways.

[2] *When Elm is measured by string-under-bark (or by string-over-bark with the allowance for bark) with the* 113 *divisor*, 40 *cub. ft. are taken as equal to* 1 *ton.*

sawn into planks, or sawn or hewn into square or waney-edged logs: Alder, Ash, Beech, Birch, Chestnut, Elm, Fir, Hemlock, Hornbeam, Larch, Oak, Pine, Plane, Poplar, Spruce, Sycamore, *measurement weight as previously stated;* sleepers, wood (including creosoted, see clause 8), stavewood (not staves), lathwood (not laths), *measurement weight;* posts and rails, *Fir*, cut square for fencing (not exceeding 4 in. in thickness), *at 66 cub. ft. to the ton;* posts and rails, cut square for fencing, including morticed posts and scarped rails, but excluding posts with butt ends, no allowance in measurements to be made for morticing or scarping, or other inequality, *measurement weight;* posts cut square, with butt ends for fencing, wood paving-blocks, pieces of roughly sawn wood, in short lengths, tied in bundles (for making packing-boxes), *machine weight.*

(2) The following are charged 10 per cent OVER the exceptional rates noted for deals, battens, and boards, but not to exceed the Class C rates, in consignments of 2 tons and upwards: flooring blocks (*not parquetry nor inlaid*), *machine weight;* boards, flooring, prepared, and other planed or prepared boards (*not parquetry nor inlaid*), *measurement weight;* boards, tongued and grooved, *as planed or prepared boards.*

(3) The following are charged 20 per cent OVER the exceptional rates noted for deals, battens, and boards, or, in the absence of exceptional rates, at 20 per cent over the Class C rates, in consignments of 2 tons and upwards: pitwood, exceeding 9 ft. in length consigned direct to a mine, telegraph, telephone, ricker, and scaffold poles (including *creosoted*, see clause 11), *measurement weight.*

(4) The following are charged 10 per cent LESS than the exceptional rates noted for deals, battens, and boards, or, in the absence of exceptional rates, at 10 per cent less than the Class C rates, in consignments of 2 tons and upwards: pitwood consigned direct to a mine, *machine weight.*

(5) The following are charged at Class C rates: Cherry-Tree wood, Maple, *sawn into planks*, Walnut, *in logs or sawn into planks, measurement weight;* telegraph pole cross-pieces, *machine weight.*

(6) The following are charged at Class 1 rates in less lots than 2 tons: flooring blocks (*not parquetry nor inlaid*), pieces of roughly sawn wood, in short lengths, tied in bundles (for making packing-boxes), telegraph pole cross-pieces, *machine weight;* boards, flooring, prepared, and other planed or prepared boards (*not parquetry nor inlaid*), *measurement weight.*

Owing to differences in the above methods of ascertaining the number of cubic feet by *measurement weight—viz.*, (1) mean quarter-girth *under* bark × length in feet ÷ 113, and (2) mean quarter-girth *over* bark × length in feet ÷ 144—and the practical classification into *heavy hardwoods,* reckoned as 40 cub. ft. per ton, and *light softwoods* at 50 cub. ft. to the ton, as well as to unprepared sawn deals, battens, and boards (in which condition a very large proportion of the foreign timber is imported) being allowed 66 cub. ft. to the ton, it is estimated that in England home-grown round timber has to pay about double the amount of railway carriage that is chargeable on imports of converted timber; while even in the conveyance of wood in the round, such as telegraph poles and pitwood, the difference in cost of carriage is in favour of foreign imports to an extent which may sometimes exceed £12 an acre on the mature crop. Thus, from Hartlepool to Cheltenham foreign telegraph poles are carried at 21s. 5d. a ton, while any other kind of round wood is charged 33s. 3d. (R. Anderson, in *Jour. Roy. Agric. Soc. England*, vol. lxiv., 1903).

The railway rates on timber are very high, ranging from 5s. 7d. to 12s. 2d. within the county confines [of Carmarthen and Cardigan], and equalling the shipping, insurance, and dock rates combined from the Baltic ports, and exceeding them considerably to the midland districts (D. W. Drummond, in *Report of Deptl. Com. on Brit. Forestry*, 1903, Appendix x. p. 174).

At the present time there is a general concensus of opinion that landowners should do something to increase the timber production of the country on national as well as personal grounds; but the rates for home-grown produce are so much higher than those for foreign timber that they constitute a serious tax on plantations in Britain, in many cases equal to half the fee-simple value of the land on which they grow.

I had occasion last November, in the course of my business as a land-agent, to make inquiries about the carriage of pitwood, and ascertained that the rate from Caerleon to Great Barr, in Staffordshire, was 15s. a ton; while from the port of Cardiff, a longer journey, it was 11s. 10d.; from Cleeve to Great Barr, 11s. 6d.; and from the port of Gloucester, 13 miles farther, and on the same line of railway, 9s. 1d. per ton. Taking an acre of Fir plantation cut for pitwood at 40 years' growth as averaging about 80 tons, it will be seen that an acre of foreign stuff in the instance first quoted can be delivered for £47, 6s. 8d., while home-grown wood, grown nearer the pits, and apparently on the same route, is charged £60, the difference in favour of the foreign production being £12, 13s. 4d. per acre. I mentioned the matter to a gentleman engaged in the timber trade, who told me that under somewhat similar circumstances an acquaintance of his had sent English pitwood a long distance by road into Newport Docks and consigned it into Staffordshire at a less cost than direct from the inland district where it was grown.

I have been supplied with many instances of this preferential treatment of foreign timber; and in view of the words of the writer of the article (in the *Times* of 8th Sept. 1904), that "it would often pay a railway company to quote a very low rate indeed for freight from an inland town to a port in order to get a load of some sort for the empty waggons sent there for foreign merchandise," it is interesting to note that round timber is conveyed from Liverpool to Stamford at 24s. 7d. a ton, but if the same timber is sent back from Stamford to Liverpool the rate is 27s. 8d.[1]

The railway companies are good customers to the timber-merchants, and the latter do not care to raise questions that may cause them a loss of custom. They therefore make the price of English timber less, in order to compete with the bounty given to foreign growers by the railway companies.

The matter really concerns others beside the actual producers of timber, as plantations afford employment for a large number of the labouring classes in winter when other work is slack; and timber-growing is not such a profitable business that it can stand a railway tax of from 4s. to 6s. an acre per annum, and often more, over and above what foreign-grown wood has to pay for conveyance over greater distances (R. Anderson, in *Times*, 11th Sept. 1904).

Timber-merchants are not always, however, willing to submit to the arbitrary demands of the railway companies in respect to method of measurement, as the following important case shows:—

The Railway and Canal Commissioners in 1901 heard a case between Messrs. Lowe of Wolverhampton and the London & North-Western and Great Western Railway Companies. The point was that, instead of string-measure-over-bark and 144 divisor as heretofore, the railway companies sought to measure by string-under-bark and the 113 divisor; also that Elm timber be carried at 40 ft. to the ton instead of 50 as heretofore.

A similar point was raised and carried to the Divisional Court in 1884, in the case of *Great Western Railway* v. *Lowe*, and string measure was held to be correct; but instead of the "most accurate measurement," the question decided was the "ordinary mode of measurement."

Mr. Birt, timber measurer at the Surrey Commercial Docks, said they took the 113 divisor and measured by tape under the bark. The difference between the 113 and 144 divisors was 27¼ per cent, and in his opinion the 144 was incorrect, and the 113 was accurate. Trees put up by public auction were sold by the 113 divisor and string-under-bark measurement.

Mr. James Reeves, timber measurer of the East and West India Docks, said he used tape-under-bark and the 113 divisor, known as the *Customs measure*. They made allowance for any irregularities in the tree.

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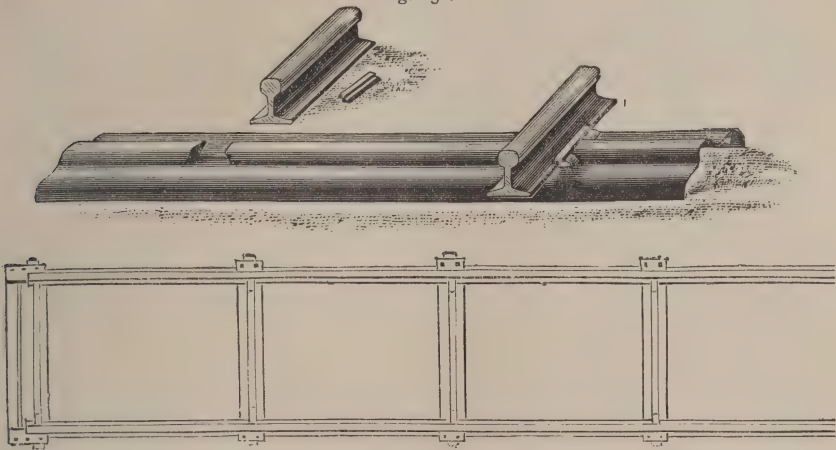
[1] This anomaly had really been rectified earlier in 1904.

For the defence it was said that no evidence had been given that the plaintiff's standard was in conformity with their provisional order, and it was not in use for the time being, except under exceptional circumstances, in the docks with foreign timber, with large allowances to the trader. The 113 divisor was not the custom of the trade, and never had been enforced by the Great Western Railway, except for three months in 1893. The whole of the timber carried at the present time had been measured by tape with the divisor of 144. A mathematical problem did not help them, because the practical way would be the most accurate mode of measurement in use for the time being. When they measured on the railway and divided by 144 they made no allowance. In the 1884 case it was held that string was the right method. The railway company was bound to take what a trader sent, and timber was not usually sent barked. In the clearing-house, prices were fixed for the measurement of round timber with the divisor of 144.

The defendant and several timber-merchants gave evidence, stating that the use of string-under-bark (*an allowance of* 15 *per cent being made for bark when measured above*

Fig. 251.



bark), with a divisor of 144, was universal throughout the trade, and was the most accurate mode in use.

Judgment was given for the companies, the court ordering that *string-under-bark with a divisor of* 113 *should be the mode of measurement; in the case of string-over-bark, a proper allowance to be made.*

The railway rates of 1902 were of course published subsequent to this decision in 1901.

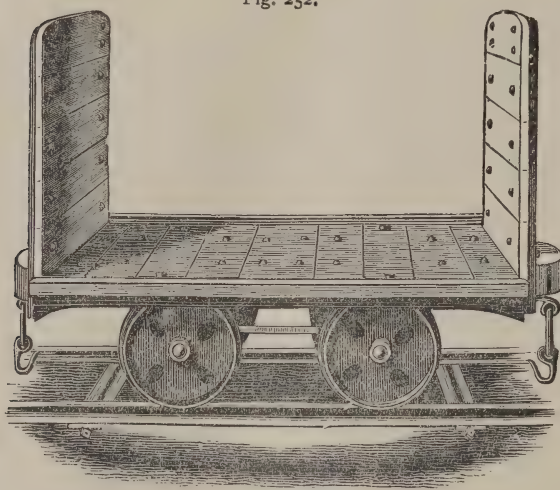
Continental Methods of Timber Transport.

I. **Railway transport** is of course much the same as in Britain, although more attention is perhaps given, especially in Germany, to details in rolling-stock and loading-machinery likely to facilitate or cheapen work.

In many forests, too, portable **tramways** are laid down and worked either by horses (and sometimes oxen) or by steam-power. Such arrangements can, however, only prove more profitable than carriage by cart when large quantities have to be conveyed only in one or two directions and for some considerable distance from woodlands not opened up by any good network of roadways fit for cartage. As the result of investigations made, Dotzel came to the conclusion that horse-tramways only proved more profitable than cartage when at least 35,000 cub. ft. of timber had to be conveyed beyond 1200 yds. *uphill*, or 2 miles *on level ground*, or 7 to 12 miles *downhill;* and that unless there were over 100,000 cub. ft. *uphill*, or over 350,000 cub. ft. *on the level* or *downhill*, horse-power was cheaper than steam-traction (Schuberg, *Transportwesen*, in Lorey's *Handbuch*, vol. iii. p. 514).

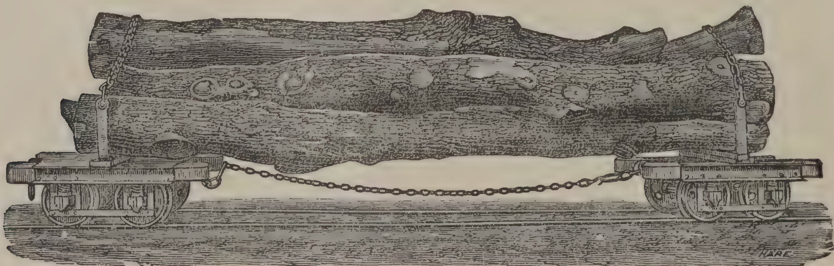
Such tramways and railroads may have a gradient up to 8 per cent (1 in $12\frac{1}{2}$), and may be made with curves having a radius of 70 ft. for long timber, though one of 16 to 17 ft. is enough for sleeper-lengths and fuel. The prepared way, which need not be more than 6 to 8 ft. wide, is top-dressed with gravel or sand, in which the light sleepers of wood or iron are bedded with rails attached. The ground has to be made level, but no other special preparation is necessary, except to fill in below sleepers to prevent the rails dipping down in hollow places. The rails and the hollow sleepers are made of the best Bessemer rolled-steel, as considerable strength and elasticity are necessary. The weight and strength of the rail and the number of sleepers required depend on the kind of load to be borne.

Fig. 252.



Rails are made weighing from about 8 to 20 lb. per running yard ; and rails weighing 12 lb. a yard will bear a load of about 2 tons, $1\frac{1}{4}$ tons and $\frac{3}{4}$ ton when the sleepers are respectively 40 in., 5 ft., and $6\frac{1}{2}$ ft. apart, the sleepers being usually 40 in. long, and varying from 7 to 18 lb. in weight per yard according to their breadth ($4\frac{1}{4}$ to 7 in.). Iron sleepers are lighter than wooden ones. The breadth between the rails is usually 24 in. The portable sections are generally $6\frac{1}{2}$ ft. long, and consist of three sleepers with the rails attached, the whole weighing from about 80 to 100 lb. ; and

Fig. 253.



the sections are lashed together with fish-plates when laid down after being moved. The holes in the fish-plates are made oval to allow for extension and contraction of the rail during changes of temperature, and short spaces are also allowed between rail-ends with the same object. When rounding curves, the outer rail is of course somewhat above the inner one to counteract the centrifugal force. Sleepers of special form and size and special forms of bent rails are made for points and embranchments, while at cross-points the direction of a truck can be changed by turn-tables. Even when steam-power is used on the main lines, the branch lines are generally worked by horses (or oxen). But, of course, when branch lines from railways are laid down towards or into extensive forests, they are made of the same gauge as the permanent way, and the main and branch lines of the temporary tramway meet it at some convenient point.

In a portable railway worked by light locomotive or animal power there should be—(1) maximum strength with minimum weight; (2) all pieces interchangeable, and portable by one or two men; (3) the fastenings should not weaken either rail or sleeper at the point of attachment, and should be strong enough not to be broken by carts crossing the line; and (4) the construction should be so simple that no skilled labour is required to lay it down.

The rails weigh usually 14, 18, or 20 lb. a yard, and are in lengths of 15 ft. (Fig. 251), with corrugated steel sleepers and strong chairs spaced 3 ft. from centre to centre. The best gauge is 24 in.

Such portable tramways are also obtainable in Britain from Messrs. A. Ransome & Co., Newark-on-Trent and Chelsea, who have kindly supplied the above illustrations.

The rolling-stock on such tramways consists of strong, but light **trollies**. The wheels, made of the best-rolled steel in one piece with the axle, and either 1- or 2-flanged (the latter being least liable to derailment), are usually only 12 to 15 in. in diameter, so as to keep the centre of gravity of the load as low down as possible.

Where the timber is small and light, the trollies can easily be loaded by pulling it up slanting leaders, two trollies being required for each load (one for each end). But when large logs are being dealt with, the butt-end is first raised by crane and fastened securely to a saddle-shaped, movable, horizontal cradle or plate (which can be turned round at right angles to receive its load) on a waggon fitted with a strong brake worked by hand-screw, while the top-end is then craned up, fixed in position, and fastened on another waggon placed at a suitable distance to receive it. Or the log is raised by the crane (some of the double-cranes used for this purpose in the woods can raise a weight of 4 to 5 tons) and suspended high enough up to allow of the rails and sleepers being placed beneath, then it is lowered into position and fixed on the fore and aft trucks for removal (Fig. 253).

When timber transport on tramways takes place downhill, the loaded waggons can often proceed by their own weight, in which case special attention has to be given by the brake-men, and it is then only necessary to pull up the empty waggons again with horses or oxen.

The cost of making, maintaining, and working such forest-tramways of course varies greatly. Some of those laid down in Germany with the intention of using the main lines for twelve or fifteen years have cost about £300 a mile, or 2s. 9d. a yard on the average, when complete, including loading-gear and timber-trollies.[1]

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[1] There are still many localities in different parts of the world with good growth of useful trees, from which the timber cannot be extracted so as to leave a margin of profit, unless new methods of haulage are introduced. Thus, on the Pacific coast U.S.A., narrow-gauge railways are formed where water transport cannot be made available from and to the "lumber-camps." Though not carefully levelled, the lines are firmly laid, as they are intended to last for years, being extended annually and not moved from place to place. The locomotive has a patent crane, which can load and unload logs of 20 to 30 tons weight (redwood logs of 16 ft. in diameter), the locomotive being kept in position meanwhile by a strong steam-brake. This patent steam-crane, worked by a donkey-engine, can also be removed and used instead of horses or oxen for bringing logs. It is fixed on a sled, and works itself forward to the place required if the hawser be fixed to trees ahead; and when it reaches its stance, it must be firmly moored to trees near at hand. It can then be used in extracting logs from coombs where dragging animals cannot possibly work.

Some of the rougher forms of timber-tramways have been found cheap and practical in countries where extraction is done in vast woodlands, in which the timber has little local value. Of this class the **pole-railroads** of North America are the cheapest and the most practical. About twenty years ago, in 1886, there were 383 such pole-railways

Wire-slides or **wire-rope tramways** are also in use for conveying short, light logs and fuel billets in mountainous districts in Switzerland, Bavaria, and Austria, but a detailed description of such would be of no practical use to the British forester.

I. **Transport by Roads and Slides.**

The network of roadways in extensive forests in Germany consists of (1) **main-roads**; (2) **side-roads**; and (3) **feeders.**

1. The **Main-Roads** or **first-class roads** are specially adapted for cart-traffic, or for large horse-sledges during winter. They usually traverse the heart of the woods, and form the main thoroughfares along which the traffic is conducted. They are generally metalled. And when they can at the same time be used as public highways (*chaussées*) for connecting villages, they are macadamised and carefully prepared. In the latter case, these main-roads have seldom a higher gradient than 5 per cent (1 in 20); but where they are to be used for timber-traffic only, and not as public highways, the gradient has often to be fixed at 7 or 8 per cent (1 in 12½ to 14), as the loaded carts go down-hill and only the empty carts have to be pulled up-hill. The gradient should vary from time to time, as occasional level stances and changes of gradient are less tiring to cart-horses than a continuous slope which necessitates the same set of muscles always being called into play. For the transport of long logs, the curves should have a radius of at least 33 ft. (though of course it must be over twice as long, if there is any intention of perhaps laying down a steam-tramway: see above). The breadth depends on the amount of traffic expected on the road, and is usually from 18 to 20 ft., as the actual width of an ordinary timber-cart is generally about 6½ ft. between wheels, or 8 ft. over all. Wherever practicable, these main-roads should lead to some convenient depôt or central point, whence further transport—by road, rail, or water—is easy.

2. The **Side-Roads** or **second-class roads** are directly subsidiary to the main-

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running over 2287½ miles, on which 428 engines and 5182 tender-waggons were employed. Instead of having rails, poles were used, like telegraph poles, having a diameter of not less than 3½ in. at the thin end. The thick end of each pole was hollowed out slightly with the axe so as to permit of the thin end of the next pole fitting into it, after which it should be pared down towards the level of the latter.

The peculiarity of the engines was that the wheels were driven by chains, and each wheel moved independently of the other, so that if any one chain should break or get into disorder, the movement of the whole was not materially affected. They had a dragging power of six waggons laden with 108,000 cub. ft. of boards, and with a gradient of 4 per cent would proceed at the rate of 5 miles an hour. Some of these railways were worked on ground having a gradient of 1 in 8, the engine being then placed in the middle of the six trucks, and when the train arrived at the steep part it was taken up in two sections.

The poles were simply laid on the ground and firmly packed with earth to keep them in place on the train passing over. Wherever necessary, rough levelling was done on uneven ground; and it was found best to lay the track during wet weather.

No sleepers were needed, as the wheels of the engine and the trucks being hollow and having deep flanges and a certain amount of free play on the axle-tree, this all served to keep the ends of the poles in position while the train passed. After a few trips there was little danger of the poles shifting.

When curves were formed, shorter poles were used, being laid down in the same manner. Wherever side-branches joined the main lines, the junction was always made in a curve.

One workman could maintain nearly 2 miles of track in order.

Construction cost under ordinary circumstances from £16 to £32 a mile, according to the nature of the ground and the rate paid for labour. In rugged mountainous tracks it amounted to from £48 to £56 a mile, labour being there very expensive.

Locomotives cost £630, and trucks £26, 5s. each; but in some parts horses, ponies, and oxen were used for dragging, though this method was usually found dearer in the long-run, besides involving great loss of time.

Those pole-railroads were mostly in use to the east of the Rocky Mountains. The trucks were generally loaded by *log-skidding* and loading machinery worked by steam-power.

roads, and branch off from these into the inner parts of the forest. As they are intended for permanent use—sometimes for cart-traffic, but chiefly for sledging (in which case they form the main sledge-roads)—they are projected in such a manner that they can be utilised continuously for the various falls in any given period of time which forms the unit of management (*i.e.*, usually 20 years), through being connected with the different annual falls by means of the feeder-paths. This class of roads may have a gradient up to 10 per cent (1 in 10), or even more if they are to be used as timber-slides or sledging-paths. They vary in breadth from about 8 to 15 ft.; but if the track is not broad enough to allow of carts or sledges passing each other in going up and down, **halting-stages** must be provided as often as necessary. These side-roads need not always be metalled; and, even if the timber is only to be carted, any necessary surface-preparation, such as macadamising with whatever metal can be obtained in the immediate vicinity, may easily be done immediately before any particular road is brought into use. If only wanted for sledging, they can be corduroyed by pegging down cross-pieces of poles about 2 to 3 ft. apart for sledding in summer (see also p. 521).

3. The small **Feeders** or **subsidiary tracks** are third-class roadways of a more or less temporary kind, not intended to be used so continuously or to such an extent as the side-roads; hence no metalling is needed. When intended for use as **dragging-paths**, they need only be about 4 to 5 ft. broad; but when projected as **sledging-tracks**, they should have a breadth of 7 to 10 ft. In dragging-paths the gradient may vary from 6 or 8 per cent (1 in 16 to 1 in 12½) up to 18 or 20 per cent (1 in 5½ to 1 in 5), according to the nature of the locality; while for sledging-tracks the normal gradient lies between 12 to 15 per cent (1 in 8½ to 1 in 6½). Where several feeders join together before reaching the side-road, they are made somewhat broader if sledges are there likely to pass and repass frequently; while it is also well to try and confine the gradient at such short stretches to 8 or 12 per cent (1 in 12½ to 1 in 10). Where such tracks curve round steep places there is always a chance of accidents, which can best be hindered by facing the outer edge with guards, consisting of logs held in place by stout uprights.

For **earthwork Timber-slides**, in which the logs are carried onwards by their own weight, somewhat higher gradients are needed, which vary from about 9 to 12 per cent (1 in 11 to 1 in 8½) on the main-tracks, up to 15 or 18 per cent (1 in 6½ to 1 in 5½) on the feeders. A continuous and, so far as possible, an equable gradient is more desirable for timber-slides and for sledging-tracks than for dragging-paths or cart-roads.

The **network of roadways** or complete road-system in an extensive woodland area should thus in its ramification somewhat resemble a tree. The main-road is like the stem or trunk, the side-roads are like the branches, and the feeders like the branchlets and twigs; whilst the breadth and the outlay incurred on the various parts should, so far as the circumstances of contour, nature of soil, &c., permit, be more or less proportionate to the amount of traffic to be provided for, and to the amount of profit these different parts are likely to bring in. In practice it is often found impossible always to have a convenient gradient without incurring considerable expense, and in many cases a slight counter-gradient may often have to be included.

On these three different classes of roadway the timber is either (1) **carted**, (2) **sledged**, or (3) **slid** down by its own weight.

1. **Carting Timber.**—So far as extraction on timber-carts is concerned, British foresters have nothing to learn from the Continent. For the conveyance of very heavy logs on metalled roads, the English timber-carriage is described on page 509.

2. **Sledding** or **Sledging Timber.**—This is a branch of forestry in which, owing to our comparatively small woodlands, we are necessarily very far behind

Continental nations,—a remark which also applies to the excellent method of extracting large quantities by means of **Timber-Slides**. Sledging is done either by woodmen alone, or also by horses, mules, and oxen.

There are various kinds of sleds or sledges, but they all consist of (1) two **runners** or long horizontal pieces of wood, often shod with iron, which in the case of hand-sleds run up into bent points in front, that are grasped firmly by the man dragging the sled; (2) **cross-pieces** binding the runners, and serving as benches upon which to rest the timber; and (3) a **brake** or **drag** to regulate the speed, the most powerful brake being the strong hooked point of an iron bar worked by the leverage of a long arm, the handle of which remains always in the grip of the sledger (it is usually fastened on the left-hand side of the sledge). Hand-sleds are only used for the conveyance of comparatively light loads of wood, like firewood

Fig. 254.

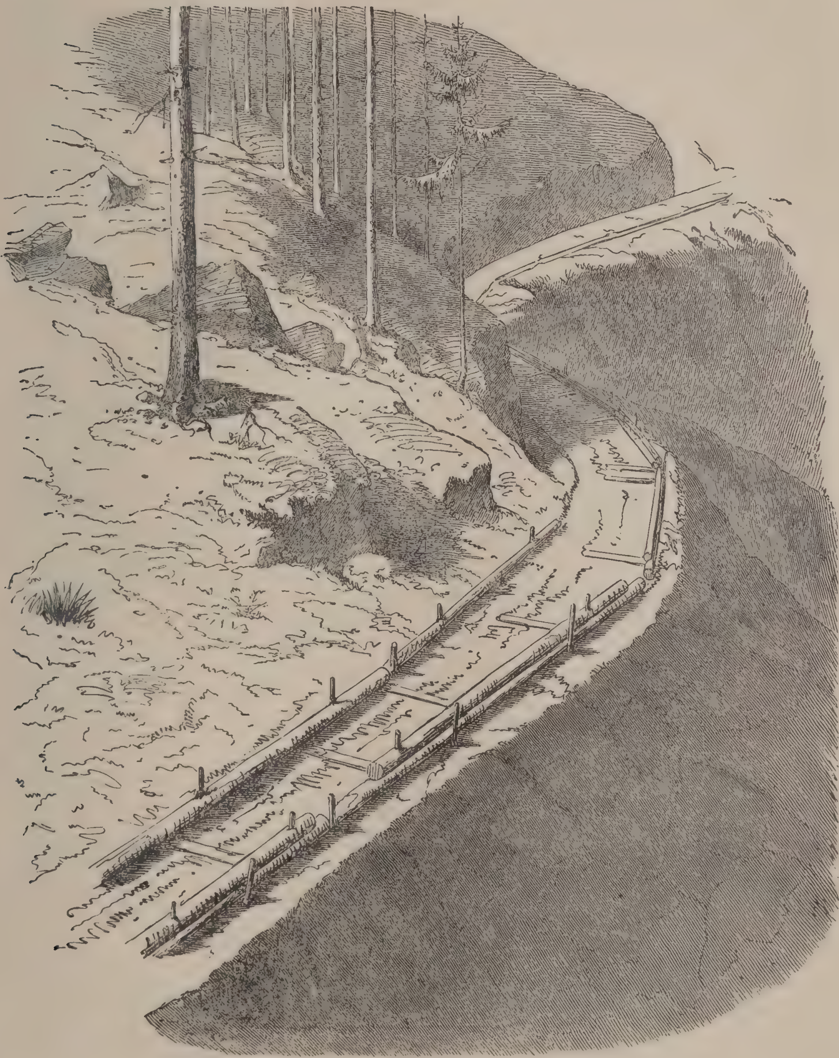
Sledging Firewood in the Vosges Mountains.

billets, light pit-props, and timber of small dimensions cut into comparatively short lengths (Fig. 254). For such sledding by woodmen the sledge-tracks are made from 4 to $6\frac{1}{2}$ ft. in breadth, and with a constant gradient not under 7 nor above 25 per cent (1 in 14, and 1 in 4). According to Gayer, the usual load consists in Germany of from 55 to 70 cub. ft. of light coniferous wood, and a sledder working on a sledding track having a favourable and constant gradient can convey from about 108 to 180 cub. ft. of wood per diem to a distance of $1\frac{4}{5}$ miles (3 kilometres), or from 350 to 425 cub. ft. for the half of that distance; but either a low or a high gradient, or a frequent change of gradient, prevents such good results.

The larger sledges used for dragging long logs by horses, mules, or oxen are heavier in construction. They consist of a front sledge and a hind sled, in order to keep the ends of the logs from trailing along the ground and cutting up the earthwork. In some parts of the Black Forest large single sledges are often loaded with from 1050 to 1100 cub. ft. of Spruce or Silver Fir wood cut up into fuel-billet lengths.

Sledging operations for extracting heavy timber mostly take place only while the ground is covered with snow, so that it is a method that can only be applicable to localities having severer winters than are usual throughout the greater part of Britain. But sledging can also be done during the summer months if the track is specially prepared (Fig. 255) by corduroying it through laying round poles on the

Fig. 255.



Timber Sledging-track for Summer use, in Bavarian Alps.

ground, or split poles with the smooth side uppermost, so as to minimise the friction. These cross-pieces have to be fenced in with poles as flange-like side-guards, in order to prevent the sledge gliding off the track. They are, in fact, just like rude railway-tracks, but the corduroy sleepers are smooth and round on the top so as to offer a minimum of friction, while the sleds run over these cross-pieces in place of along the guard-line of parallel poles. The corduroyed cross-pieces must not be farther apart than will admit of the sledge always resting on two—*i.e.*, will prevent any portion of the sledge touching the ground—and not farther apart than about 2 ft. when the sleds are to be worked by men, as they must have good foot-hold to keep their loaded sled under control. According to Gayer, the preparation of such summer sledging-tracks made with Silver Fir and Beech for the extraction of firewood at Hochwald, near Barr, in Alsace, over a total distance amounting with ramifications to 12½ miles, cost a little over £33 a mile, or 4½d. a yard, and the sledding-track lasted ten years, while the cost of sledging came to about 3s. 6d. to 4s. per cord or cubic fathom of 216 cub. ft. of stacked wood.

3. **Timber-Slides** for the shooting-down of timber, to be carried by its own weight, are a branch of transport widely and cheaply practised throughout all the mountainous tracts of Central Europe. Its advantages are greatest where the timber-slide can be made to terminate at any river or good water-way, which can be used for floating to some favourable mart or to large saw-yards, whence further transport of the sawn timber is favourable by road, rail, river, or sea. There are different forms of timber-slides, constructed either of wood or of earthwork; but the leading principle is, in either kind, that a good bed should be prepared, down which the timber can glide with a minimum of friction, while side-guards protect the logs or fuel-billets from springing out of the slide.

(1) **Road** or **Earthwork Timber-Slides** are an excellent means of transporting large quantities of long timber from mountain forests, when the horizontal projection of the pathways and side-roads has taken place in long sweeping curves, round which long coniferous logs can easily glide. They can be made about 5 to 8 ft. broad, and in much the same manner as has already been sketched for constructing sledging-tracks for summer use (Fig. 255). The best gradient for laying out the roadway may vary from 9 to over 15 per cent (1 in 11 to over 1 in 6½), according to the use to be made of the slide. A fall of 8 to 10 per cent (1 in 12½ to 1 in 10) is enough for winter-slides with snow, while at least 15 per cent (1 in 6½) is required for shooting the logs in summer (Schuberg; though according to Gayer, 8 to 12 per cent (1 in 12½ to 1 in 8) are needed for sliding down on snow in winter, and 12 to 18 per cent (1 in 8 to 1 in 5½) for shooting logs in summer). In either case, however, the greatest gradient is given at the top end to start the logs on their downward course, and the lowest gradient is at the lower end where the slide terminates.

The leading principle is to have broad, sweeping curves, and to avoid as much as possible any sharp turns and sudden changes in the general direction which the logs must follow. Often, however, sharp turns and sudden changes in direction are unavoidable, and they are then arranged for in the manner indicated in Fig. 256. Here the stem sliding down in the direction *ab* bumps against the bundle of faggots fixed as a buffer, rolls over into the lower track diverging at a very acute angle, and continues its way slowly in the new direction *mn*.

In mountain tracts, transport by roadway timber-slides deserves far more attention than has hitherto been given to it. It wastes no timber; and it is economical, as from 1000 to 1300 logs can daily be shot down a slide nearly 1⅓ miles long,—while the roadway can also be used for sledging. It therefore offers particular advantages in localities where carting is impossible (Gayer).

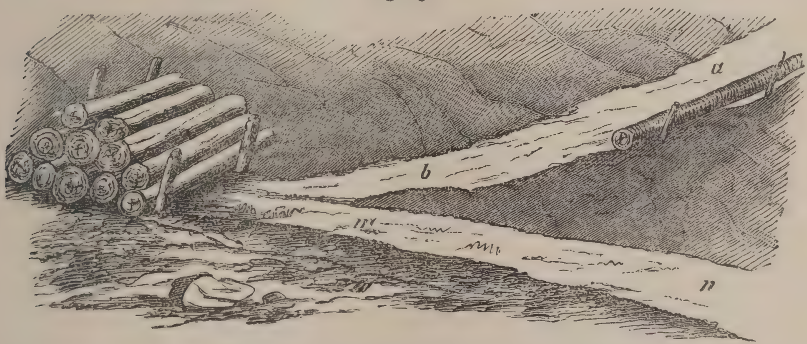
The logs should be launched butt-end foremost into the slide, after the points have been adzed or rounded with the axe to ensure their gliding smoothly over the cross-pieces or sleepers corduroyed at short intervals across the track. As may be seen in Fig. 256, where the logs are not likely to run out of the track on the upper side, a flange-pole is then only needed on the lower side; but, otherwise, guard-poles have to be fixed along both sides of the slide.

Operations of this description require to be conducted with something like military precision and good organisation in order to prevent accidents. Before timber is launched at the upper end, a bugle or horn signal is given, which is repeated down the line by men stationed at different points, and then passed up again, to ensure that the slide is clear, before the log leaves the top. Its arrival at the depôt below is indicated by another preconcerted signal being passed up the line; and so on with each log.

If the slide be no longer required, when all the timber from the fall has been transported, the logs used in the corduroying and fencing-in of the roadway can also be slid down, commencing at the top.

(2) **Wooden timber-slides** are constructed more or less semicircularly of 6 or 8 logs or poles of from 4 to 12 in. in diameter. The two lowest of these form the base of the slide, the whole breadth of which usually varies from about 2½ to 5 ft. So far as possible the slide rests on the ground; but wherever required to maintain the gradient, it is raised to the necessary height by trestling sections of logs to form suitable supports. The slides intended for transport of large logs of timber

Fig. 256.

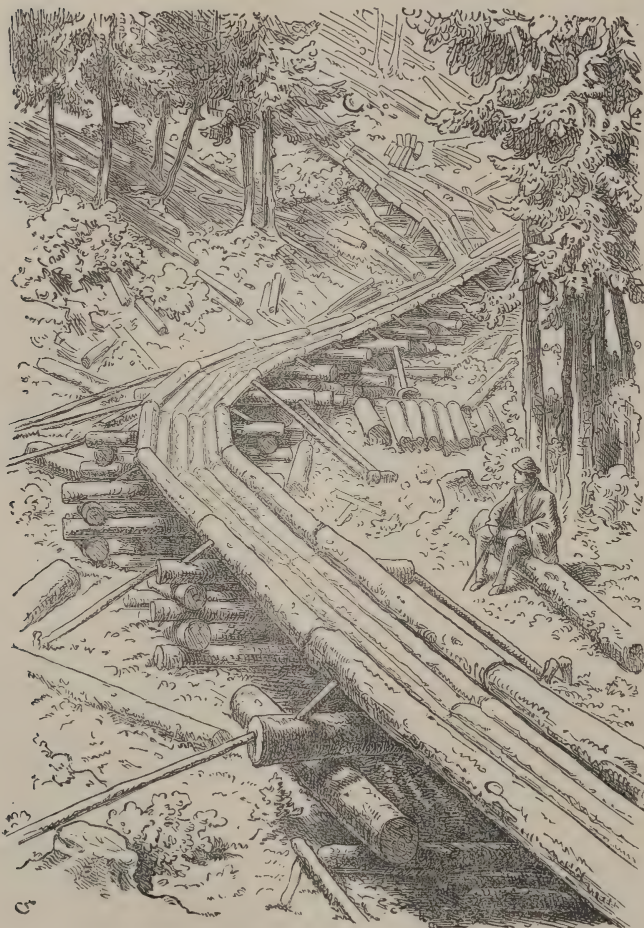


A Turning-Point on a Road-Slide or Earthwork Timber-Slide.

must of course be constructed more solidly than those required only for fuel billets. That shown in Fig. 257 is a slide for long logs in the Triftenthal, North Tyrol.

The gradient is a very important matter in constructing wooden timber-slides. With too low a gradient they are practically useless, while too high a gradient is apt to induce such a velocity as to cause the timber to spring out of the trough. But the gradients permissible, and also those that may prove best, vary between wide limits, according to the circumstances of each case. Thus **dry slides**, used only in summer, need a gradient of 20 to 25 per cent (1 in 5 to 1 in 4), and even up to 40 per cent (1 in 2½) is not excessive for fuel-billets and small log-sections; while for long heavy logs from 15 to 20 per cent (1 in 5½ to 1 in 5) is ample. But when transport is to be on a **snow-slide** during winter, the best gradients are from 6 to 12 per cent (1 in 16 to 1 in 8½) for small log-sections and fuel-billets, and from 3 to 6 per cent (1 in 33 to 1 in 17) for long logs. Where the gradient is below about 6 per cent (or 1 in 16 to 17), long logs can only be shot down when the slide is watered during frosty weather, and thus made into an **ice-slide**. Men are then required to water the slide constantly. As the shooting of the logs is then dependent on the frost, work is often, especially when warmer weather comes in spring, confined to the cold night-time, in place of during the day. In the damp climate of the Highlands of Scotland the slide might generally be used during wet weather, when a gradient about half-way between the two extremes for summer and winter slides would probably suit best. Wherever a high gradient is unavoidable in any particular part of the slide, it should be followed by a short horizontal stretch, or by a slight rise, in order to check any tendency to excessive velocity in the timber. The velocity may also be checked by means of a **brake** or **drag** (Fig. 258), consisting of two poles fixed at their upper ends, but with their lower ends resting loosely in the slide, between which the logs have to pass on their downward passage; and the friction thus caused by striking against and lifting these diminishes the velocity already acquired by the timber, and prevents it becoming excessive. Another method is to form checks by leading the slide slightly up-hill for a short distance, and then changing its direction. Slides for the transport of long logs should always run slightly up-hill for a short way, or else horizontally for a considerable distance, before terminating; and even then the stems are often shot out to about 80, 90, or 100 yards over gently sloping ground on issuing from the slide.

Fig. 257.

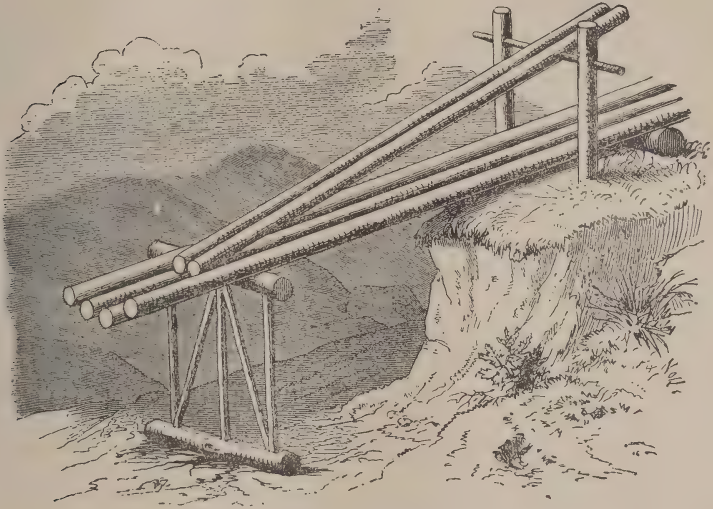


Wooden Timber-Slide.

Wooden timber-slides cost a good deal more to make and maintain than roadway-slides, and they do not last so long. Much wood is used in making them; the timber sometimes gets badly shaken and split; and the slides usually begin to need repairs in 3 or 4 years' time. They seldom last more than from about 6 years to 8 at most, or about 7 on the average; and a considerable proportion of the logs then forming the slide are unfit for anything but fuel.

Flumes or Water-Shoots.—In California, throughout the Rocky Mountain tracts, enormous quantities of timber are conveyed for immense distances in flumes or water-shoots, which are wet slides worked by water-power, and constructed as shown in Fig. 259. They consist of a water-tight trough formed of side-boards *mm*, and are worked by means of diverting the flow of any rivulet into the trough, so as to carry down the timber launched therein. They are, in fact, nothing more than

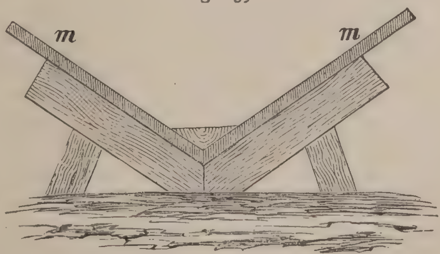
Fig. 258.



A Brake or Check on a Wooden Timber-Slide.

water-troughs or floating-channels on a small scale. They seem, however, to be very economical and practical. The **flume** consists of strong boards 32 in. broad and 16 ft. long, nailed together so as to form a **V**-shaped channel, occurring one after the other for miles sometimes. It was first developed and used in Washington. Endeavours had often been made to transport timber in troughs; but the latter had always been made rectangular, and this caused their non-success.

Fig. 259.



A Californian Flume or Water-Shoot.

Semler (*Tropische und nord-amerikanische Waldwirthschaft und Holzkunde*, 1888, p. 334), gives the following account of a Californian flume :—

A flume is not so easy to make as one might suppose. It demands the whole art of the engineer, especially on broken, hilly ground; and many assert that a railway is easier to project and construct than a flume. First of all, attention must be paid to the water supply, for which a reservoir must be formed. Simultaneously therewith the laying of the flume is commenced, and of course it must have no sharp bends or short curves. Here the bed must be worked out of the rock, there the framework has to stretch across gullies from 160 to 240 ft. deep, above which it is supported by a strong wooden framework resting firmly below, and connected with the sides of the gully by stout iron rods to protect it against the violent winds that, sweeping down the small valleys, would otherwise soon destroy it. It need hardly be said that when a flume has to cross many gullies it becomes rather costly; the construction amounts to as much as £960 to £2000 per mile, and even more when there are special difficulties.

When the flume is ready, and the necessary head of water has been provided, the logs are brought and launched singly, and are borne rapidly down to the mills, 20, 30, or 40 miles distant. With a fall of 1 in 192 (or little over ½ per cent) a speed of 2 to 3 miles an hour is attained, while with double that fall the speed becomes trebled, and with a gradient of 10 to 12 in 192 (*i.e.*, 5 to 6 per cent) the timber acquires a velocity of about 20 miles an hour and more. From the highest starting-place in the mountains down to Sacramento is a distance of over 31 miles, and this is covered in 3½ hours. To Chico, a distance of 42½ miles, the transport is still more rapid, as it takes place in less than four hours. The Chico flume is nearly 47 miles long. The last logs are started at three o'clock in the afternoon, and reach Chico about half-past six in the evening. Formerly, when the timber had to be brought down by waggon, 1000 metres (36,000 cub. ft.) cost £7 for transport, while by flume it may be estimated as under 10s. The above-mentioned main channel of the flume can bring down 30,000 metres (1,080,000 cub. ft.) per diem, and the whole flume system can bring down three times that quantity.

Along the whole distance, from the highest starting-point down to its mouth, men stand at stated intervals to superintend the flume and see that no obstruction takes place —a matter of necessity at places where side-branches join the main flume. For this purpose a board gangway is ranged alongside the flume in order to permit of the men moving quickly from point to point.

The only drawback to this method—and it is one that can hardly be removed—is the want of water that occurs almost every summer. Wherever practicable, this is modified by the formation of large reservoirs that can fill themselves when the snow melts, and by husbanding the water supply and only opening the lock-gates when the starting of logs can take place continuously; during other times the flume is kept dry. More frequently, however, the work of felling takes place throughout the summer, the timber being extracted to the camp-depôts along the flume, whilst the transport is carried on during the rainy season. . . . The whole flume-net has a total length of nearly 125 miles, and it is continually being extended.

At Chico the flume above described ends in a lake into which the logs shoot, and from which they are taken to the permanent depôt near the saw-mills. The Sierra Flume and Lumber Company, to whom the concern belongs, employ 500 hands in their mills and in the forests, and pay £100,000 annually in wages; they keep 100 horses and mules, 500 oxen, and 61 timber-waggons at work, mostly in the mountain-forests. Their mills have an annual output of 16 million metres of boards (575 millions of cubic ft.), which represents exactly half of the annual outturn from the State of Oregon (1888).

Dragging.—Dragging is often necessary for bringing out logs to places whence it can be carted, sledged, or shot down, but should not be permitted on tracks specially prepared for any other mode of transport, as it is very likely to damage them. Where dragging from the interior of the wood to the nearest roadway has to take place by horses, it may be calculated that one horse can drag on an average about 15 or 16 cwt., or, say, ¾ of a ton, dead-weight of timber; but of course much depends on the nature of the soil at the time of dragging, while the use of a shoe or end-support diminishes friction considerably (see Fig. 248). Dragging with horses is easiest and safest when the paths have a gradient of 7 to 15 per cent. (1 in 14 to 1 in 6½), but if it be only 7 to 10 per cent (1 in 14 to 1 in 10), the pathway has to be corduroyed for heavy logs.

III. **Transport by Water.—The floating of timber**, either simply by means of **drifting** in single logs, or of **rafting**, when from a few logs up to several hundreds are lashed together to form a **raft**, is a method of transport which, with so heavy and bulky a raw product, must always come far cheaper than any other mode of conveyance, wherever waterways can be utilised to lead to any great central mart or depôt.

All our coniferous woods and the great majority of our broad-leaved trees are floatable even before seasoning (see table of specific gravity, p. 436).

Floating is a common method of transport for Scots Pine in the Strathspey district; but the highest development of drifting and rafting has been attained in the mountainous tracts extending from the Black Forest eastwards throughout the Bavarian Alps into Austria. Large forest-engineering works are maintained for reservoirs to flood the channels when required; and costly dams, sluices, corrections of the channel-beds, and paving of the sole of the bed, have been undertaken on a large scale in order to permit of the extraction of the timber in the most effectual and ultimately the most economical manner.

Drifting may be begun anywhere in the heart of the forest, simply by launching the logs into the bed of the floating-stream; but **rafting** can only begin at some convenient depôt, such as may be formed at the junction of two streams, or at the termination of some main road or timber-slide, where a large number of logs can be collected for further transport to market or to the place of conversion. Both drifting and floating operations are confined to localities in which there are good supplies of water.

Drifting is the oldest and most primitive form of floating; and it needs least capital, and least labour. But when long logs are simply cast into the water and allowed to drift, they are apt to get jammed and to form obstructions, so that this method is usually on the Continent confined to fuel-billets and short log-sections up to 6½ ft. long, though also occasionally for sleeper-piece lengths of up to 10 ft. There is, however, always risk of water-logging, and the loss on this account generally averages from 1 to 5 per cent, although it may sometimes be very much higher.

For drifting, a fall of 1 to 2 per cent is required, the slighter fall being sufficient with plenty of water, and a depth of 2 to 3 ft. of water is enough for fuel-billets and short sections of Conifers. The minimum breadth of the water-way need only be about a couple of feet more than the length of the longest billets or log-sections. Streams generally require some preparation in the way of bank-repairs, rounding off sharp corners, blasting rocks, &c., before they can be used for drifting. Wet spring weather is the best time for drifting, but it can of course be done at any time of the year provided water be stored, wherever necessary, in reservoirs constructed with dams and opening out with sluice-gates; and the wood must, on reaching its destination, be caught in depôts, or by means of booms or gratings of one sort or another. Where any block takes place, this has to be freed with the long rafting-hook (Fig. 243), or similar implement.

In drifted wood the heating-power is less, and the short logs are apt to split and crack. Pulp-makers dislike it, because small stones get pressed into the wood, which damage their machinery. On large water-courses there is most chance of losing wood, and on small water-courses it may easily get stranded. As rafting can be done with just the same amount of water as drifting, the former is therefore preferable for other reasons in addition to the very important one that it is the only good way of transporting long timber.

Rafting of long and heavy Conifer logs can be done with a depth of 2 to 3 ft. of water; and even in small hill-streams large timber can be rafted, if this depth of water can be provided by means of reservoirs and sluices. The breadth of a floating-channel must be at least as great as that of the first section of the raft, as the outer logs at the sides of the raft can drag along the banks, unless this is likely to damage these latter. But the bed of the stream must not be winding and with sharp bends, and any such turns need to be cut through and corrected. Rocks and boulders have to be removed wherever necessary, and small waterfalls have to be negotiated by means of stone weirs or of wooden shoots, down which the raft can glide, while larger waterfalls must be circumvented by digging a canal in a curve round them. If the banks of the stream are only earthen, they are cut back to a slope of about 30° to prevent erosion, and are sometimes also sodded with turf or planted with osiers to firm and bind them, while parts specially apt to be eroded are faced with stones or wattle-work. Besides a certain amount of levelling by the removal of large stones, wherever there are rapids the bed of the stream may need to be soled and strengthened by means of terracing in long, shallow steps-and-stairs with flat stones laid in a framework of poles. The starting-point, where the raft is made up, should be as broad and level as possible, so as to enable the timber to be handled easily; and the water there should be at least 2 ft. deep, being raised to this height by a weir or dam if necessary.

On small hill-streams the logs forming the various sections of the raft are generally lashed together with withes of heated and twisted Spruce branches and Hazel rods inserted through two triangular holes notched at each end of the log with a small-headed axe or narrow hatchet, and then bored completely through with a large auger before the log is launched into the water. Neither the individual logs nor the various raft-sections are firmly lashed together, because each log must be allowed a certain amount of play both horizontally and vertically, and each section must also have a fair amount of freedom in turning round corners. The number of logs of equal length and size lashed together, with cross-pieces formed of small poles and fixed with withes, to form each section of the raft, depends on the breadth of the floating-stream, and of any weir-openings the raft may have to pass through.

When Oak has to be floated, one log is put into the middle of each raft section and firmly secured to the lighter Conifer logs.

In the Black Forest the first section generally consists of four logs, the tops of which are firmly secured to the pointed and upturned **head** or **prow** of the raft. Into this front piece a pole is fixed at a low angle for the purpose of guiding the prow and tilting it up somewhat, as occasion requires. Thus the raft is steered from the prow, and the steersman's work is the most difficult, responsible, and dangerous in the whole of the rafting operations.

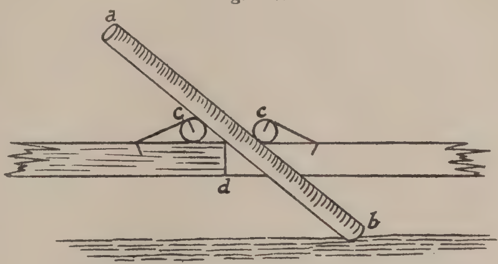
Behind the first section, the number of equal-sized logs in the other sections gradually increases from 4 to 5, 6, 7, 8, and 9 or 10 (according to the breadth of the stream, and of any weir-openings that may have to be passed through), the smaller top-ends of the logs being in front and the outer logs being often left free at the larger end, so that they may have greater play in passing round corners. The middle sections are often broader than the bed of the floating stream, but the side logs are lifted up and turned back over the inner logs in the section as the raft is swept along.

The front sections are formed with the lightest logs, as they float most easily; and the larger and heavier the logs, the more they are kept towards the end of the raft, which therefore gets broader as the diameter of the logs increases. The raft ends in a loose **tail** of logs lashed together only in front, and thus enabled to spread out like a fan or a fish's tail and act as a kind of **drag** to obviate any danger of the back part of the raft buckling over any of the parts farther forward—as would be much more likely to happen if the heavy logs were put near the head of the raft, and the lighter, quicker-floating ones formed the middle and final portions.

In addition to this dragging tail-end, special arrangements are also needed in the shape of a **brake** (Fig. 260), consisting of a short but strong log (*a b*) passing down through the middle of the last section so as to drag at an angle of about 45°, which is held in position by two cross-stems (*c c*) about 30 in. apart, firmly lashed or clamped to all the logs forming the section. As the brake gets worn away at the lower end (*b*) by rubbing against the bed of the stream, it can be hammered farther in at the top-end (*a*). The opening needed to allow the brake to pass down through the middle of the raft-section is made by putting in a short log (ending at *d*) instead of a full-sized log of the proper length. When there is only one brake, it is made on the last section before the tail of the raft; but in long rafts several brakes are required, which are all made as near to the end of the raft as possible. For this purpose the last section before the tail is made of the actual breadth of the water-way. Some rafts consist of 50 or 60, and even up to 70 sections, and contain from about 350 to 500 logs, or an average of about 7 per section. When a brake is no longer required, the hind cross-stem can be removed, when the drag ceases to act.

When all the sections of the raft have been lashed together in a mountain-stream, it is moored with ropes to the bank, and the sluice-gates of the large water-reservoirs and weirs farther up-stream are opened to let the stored water rush down the bed,—because in mountain-streams rafting can only be done with such assistance. The flood of water thus let loose should have an hour's start before the mooring-ropes are loosened, and the raft is allowed to travel down on the flood-water; because otherwise, as the raft moves quicker on the top of the water than the front of the flood can travel along the rough, stony bed of the stream, it would soon overtake the head of the current and get smashed up in consequence. With a good flood of water given even half-an-hour's start a raft can travel for between one and two hours, when other reservoirs and weirs must supply more water, and so on till the raft reaches some water-way with a sufficient depth of water for further floating.

Fig. 260.



Brake on end-section of a raft, dragging on bed of floating-stream.

On such rafts in mountain-streams the men employed stand either at the **head** and on the first four or five sections, to guide the front part, or else at the **tail** to work the **brakes** at whatever parts of the stream their application may be necessary. By long experience the brakesmen know exactly when to apply them, and when to ease them off, according as the front and middle parts of the raft may be at dangerous parts of the course. When the brakes are applied, the hind sections bump, and jolt, and creak as the brakes drag along the stones and rocks forming the bed of the stream. Raftsmen have hard and dangerous work. They have often hard work to steady themselves, and each has a *Krempe* (Fig. 244, p. 508), which he drives well into a log in front of him, and to which he can hold on firmly when necessary.

The raft rushes down as quickly as one can run along the bank. As the raft passes different points its arrival is signalled or telephoned to the reservoirs and weirs lower down, in order that their sluice-gates may be opened to let their water into the bed at the proper time.

On reaching the stiller and deeper waters of a river, the rafts from the mountains are broken up and formed into much longer and broader rafts, of up to about 660 ft. or one-eighth of a mile long, and with sections about 150 or 160 ft. broad. The sections are fixed with cross-pieces lashed or trenailed fore and aft to the ends of the logs, and sometimes let into them. When trenails are used, the holes are afterwards plugged with wood, so as to cause no loss of timber in conversion. These river-rafts are usually steered with long broad sweeps, or by rudders when they are towed by steam-launches or tugs on slow-flowing rivers like the Rhine. At the same time these rafts are also used for transporting fuel, sawn-timber, and various kinds of bulky raw produce.

Sawn-timber used formerly to be also formed into rafts and floated to distant marts; but this custom has gradually fallen into disuse, as the boards, &c., lose a good deal in value after such immersion in water. Converted timber is therefore now conveyed mostly in barges, unless it can be piled dry as ballast on log-rafts.

Critique of the Various Continental Methods of Transport.—The loss of wood in **carting** and **sledging** is usually nominal, and, so far as the out-turn in timber is alone concerned, these are the most economical methods. But the loss by transport down well-planned **timber-slides** not interrupted by precipitous rocks barely exceeds 1 per cent, though, when such interruptions are unavoidable, the loss may amount to 15 or 20 per cent, especially if the precipitous places are in the lower half of the slide, where the velocity of the timber is naturally greater than higher up. **Drifting** usually causes a loss of from 2 to 5 per cent of the wood originally launched; whereas the loss in **rafting** is only nominal, unless the current is so swift as to cause the breaking up of a raft occasionally, and the carrying out of logs to sea. According to Gayer, at Ramsau, in the Bavarian Alps, where all the above methods of transport are in operation under local difficulties far greater than would usually be presented in even the most mountainous and wildest tracts of Britain, the total loss of timber during transport amounts to about 6 per cent, of which 4 per cent is incurred during **transport by land,** and 2 per cent during **transport by water.** These results have improved since good roadways were made, suitable for sledging and timber-sliding.

Experience, both in France and in Germany, has shown that the conveyance of wood by tramway is only about one-third of the cost of cartage, and that even a considerable initial outlay may prove highly profitable where large quantities of timber have to be extracted, while the extra capital thus invested may be expected to give a return of from 4 to 6 per cent on the outlay. Rafting is always, however, the cheapest method of transport, unless when exceptionally expensive operations have to be undertaken in forming reservoirs and weirs, and in preparing the banks and beds of the floating streams.

CHAPTER IV.

THE PRESERVATION OF TIMBER.

Apart from the disintegrating and wasting influences to which timber is liable, and which likewise affect iron, steel, &c., in the shape of disturbance of molecular and other forces, the main causes of its more or less speedy decay are of purely organic origin, and arise from attacks of fungi and insects or other animals. Some kinds of timber have a better natural protection than others against attacks by fungi and insects through the tannic acid, &c., contained in their tissue (*e.g.*, Oak); others have essential oils distasteful to most insects (*e.g.*, Teak, Deodar); and others again are more or less protected by natural processes of resinification (*e.g.*, Larch, Pine). Adopting a broad generalisation, it may be said that the durability of timber *per se* is in the inverse ratio to the amount of albuminoid matter present in the wood in a form which can be utilised as food by fungi and insects or other wood-consuming animals. Rapid alternation of dampness and drought, or the combined action of dampness and high temperature, will facilitate attacks on wood by both of these classes of destroyers; but, for the sustenance of life in the vegetation of fungi or in the alimentary processes of insects, albuminous food is an essential requisite. If the albumen can be sterilised and rendered unfit for utilisation as food, by being made to undergo a permanent change rendering it immune to fungous and insect attacks, the woody-fibrous tissues of timber must benefit both directly and indirectly. They gain directly by offering practically no points of attack to saprophytic fungi and insects; and they gain indirectly by becoming thereby exempt from the destructive and disintegrating processes induced and hastened by the fermentation of the substance and contents of the cells which accompanies the action of fungi and insects, and which first of all loosens and then destroys the woody tissue.

Though the liability to be attacked by fungi and insects, as also the power of resisting the attacks when once begun, varies greatly in different kinds of wood, it is for one and the same kind of wood to a certain extent dependent on the amount of sap contained and on the proportion of constituents held in solution therein which can serve for the food of fungi and insects. The felling-season is consequently of importance, and wood felled in winter, when there is least sap in the tree, is better than wood felled in spring and summer, while the sap is in full flow. Any process, therefore, which can increase the durability of timber is of advantage; and especially is this the case in Britain, where we are unfortunately mainly dependent on imports to supply our annual requirements. The preservation of wood is, indeed, a matter of national importance. We import annually over £25,000,000 worth of wood; and whence are our future supplies to come, seeing that demands for timber are everywhere on the increase, whilst the actual wooded area throughout the world is annually decreasing? Every means should therefore be used to try and lessen our requirements by preparing the timber so as to make it last longer, because it is clear that if timber can henceforth be made to last twice as long as it has done in the past, then only one-half of the quantity now consumed could be made to answer our future requirements as to repairs and renewals.

Timber can be preserved, so as to increase its durability, in one or other of the following six different methods: 1. *Seasoning naturally* in the open air; 2. *Drying artificially* by superheated air; 3. *Dissolving the sap;* 4. *Steaming;* 5. *Superficial application of preservatives;* and 6. *Impregnation with antiseptics.* The oldest of all such artificial processes, and one known even among most savage tribes, is charring the surface of wood that is to be inserted in the ground.

1. **Seasoning naturally, in the open air.**—For many purposes it is sufficient to allow the water contained in the wood to evaporate so far as to bring this into an "air-dried" condition, when it still contains from about 9 to 15 per cent of water (see p. 440). Timber thus naturally seasoned is durable for a long time if used for interior work, and its durability can then be increased by painting, earth-oiling, &c. But if used for structures in the open air, its durability decreases in proportion to the frequency and extent of changes from damp to dry. Employed entirely under water, some kinds of wood are extremely durable, but all kinds decompose quickest when used on or in the ground, where it often gets wet without ever being able to dry thoroughly (*e.g.*, railway-sleepers, fence-posts, pitwood-props, &c.). For such unfavourable conditions mere natural seasoning, or even artificial exhaustion of the cell-sap, is not a sufficient protection, and the timber can only be preserved by impregnation with some sort of antiseptic substance. But timber of all kinds, ages, and sizes will rot much sooner if used green than if well air-dried first of all.

Where any large fall of timber takes place, either in the ordinary course of management or as the result of a gale, the logs should be barked and air-dried as soon as possible, if the timber cannot at once be removed and converted into planks for seasoning. This is more especially necessary with regard to Conifers, which otherwise soon become infested with beetles. Unless logs are barked, they may take years to season, and those which contain much water (*e.g.*, Birch) may then even rot in place of becoming air-dry.

Barked or converted timber gradually parts with its moisture till it reaches a condition in which there is a sort of equilibrium between the dampness of the air and the hygroscopicity of the wood; and the time taken to reach this air-dried condition depends mainly on the kind of wood, on the extent and nature of the surfaces exposed to the air, and on the free play of fresh air over these surfaces.

The usual method of seasoning timber is to saw it into planks, and to stack them so that air can everywhere circulate freely between the boards. It is best to stack them in open sheds, or under a high and projecting roof of boards, so as to protect them against sun and rain. Even under the most favourable conditions, boards do not become air-dry for several months; and of course the thicker the planks, the longer they take to season; while for hardwood planks about a year has to be allowed for each inch of thickness. As Ash does not shrink and warp much, it can be sawn into planks and stacked at once, but Oak is generally kept for a year in the log, and Elm often much longer than that, before being sawn up.

This natural process of seasoning takes a long time, and requires a large area for stacking the planks and other converted wood. It therefore soon locks up a considerable amount of capital, so that artificial processes of seasoning are often preferred as being more rapid. These artificial processes consist of drying with hot air, exhausting the sap, or steaming the wood, all of which are carried out in special chambers or boilers.

2. **Drying artificially by Superheated Air.**—This takes place in drying-chambers, in which the wood is ranged horizontally, so that the hot air can circulate freely between the individual pieces. The seasoning may then take place merely by introducing slightly superheated air and keeping it in circulation by means of large revolving fans. Usually, however, the heating is done either by steam-pipes or hot-air tubes.

The size of the drying-chambers depends on the length of the wood to be treated, but if they exceed from 10,000 to 14,000 cub. ft., it is difficult to keep the warmth and the rate of seasoning equable. Usually they are much smaller than that; but whatever the size of the chamber, about one-third is filled with wood and two-thirds with the hot air (p. 548). The chambers are generally made of masonry, and with a rectangular ground-plan. In steam-heating, parallel rows of pipes are ranged under an open lattice-work flooring, between the lathes of which the warm air ascends; and the pipes are set at a slight angle to allowing condensing water to run off. The steam is usually obtained from the waste-pipe of the mill-engines, because if special boilers and furnaces have to be erected to supply the steam, it is then preferable to use hot-air pipes in place of steam-piping.

Seasoning by hot-air, which is the usual method, may take place in either of two ways. In the first, a stove or calorifer is built of masonry under or alongside the drying-chamber, and a cast-iron grating is made red-hot to superheat the air which passes through it and is conducted thence to the closed chamber. In the second, the hot-air is generated by a furnace apart from the chamber, and is conducted into it in metal pipes running under the open lattice-work flooring. The drying-chamber must be properly ventilated, so as to produce a continual current of hot air and to enable the temperature to be regulated. This can often be effected merely by ordinary small chimney-pipes with circulating vanes and cowls (to prevent ingress of cold air), but if necessary the dry air has to be pumped in and the moist air exhausted.

Where large drying-chambers are continuously at work, the timber is loaded on trollies and run in on a tramway at one end of the chamber, then brought gradually into the hottest position, and finally removed at the other end, to make room for a fresh trolly-load. Otherwise, each lot of wood operated on is simply left in the chamber to cool entirely before removal.

The chief points in such artificial seasoning are as follows (Schwackhöfer, in Lorey's *Handbuch*, vol. ii. p. 301):—

(1) Drying should only take place at a moderate temperature, not exceeding 110° to 140° Fahr., though as a rule 95° to 105° Fahr. is sufficient. The damper the wood, the slower should the rate of seasoning be, because too rapid heating makes the planks warp and split.

(2) There should not be too much ventilation; it is sufficient if the air be renewed once every five minutes. But this depends mainly on the dampness of the air, because in very dry air the evaporation of the sap proceeds so quickly that the wood may easily become split and cracked.

(3) After drying, the wood should still contain about 10 to 12 per cent of water, because if thoroughly dried it is brittle, is difficult to work, absorbs moisture rapidly, and is then apt to warp.

(4) The time taken to season wood depends on the kind of wood, and on its shape, size, and degree of moistness. For thin boards and planks about three to five days suffice, while from eight to ten days are needed for wood of larger dimensions.

A more elaborate method is the **Haskin process of vulcanising timber**, now carried on at large works in Millwall Docks, London, and in Newcastle.

The principles underlying this process are—(1) that a temperature of about 160° Fahr. effects the coagulation of albumen, so that it cannot be used for the food of fungi or insects; and (2) the well-known fact that many of the transforming and perfecting processes of nature are carried out under the application of great heat and enormous pressure. Such natural processes are here imitated, and the vulcanisation process may be briefly described as a method of rapidly seasoning timber by hermetically sealing it in powerful iron vessels and exposing it under a pressure of about 13½ atmospheres (200 lb. per square inch) to the influence of dry (?) air superheated to between 200° to 300° Fahr., the precise temperature being the secret of the process. If the amount of heat be inadequate, the full advantages obtainable by warmth and pressure are not obtained; while, on the other hand, excess of heat might induce dry distillation that would weaken the quality of the timber for technical purposes.

At the same time other organic changes take place. Through the heat and pressure applied, the constructive potentialities of the sap are utilised, the transformed portions being apparently incorporated into the woody tissue in the form of antiseptic substances. The changes that take place in this respect appear to resemble such as occur in the transformation of sapwood into heartwood, a change which enhances the durability.

In coniferous timber a process of resinification is also very noticeable as the result of treatment, the production of resin in large quantity no doubt being due to the action of heat and pressure on the sap and also on the less durable portions of the cell-walls; for it is known that the chemical transformation of the latter assists in the natural production of resin.

The vulcanisation process is said practically not to alter the weight of the timber to any considerable extent, and but little water is given off during the treatment. This would seem to show that the sap contained in the wood is for the most part transformed and incorporated into the sterilised woody tissue. The vulcanisation is most effective if fresh, unseasoned wood is treated.

The timber to be operated on is brought in from the yard on a narrow tramway and run into one of the cylinders, in which vulcanisation takes place. There are four such cylinders, each 112 ft. in length (consisting of four sections of 28 ft. each), so as to admit of treating the largest size of telegraph posts. The timber being operated on when I visited the yard (1898) were sleepers, of which some 1410 cub. ft., or 28 tons, could be railed on little waggons into each cylinder. When deals are dealt with, the feeding consists of from 1000 to 1415 cub. ft., according to the way they pack on the small trollies.

The cylinders are built of boiler plate, and are anchored at the top end; while the other portions are supported by rollers on runners, to allow play for the expansion of between 1½ inch and 2 inches, due to the hot air applied within.

When the load of timber has been trollied into one of the cylinders, the open end is hermetically closed by means of a heavy steel lid hinged at the top and heavily counterpoised (weighing in all about 9 tons), which is opened and shut by means of a cog-wheel worked by the leverage of a hand-wheel. On the lower end being brought into position, the complete closure against air-leakage is effected by means of numerous curved levers radiating like the spokes of a wheel from the centre of the lid, whence the levers are actuated, and pressing powerfully on the lid so as to seal it hermetically against the air-pressure of 200 lb. per square inch from within. To facilitate air-tight closure, the lid of the cylinder is coated with asbestos packing. There are forty of such spoke-like levers, and each fits into a strong steel socket or slot. The opening or closure of the lid can take place in less than two minutes, only two men being required to work the wheel and apply all the requisite leverage. The lid having been closed on the filled cylinder, steam is turned into the pipes and surplus moisture from the outside of the wood is expelled and run off through cocks at bottom of the cylinder. The cocks being again shut, superheated compressed air, between 200° and 300° Fahr., is then driven into the cylinder. This is provided by an air-compressing machine in an adjoining chamber. The air-compressing engine (weighing about 35 tons) has steam and air cylinders, each 18 inches in diameter, and with a 30 inches piston-stroke, in which the air is compressed to a pressure of 200 lb. per square inch, while a spray of water is at the same time injected into it to absorb the heat evolved by compression. This moist compressed air is next filtered through a water separator which dries it thoroughly (?), after which it is pumped by the circulating engine (also of about 35 tons weight) first through cylinders containing tubes heated by steam and then through a kind of pipe-stove heated by a coke furnace, whence it is conducted to the cylinders where vulcanisation takes place. It is essential that there should be constant circulation of the superheated air in the vulcanising cylinders, and each complete stroke of the piston of the air-circulating machine displaces 35 cub. ft. of air. Fresh superheated air is forced into one end of the vulcanisation cylinder, and a corresponding quantity is drawn off from the other end. From the cylinder the air passes to a tubular cooler, and is conducted thence to the circulating pump for re-distribution. Any loss of air-pressure due to circulation is replaced by the occasional use of the air-compressing machine. Both the air-compressing and the air-circulating machines are worked at a slow rate.

The time taken in vulcanisation depends of course on the dimensions of the timber to be operated on, but for sizes like sleepers it occupies about eight hours; and no advantage has been found to accrue from continuing the treatment beyond this time. When the plant is not fully employed, the cylinders are fed in the morning, operated on during the day, and allowed to cool at night, the load being taken out early next morning and replaced by fresh wood for treatment. If worked under pressure of a large business, cooling can be facilitated by gradually lowering the temperature of the air pumped into the cylinders.

The effects claimed to be produced on wood by vulcanisation are—(1) that it will not decay; (2) that the cheaper kinds can be utilised for sleepers, mine-props, piles, &c.; (3) that the technical properties of wood are improved, especially as regards diminished shrinkage; (4) that the resinous, oleaginous, and other properties of the sap within the cells and fibre become solidified; (5) that all "fungi," "germs," or "insects" are killed;

(6) that the germinative principle inherent in the fluids is destroyed ; and (7) that the wood is indurated, strengthened, perfected, and rendered less inflammable.

Samples of Pine sleepers, said to have been in the ground for about ten years, were shown to me in a thorough state of preservation ; and if they really were what they were said to be, they furnished a striking proof of the utility of vulcanisation. During my visits to the works I had opportunities of examining Baltic Pine baulks and sleepers under treatment for the Natal Government, and of comparing them with the unvulcanised wood ; and I could not but remark the highly resinous condition of the vulcanised wood in comparison with that awaiting treatment. This resinification, this transformation of sap and of the less durable portions of cell-walls into substances which become incorporated into the woody tissue, must increase considerably the resistance which the saturated fibres are able to offer to the natural processes of decay.

While it is easily intelligible how the transformation of albuminous substances, sap, and portions of cell-walls capable of undergoing transformation under heat and pressure can and probably must increase most of the technical properties of timber, yet it is almost impossible to accept in its entirety the statement put forward that vulcanisation renders wood less inflammable. Certainly for non-resinous woods this will be so, but in the case of Conifers resinification must produce greater inflammability ; and in all woods operated on the heating-power must become enhanced.

The cost of vulcanising is 2½d. per cubic foot for softwoods and about 4d. for hardwoods, a reduction being made for larger quantities. It is therefore somewhat cheaper than creosoting. The difference in the scale of charges between softwoods and hardwoods does not arise from any difference in treatment, but is due to hardwoods being usually sent in smaller quantities and in forms (*e.g.*, veneers, cabinet-woods, sounding-boards for pianos, &c.) which involve more handling in the yard and during the process of vulcanisation than sleepers and baulks of Pine and Fir. So far as the actual treatment is concerned, the vulcanisation process is identical for both classes of timber, and mixed timber can be run into the cylinders. The *actual cost of vulcanising* must be very small if there are regular supplies of timber to operate on ; but the first cost for machinery is very heavy.

3. **Dissolving the Sap** not only reduces the amount of moisture in the wood, but also weakens its hygroscopicity, so that it seasons quicker and shrinks less, while the shrinkage is more even and uniform in the various directions. It is not, however, a method capable of application on a large scale.

The simplest way of dissolving the sap is to completely immerse converted timber, or barked sections of logs, for several months in running water. But large stems may require to be left for several years in water, as the sap can only be washed out by diffusion, which is a very slow and gradual process. This method can only be applied immediately after the logs have been felled, as certain constituents in the sap become insoluble if the logs have been long exposed to the air. Apart from the length of time this takes, and the amount of capital it therefore locks up, this method of treatment by immersion in river-beds does not fulfil the object in view.

Oak for flooring, which would require two years' seasoning in the open air, may be dried in four months after having been immersed in a stream for three or four months; and if immersed in water of a temperature of about 85° Fahr., the time of immersion may be reduced to fifteen or twenty days. After rafting the wood dries more rapidly, because of the sap having been partially driven out and replaced by water, which evaporates more readily than the sap.

For small timber, such as is used for turnery and carriage-making, the sap can be better dissolved by boiling the wood in water, though even then the sap is never thoroughly got rid of. It prevents warping and splitting, however; but is far less effective than steaming.

4. **Steaming.**—The converted timber is usually put into thick wooden boxes or cases 10 to 12 ft. long and 5 to 7 ft. broad and high, strongly bound with iron and capable of being hermetically closed at each end by means of iron screws and bolts. The box rests somewhat slantingly on strong supports, so that the condensed water can be run off at the lowest part by a turn-cock, while the mouth of the steam-pipe enters at the opposite end. To economise steam, the wood is packed as closely as possible into the box, care being taken, however, that the surfaces of the different pieces of timber should come into contact as little as possible, boards being set on edge.

When the box is packed and closed hermetically, the steaming is begun. At first the condensed water runs off fairly clear and colourless, but later on it gets much darker and discoloured, and has a peculiar woody smell from the extracts dissolved. The steaming is continued until this stage has passed and the condensed water again runs clear and colourless, showing that the sap has been dissolved and withdrawn to the full extent possible.

In steaming timber in wooden boxes great superpressure can of course not be applied; nor is this desirable, because then the timber loses in strength. After being steamed, the wood is either dried in the open air, or in special drying-chambers.

Steaming takes from about forty to eighty hours, according to the size of the timber operated on. Steamed wood differs in colour from wood naturally seasoned, and is generally darker. Oak turns dark-brown, Maple reddish, and Cherry yellow to red, while Beech turns brown to pinkish, and is then preferred for such work as parquet-flooring. Steamed wood dries quicker, is lighter, and is less liable to warp and split than unsteamed wood of the same degree of dryness. While still warm and moist as it comes from the steaming-box, it is very flexible; and in cooling and drying it retains the form given to it while still warm and moist. This quality is made use of in bending wood for ship's planking, carriage- and waggon-making, cooperage, chair-making, &c.

Some processes are, however, much more rapid than the above, as, for example, that known as the "S.S." (superheated steam), practised in London by the Wood Syndicate, Ltd., as follows:—

> The wood is placed in a specially constructed chamber and treated with superheated steam at atmospheric pressure for a time varying from 10 to 40 hours, according to the kind and thickness of the timber—softwoods with an open tissue taking from 10 to 18 hours, while closer hardwoods take from 18 to 40 hours. Superheated exhaust-steam may be used, and the total cost is said not to exceed 2d. per cubic foot. The timber may be used immediately after treatment without fear of shrinkage, warping, or twisting, and it can be planed just as when naturally seasoned.

Superheated steam is also employed under great pressure in almost precisely the same way as superheated air in the Haskin process of vulcanisation, above described. The wood is enclosed in two strong iron cylinders, hermetically sealed and packed round with asbestos ; then steam is introduced after passing through a system of pipes to free it from water carried along with it and to superheat it. Under the pressure of the steam the sap is expelled and runs off with the condensed water, and under longer exposure to the superheated steam the water contained in the wood is reduced to 10 per cent. This kills all fungi in the wood, and makes it much less liable to warp and split, but it diminishes its strength very considerably, as the steam affects the tenacity of the fibres.

In **Leclerc's process** the wood is arranged in a close chamber of masonry (being piled upon the open-work floor, and inclined slightly to induce the sap to move), and the steam is brought in for forty-eight hours by perforated pipes. Under this action part of the sap is drawn from the wood, and part is coagulated, but the result is not complete. The steamed wood is then dried by causing a current of air heated to from 85° to 95° Fahr. to circulate throughout the chamber for a fortnight in the case of planks of ordinary thickness. Each piece of wood is separate, to allow the steam and air to circulate freely over the whole surface. For drying, the warm air is alternately introduced from above and from below, and at one or the other extremity of the chamber, and is drawn in through the wood and exhausted by a ventilator working at the opposite extremity.

5. **Superficial Application of Preservatives.**—This can take place in three different ways—by (*a*) polishing, (*b*) painting, or (*c*) charring and then coating with antiseptics.

(*a*) **Polishing** with shellac or wax is for the direct purpose of improving the ornamental appearance of the wood, although indirectly it also preserves it by hermetically closing the superficial pores. The polish used for furniture consists of shellac dissolved in alcohol, which is applied to the smooth prepared surface with a soft ball of rag, and well rubbed in with a little oil. For parquet-flooring the polish consists of bee's-wax and turpentine, and is rubbed on with a hard brush.

(*b*) **Painting or Coating superficially** with oil-paint, earth-oil, coal-tar, wood-tar, carbolineum and other tar-products, linseed oil, or varnish also closes the superficial pores of the wood. It therefore prevents warping and splitting, due to hygroscopic changes, and hinders the entrance of fungous spores. Even when such a coating is only given for an ornamental purpose (*e.g.*, painting of interior wood-work of Pine or Fir, or rubbing over Oak wainscotting with linseed-oil), it acts as a preservative if applied to well-seasoned wood. But if the wood painted be still green, the effect is then only to make it rot quicker, by preventing the evaporation of the excess moisture still contained above what there should be in an air-dried condition.

Tarring the surface of wood is only to be recommended when the objects coated are to be used in the ground, or in or under water, and not when they are to be exposed to the direct action of the sunlight, because then the black surfaces absorb a great deal of heat, and the wood is apt to split and crack. Coal-tar is preferable to wood-tar as a preservative, and some of the other tar-products (*Carbolineum*, *Stop-rot*, &c.) enter farther into the wood than tar.

A coat of tar is durable, and is a good protection against damp ; but its action is almost purely mechanical, and thus applied it has little really antiseptic effect. It forms an impervious layer, and does not penetrate into the wood. It is warmed to make it sufficiently fluid for application, but its consistence is increased in drying by the addition of a little slaked lime burned and powdered, or of a little cement.

The two preparations of tar most suitable for this class of work are *carbolin* and *antinonnin*. **Carbolin** is a tar-oil containing about 10 to 15 per cent of creosote, of a light-brown to deep dark-brown colour, which smells strongly of tar, and has a sp. gr. of 1·13 to 1·19, and a boiling-point of 480° to over 640° Fahr. It can be used for coating bridge-piles, gate- and fence-posts, and other outside woodwork, but it should not contain above 15 per cent of creosote, as it then eats into the woody substance. Owing to its strong tarry smell it is not suitable for coating interior woodwork. **Antinonnin**, so called because it was originally used for "grease-banding" stems to prevent the caterpillars of the nun-moth from re-ascending them, is a combination of nitrous oxide, creosote and potash, with glycerine soap or other substance added to obviate the risk of explosiveness common to nitrous products. It is sold as a yellow paste, soluble in water to the extent of 5 per cent. It is better, however, to use only a 2 per cent solution, and to give two, or if necessary three, coats. These soak into the wood and have a direct antiseptic action. It is used for coating interior woodwork, and protects it against *Merulius lacrymans* and other fungi (see p. 187). It is almost odourless, and is therefore preferable to carbolin for inside woodwork; but it is less suitable for outside work, as it gets gradually washed out by rain. It is also mixed with lime for the white-washing of walls (2 per cent solution).

Linseed oil is one of the oils which dry; and it possesses the property of absorbing atmospheric oxygen, and thus of thickening and forming a thin hard layer over the surface of the wood. This thickening takes place more rapidly if the oil be oxidised artificially by heating it to about 480° Fahr. and then rubbing in soluble metallic combinations (chiefly lead and manganese), when the oil becomes a **varnish**. In consequence of the metals and colours added varnish is thicker than oil, and has to be mixed with a little turpentine to enable it to be easily applied with a brush, whereas linseed oil can, like polish, best be applied with a soft ball of rag.

(*c*) **Charring** the wood when it is to be inserted in the ground, perhaps the oldest preservative process of all, ensures good results, but has its drawbacks and its limitations. It is not so much that the charred surface protects the interior of the wood from the action of either dryness or moisture, or heat or cold, as that the heat developed during the charring process transforms the fluid substances into preservative solids, and at the same time destroys saprophytic fungi, although the general character and appearance of the wood, however, remain unimpaired. But in order to get the heat to penetrate the wood beyond the charred surface, much of the timber has often to be burned away, thus reducing the size of the timber. Unless, however, the charred surface be tarred or treated with some antiseptic, it remains strongly hygroscopic; and this is of course a disadvantage for poles and posts used in the ground.

Superficial carbonisation is suitable to hardwoods which cannot be impregnated with antiseptic substances. The charring is produced by a flaming jet in a current of compressed air, which forms a kind of blow-pipe, producing great heat. The flame draws out the water from the superficial layers, dries the fermentable portions, carbonises the external part completely, and produces a thin torrefied surface impregnated with the distilled products, which are creosoted substances.

6. **Impregnation with Antiseptics.**—This is by far the most important means of preserving timber, and is very extensively employed for railway-sleepers, pitwood, telegraph-poles, fence-posts, and all other woodwork used under conditions exposing it to rapid decay. Various methods have from time to time been tried and recommended, but the number of these which combine **cheapness** and **efficacy** is limited. The ideal fluid for impregnating timber would be one which (1) is highly preservative, (2) penetrates easily and deeply into the wood, (3) remains there and is not liable to be washed out again, and (4) is cheap. No impregnating substance has yet been discovered which combines all these four desirable qualities. Originally, the chief impregnating substances and processes, from which numerous and more recent improvements have been developed, were the following :—

Impregnating substances.	Process invented by	Method of impregnation.
1. Chloride of mercury or corrosive sublimate . .	Kyan, in 1832.	Imbibition by immersion.
2. Chloride of zinc . . .	Sir Wm. Burnett, in 1838.	Pneumatic pressure.
3. Creosote or heavy tar-oil .	Bethell, in 1838.	,, ,,
4. Sulphate of copper or blue-vitriol	Boucherie, in 1857.	Hydrostatic pressure.

Before the earliest of these dates, however, the preservative properties of solutions of **Slaked Lime** or **Hydrate of Lime** and of **Chloride of Sodium** or **Common Salt** were facts of common knowledge. The former was extensively used throughout Britain for timber for estate work, and it was well known to the timber merchants at the mouth of the Spey, down which large quantities of timber had long been floated, that the logs which remained longest in the salt sea-water afterwards proved to be the most durable.—**Slaked Lime** or **Hydrate of Lime** was mixed with water in a tank till the solution (about $2\frac{1}{2}$ per cent, or 1 in 40) became the thin and watery **Milk of Lime**. Into this seasoned and sawn timber was immersed and allowed to lie for several days, according to its size. For small scantling and boards seven days were long enough, while larger sizes required from two to three weeks. After being taken out of the tank it was thoroughly dried before use. Fence-timber treated thus often lasted upwards of twenty years.—**Common Salt** or **Chloride of Sodium** ($NaCl$) was also dissolved in water in a tank, and the converted timber immersed in the brine; but as the solution of salt enters the vessels of the wood much sooner than milk of lime does, impregnation usually took place in only about half the time required for the lime solution.

1. **Chloride of Mercury** or **Corrosive Sublimate** ($HgCl_2$) has the strongest antiseptic properties among metallic salts. Even when used in very small quantities its action is highly preservative ; but its disadvantages are—(1) that it is dear; (2) that it is poisonous, and therefore not suitable for timber-work in dwelling-houses, stables, &c. ; (3) that it is soluble, and therefore not suitable for wharf-posts or other timber in wet places. It is a process still used for impregnating railway-sleepers in Southern Germany, but as it corrodes iron, and is apt to cause sores among the workmen handling the wood treated with it, it is no longer extensively used in Britain.

2. **Chloride of Zinc** ($ZnCl+2H_2O$) is very much less antiseptic than chloride of mercury, and even considerably less so than sulphate of copper, but it is much cheaper than either of these, and is in fact the cheapest of all the preservatives,

a 2 to 3 per cent solution of chloride of zinc (containing 25 per cent of zinc) being employed. Wood that has been impregnated with chloride of zinc can easily be coated with oil-paint, whereas timber treated with chloride of mercury or sulphate of copper causes rapid discolouration of the paint. In general, no reaction takes place between chloride of zinc and iron (as in and on railway-sleepers), but the great drawback to its use is that it is (like chloride of mercury) easily soluble, and is therefore apt to get soon washed out of wood impregnated with it. This process is therefore equally unsuitable for timber to be used in water.

Another chloride recently recommended by M. Flamache, a Belgian engineer, for impregnating sleepers, pitwood, and other timber is **chloride of barium**. It is cheap, very soluble, and can be easily injected. Besides killing fungi, it is said to form an insoluble precipitate which resists fermentation, and though poisonous to insects and rodents, which will not attack wood impregnated with it, yet it is not poisonous to man in doses of less than $\frac{1}{3}$ to $\frac{1}{2}$ an ounce; and as it is not absorbed through the skin, it is therefore not dangerous to use. It is further recommended as being specially suitable for impregnating wood in tropical countries, to prevent the ravages of white ants.

3. **Creosote** or **Heavy Tar-oil**, called **Dead-Oil** in America, has far greater antiseptic properties than chloride of zinc or sulphate of copper, and in this respect nearly equals chloride of mercury; but it is the dearest process. For impregnating timber for outside work it is preferable to any of those metallic salts, and it is now what is chiefly used in Britain. It is unsuitable for indoor woodwork, however, on account of its strong pungent odour and its great inflammability.

Wood should be impregnated with creosote as soon as possible after being thoroughly seasoned, naturally or artificially. The creosoted wood becomes black, hard, tough, and comparatively non-hygroscopic, and the oil does not corrode iron coming in contact with it.[1]

The dark oily substance known commercially as **Creosote** in Britain is the crude heavy **oil of tar**, obtained by the dry distillation of coal-tar; but it is not the true *creosote*, which is obtained only by the dry distillation of wood-tar (see p. 603).

When coal-tar undergoes dry distillation at a temperature ranging from 180° to 750° or 800° Fahr., it yields three different kinds of main products—viz., (1) *light oil*, with a sp. gr. below 1·00, which is highly volatile, and is given off first; (2) *heavy oil*, *oil of tar*, or *dead oil*, with a sp. gr. above 1·00; and (3) *pitch* is left as the ultimate residuum. The *light oil* can by further *fractional distillation* (at a slowly rising temperature) and special treatment be resolved into benzole, naphtha, and carbolic acid; while the *heavy oil*, known commercially in its crude form as **Creosote**, can also be resolved into cresol, chinoline, naphthaline, carbolic acid, heavy lubricating oil of anthracine, and the solid substances, naphthaline, anthracine, phenanthrine, &c. In this crude heavy oil, the constituents of most use in preserving wood by impregnation are the *cresol* chiefly, then the *naphthaline* and similar semi-solid constituents; for the carbolic acid is volatile and soon evaporates.

Pure *cresol* (C_7H_8O) is a colourless oily fluid with a camphor-like smell, which has a sp. gr. of 1·042 to 1·049, and which boils at from 365° to 400° Fahr. It is only soluble to 1 in 50 in water, but dissolves readily in alcohol or alkaline lye. It is less poisonous than carbolic acid, but has a far greater antiseptic power than the latter. In its crude form it is of a dark reddish-brown colour, and is the carbolic acid of commerce. The true and pure *carbolic acid* (C_6H_6O), however, crystallises in long colourless needles (which

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[1] Instructive articles on creosoting timber for estate purposes will be found in the *Trans. High. and Agric. Socy. of Scot.*, Fifth Series, vol. x., 1898, pp. 1-26, and *Trans. Roy. Scot. Arbor. Socy.*, vol. xvii. part i., 1903, pp. 93-98; see also pp. 555-558.

dissolve at 87½° Fahr.), and boils at 305° Fahr. ; but in odour and solubility it resembles cresol. It is very poisonous, and burns the skin when applied to it.

The preservative action of creosote is threefold—viz., (1) *mechanical*, in filling up and clogging the pores of the wood, and thus preventing the entrance of air and moisture ; (2) *chemical*, in coagulating the albumen ; and (3) *physiological*, in poisoning the wood so that insects will not attack it. The heavier the creosote and the higher the temperature (600° Fahr. or above) at which the oil has been obtained (*i.e.*, the further the elimination has proceeded of the more highly volatile light oil or naphthas), the better is its quality for impregnating timber.

Tidy's specification of satisfactory creosote, largely approved in Britain, is in its main points as follows :—

(1) At 100° Fahr. it must be quite liquid, and no deposit should take place till its temperature falls to 93°.
(2) It must contain 25 per cent or more of constituents that do not distil over and become eliminated at a temperature of 600° Fahr.
(3) It must show 8 per cent or more of tar-acids, when tested by the caustic soda process.

The specification insisted on by the German and Austrian railways for the impregnation of sleepers is as follows :—

(1) Only oil of tar from coal-tar may be used, and it must contain only a minimum of volatile constituents.
(2) The boiling point of the tar-oil must lie between 355° and 750° Fahr., and the greater portion should only distil over at 455° Fahr.
(3) The acid constituents soluble in concentrated caustic soda lye must amount to between 20 and 25 per cent.
(4) At 77° Fahr. the oil must be fluid, and so far free from greasy constituents that, when poured upon a dry transverse section of a log, it immediately soaks into it without leaving any other than an oily residuum.
(5) The sp. gr. of the oil must not be below 1·08, and there must be few or no oils below 0·92 sp. gr.

Some of these Central European railway companies permit an addition of up to 25 per cent of oils distilled from the tar of anthracite, peat, or wood, so long as they answer the above specifications.

Investigations made by Seidenschnur, the results of which were published in 1901, show that the antiseptic properties of creosote are about thrice as great as those of chloride of zinc in procuring immunity from fungous attacks.[1] But

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[1] Immunity against fungi was obtained by impregnation to the following extent :—

Over 0·3 per cent of creosote or over 1 per cent of chloride of zinc, against *Proteus bacilli*.

With 1 per cent of creosote or 6 per cent of chloride of zinc, against *Mucor mucedo*.

With 3 per cent of creosote or 9 per cent of chloride of zinc, against *Penicillium glaucum*.

Seidenschnur's experiments have also shown that for railway sleepers an emulsion of creosote and resin-soap penetrates the wood more easily and deeply than creosote alone. In preparing such an emulsion, 50 lb. resin and 6⅔ lb. soda are boiled in 33 gallons of water, and then mixed with 9 cwt. of creosote (deoxidised creosote is best), water being added and the mixture kept constantly stirred till the emulsion has the desired proportion of creosote. The sleepers to be operated on are first steamed for half-an-hour under a pressure of 1½ atmospheres (21 lb. per square inch), then the air is evacuated down to a barometric pressure of 27·6 in., and they are left for half-an-hour before being impregnated with the emulsion for half-an-hour under a pressure of 7 atmospheres (100 lb. per square inch). Treated with a 15 per cent emulsion, Scots Pine sleepers absorb creosote to the extent of 8 per cent of their air-dry weight, while with a 3 per cent emulsion Beech sleepers absorb 11·6 per cent. The absorption of creosote is thus less than in the usual process (see p. 553), but the oil penetrates deeper into the wood.

chloride of zinc is very much cheaper than creosote, and it therefore follows that a process which can utilise these two substances simultaneously ought to be more effective than the former and yet cheaper than the latter. The advantages of such a combination, where each substance would supplement the weaker qualities of the other, are as follows (Schwackhöfer, *op. cit.*, p. 312):—

	Chloride of zinc.	Creosote.
1.	Is cheap.	Is dear.
2.	Penetrates wood easily, and is absorbed in large quantity.	Only penetrates wood with difficulty, and is only absorbed in comparatively small quantity.
3.	Dissolves easily, and gets washed out.	Is neither volatile nor easily washed out.
4.	Has not very strong antiseptic properties.	Has very strong antiseptic properties.
5.	Cannot penetrate into resinous cells.	Dissolves resins, so that they do not interfere with the impregnation.

Although creosoting is by far the most general process among British railway companies, yet on account of its cheapness the chloride of zinc method is still apparently usual in Central Europe. From the returns of 27 of the latter, it was found that 21 used chloride of zinc, 6 chloride of zinc and creosote, 4 creosote, 2 sulphate of copper, 4 chloride of mercury, and 1 no method of impregnation for their sleepers,—this total of 38 being due to some companies making comparative experiments (to the number of 11 in all) of different methods. These returns show, however, that chloride of zinc is there, owing to its cheapness, by far the principal method of impregnating sleepers.

4. **Sulphate of Copper, Copper Vitriol,** or **Bluestone** ($CuSO_4 + 5H_2O$) is far less antiseptic than chloride of mercury, but it is even a cheaper process than chloride of zinc, the sulphate only costing about 13s. or 14s. per cwt. Still, it is rather an expensive impregnating substance, for it has to be used as pure as possible. Its other drawbacks are—(1) that it makes the wood brittle, though harder; (2) that it does not prevent the growth of mould-fungi; and (3) that when it comes into contact with iron (as where non-galvanised spikes, screws, bolts, &c., are fixed in railway sleepers) a chemical change takes place, the copper-vitriol becoming transformed into iron-vitriol, and copper being set free (when $CuSO_4 + Fe = FeSO_4 + Cu$). This process is therefore no longer used for railway-sleepers; but telegraph-poles are still treated by it in Germany, though creosoting is preferred by the British Telegraph Department.

The Methods of Impregnation vary almost as greatly as the antiseptic substances employed in them, but may be classified into the following main groups:—(1) *Immersion*, (2) *Pneumatic pressure*, (3) *Hydrostatic pressure*, and (4) *Electricity*.

1. **Immersion** is the oldest of methods, long since practised with milk of lime and brine solution (see p. 540), and was that adopted in *kyanising* (1832) with a solution containing at least 0·7 to 0·8 per cent of chloride of mercury. A strong solution formed of 1 lb. dissolved in 10 gallons (625 lb.) of water will suffice to impregnate 50 cub. ft. of timber.

This is the simplest of all methods, the converted wood (sleepers, posts, &c.) being merely steeped and weighted down in the liquid contained in a large trough or vat made of Oak or Larch. The timber must be well seasoned, as the solution will not penetrate into damp wood. Softwoods of about the size of sleepers need to be steeped for 8 to 10 days, while hardwoods require

12 to 14 days' immersion. Before use, sleepers thus treated should lie for some months in the open air, to let the impregnating substance soak deeper into the wood. Or for interior woodwork a solution of 1 lb. of sulphate of copper to every 5 gallons of water makes a cheap bath, $1\frac{1}{2}$ gallons of solution being allowed for every cubic foot of wood to be impregnated.

This method is no longer employed on any large scale, but it can be very conveniently used for creosoting fence-posts, paling-rails, and any other wood converted for estate purposes, the wood being placed in any raised metal tank filled with creosote and fire being kindled underneath, but kept well below the boiling-point of the creosote (365° Fahr.). For creosoting on a small scale this is one of the best and cheapest methods (see p. 556).

In Central France, Beech sleepers about $8\frac{1}{2}$ ft. × 10 in. × 5 in., and containing about 3 cub. ft. each, are largely made from rough Beech at a cost of about 5s. each. They are well creosoted by being soaked, in lots of 120 at a time, in tanks 26 ft. long and $6\frac{1}{2}$ ft. broad. To prevent splitting, S-shaped iron clamps, 5 in. long and $\frac{3}{4}$ in. deep, are driven into the ends, and for purposes of identification a flat-headed nail with the year moulded on it is hammered in. These creosoted Beech sleepers are said to remain serviceable for about thirty years.

Pitwood for mines is also in France impregnated by immersion for 20 to 24 hours in wood-tar heated to 140° C. (284° Fahr.), or in about a 3 per cent solution of sulphate of iron, either of which is less likely to act poisonously on the miners than creosote or the other metallic salts.

Aitken of Falkirk in 1882 introduced a process of immersing timber in melted **naphthaline** for from 2 to 12 hours according to its size, but the method was abandoned. It has recently been revived, however, for small timber for estate purposes (fencing, &c.), and with excellent results (see p. 559).

2. **Pneumatic pressure** by means of a force-pump was originally applied by Bréant and Payen, and was the method adopted with chloride of zinc by Burnett (1838), and with creosote by Bethell (1838); but these older methods have since been improved on by Blythe, Boulton (1879), and others. It is used for impregnating with a solution of chloride of zinc, or with creosote, or with a mixture of both of these. The converted timber (sleepers, posts, boards, &c.) must be first dried or steamed, then exposed to partially exhausted air, and finally impregnated with the antiseptic fluid under high pressure.

The converted wood (sleepers, &c.) is brought into a large, strong iron cylinder, of 30 to 40 ft. long by 6 to 7 ft. in diameter according to requirements (and capable of bearing a pressure of 8 to over 10 atmospheres, or 120 lb. to over 142 lb. per square inch), the front end of which forms a door that can be hermetically closed, while the necessary air- and other turn-cocks, thermometer, manometer, and vacuometer are at the back end. Above the cylinder there is a dome-like apparatus connected with the steam-pipe and an air-pump. On the lower side of the cylinder there are the pipes and cocks for running off condensed water and then filling the cylinder with the impregnating fluid by means of a forcing-pump, and for emptying it again when impregnation is completed. Besides these, a steam-engine, boiler, and vessels for preparing the antiseptic fluid are needed. And if creosote alone is to be used, a drying chamber has also to be provided.

To facilitate the charging and emptying of the cylinder, the converted wood is packed on a trolly, which is run along a tramway into the cylinder. The pieces of wood should be arranged as closely as is possible, while still allowing proper room for the circulation of the impregnating fluid. Some cylinders can contain four or five trolly loads of sleepers, &c., long beams and scantlings being placed on two trollies; for telegraph-posts, cylinders of 50 to 60 ft. long are needed.

When only **chloride of zinc** is to be used for impregnating railway sleepers, they are packed on trollies and put in the cylinder, which is then hermetically closed, and steam is then injected and kept at a temperature of 230° Fahr., which produces a pressure of 1½ atmosphere, or 21 lb. per square inch, the condensed water being run off from time to time. This extracts a certain amount of the wood-sap and replaces it by steam, but neither the steaming nor the pressure should be so great as to impair the strength of the wood. When sufficiently steamed, the pressure is removed and the air-pump applied to exhaust sufficient air to reduce the barometric pressure to 24 inches. This decrease of pressure must be attained within 30 minutes, and must continue for other 40 minutes, so as to weaken as much as possible the resistance of the air and steam in the cell-spaces to the penetration of the impregnating fluid.

The actual impregnation then begins, the chloride of zinc solution (of a strength of 2 to 3 per cent) being drawn up into the cylinder by the action of an air-pump. When the cylinder is filled, the air-pump is replaced by the forcing-pump, and this is kept working for about 40 minutes, till a pressure of 7½ atmospheres, or 105 lb. to the square inch, is obtained. The more the fluid penetrates the wood, the more the force-pump has to be kept at work to maintain this necessary pressure; but the impregnation is completed when the manometer shows for at least 20 minutes that, without further pumping, the pressure has remained stationary at 7½ atmospheres—thus showing that the fluid was no longer penetrating into the wood. The remaining fluid is then run off again into its reservoir, the door of the cylinder is opened, and the wood taken out and dried in the air, while the cylinder is cleaned as soon as each charge is withdrawn.

To prevent sleepers splitting (especially Beech), S-shaped clamps with a sharp edge on one side are hammered into the ends. Beech sleepers are treated as soon as possible after felling (else the logs soon begin to decompose), but the better seasoned the other kinds of wood are, when thus impregnated, the longer do the sleepers last.

When a mixture of **chloride of zinc and creosote** is to be used, the mode of operation is the same as above, except that a 3 per cent solution of chloride of zinc must be used, which must be heated to 112° Fahr., and must have 4·4 lb. of creosote added for each sleeper to be impregnated.

When only **creosote** is used, the procedure is different, because the presence of moisture hinders the injection. The sleepers, or other wood, are therefore dried artificially with hot air, in place of being steamed. And a much stronger pneumatic pressure is needed to force this thick oil into the wood.

The well-seasoned sleepers, &c., are first thoroughly dried by exposure for at least 8 hours in a drying chamber, at a temperature of 212° Fahr., the boiling-point at which water passes into steam. While still warm they are put into the impregnating cylinder (filling it to about 75 per cent of its total capacity), and kept there for half-an-hour under a reduced barometric pressure of 24 inches. Creosote, which should contain at least 12 per cent of *cresol*, is then pumped into the cylinder after being previously warmed (by iron-piping laid in the tank) to 120° Fahr., in order to dissolve the naphthaline it contains, and to render the creosote perfectly fluid, the force-pump being kept in action till a pressure of 10 atmospheres, or 142 lb. per square inch, is attained; and this pressure is maintained for 1½ to 2 hours.

The creosote tank is usually placed under the cylinder, and must of course be of sufficient capacity to provide all the oil required. A pipe, with a stop-valve conveniently fixed, leads from this to the lowest point of the cylinder for filling and emptying it. The cylinder is connected by other pipes, each with a stop-valve, to the air- and force-pumps driven by a steam-engine; and it has also a safety-valve, a vacuum-gauge, and a pressure-gauge.

On the cylinder being packed with wood, closed and bolted, the air-pump is worked for about 15 to 20 minutes till the vacuum-gauge shows the desired reduction of pressure. Then the air-pump valve is closed, and the stop-valve of the tank opened to admit the in-flow of creosote from the tank, the air-pressure on which causes the oil to ascend freely and fill the cylinder, when this valve is closed and that on the pipe connecting with the force-pump opened. With the force-pump more creosote is driven into the cylinder; but as this was already full, the additional oil can only find room by forcing some of the oil already in the cylinder into the pores of the wood. The force-pump is kept going until either (1) the desired quantity of creosote has been injected into the wood, or (2) the safety-valve, loaded to a pressure of 8½ atmospheres (120 lb. per square inch), begins to rise, thus showing that the pressure is too great for the rate of absorption, or that the limit of absorption is being reached.

The quantity of creosote actually absorbed can be measured by the level of the oil in the creosote tank. Thus, if the tank be 8 ft. by 6 ft., each fall of 1 in. in the tank, after the cylinder has been filled and the force-pump brought into play, would indicate the absorption of 4 cub. ft., or about 25 gallons of creosote. If the cylinder were charged with 250 cub. ft. of timber, which it is desired to inject with about a gallon (*i.e.*, from 10 to 11 lb.) of creosote per cubic foot, then it would be necessary to keep on force-pumping until the oil in the tank shall have sunk 10 in. from the time the pumping began.

When the desired quantity of creosote has been absorbed, the pressure is continued for an hour or two, before running off the surplus oil back into the tank, and then discharging the load of creosoted timber.

Sulphate of Copper can also be used, in a 1½ to 2 per cent solution, for impregnating by pneumatic pressure; but as in this case the cylinder has to be made of copper, this method is not in general use.

The pneumatic process is that now generally employed, and is certainly the method most suitable for use on a large scale. It takes altogether only 6 to 7 hours, and 150 to 175 sleepers, or more according to the capacity of the cylinder, can be impregnated at a time. As the wood is converted and fashioned before impregnation, there is no wastage of the antiseptic substance; and the outer portions of the wood, which are those most liable to decay, are thus most thoroughly protected. The surplus impregnating liquid run off from the cylinder can of course be used again on being brought up to the proper strength.

The chief modifications of the original pneumatic processes of Burnett and Bethell in 1838 have been invented by Blythe, and by Boulton (1879).

Blythe's Process, called **thermo-carbolisation**, and used for impregnating sleepers at Bordeaux, consists in treating the wood with carburetted steam to extract the sap and water, and at the same time inject it with creosote held in suspension. The steam has to be furnished from the boiler at a minimum pressure of about 6½ atmospheres, or 90 lb. per square inch, and the creosote must contain 6 per cent of carbolic or phenic acid; and nearly 2 lb. of creosote have to be allowed for each cubic foot of wood to be impregnated. It is claimed for this process that as the sap and water are removed under the heat and pressure, the carburetted steam taking its place acts so as to coagulate the albumen by its heat and to sterilise it by the carbolic or phenic acid. That creosote-steam can penetrate deeper into the wood than the fluid oil itself is unquestionable, but to be effective the process takes from 12 to 18 hours, or from two to three times as long as with chloride of zinc, and it is much more expensive than either of these methods. Furniture-woods thus treated for six hours or longer become very dark in colour, and as the wood comes out softened, it can be rolled and pressed to improve its appearance. For this purpose, however, it is better to treat the wood with the carbolic acid of commerce than with creosote. Fresh, green wood is the best to operate upon.

Boulton's Process, patented in 1879, is based on the fact that artificial drying at a high temperature above 230° Fahr. must diminish the strength of the wood for structural purposes. He therefore gets rid of the moisture simultaneously with the injection of the creosote. The wood, either fresh or seasoned, being placed in the cylinder, creosote heated to over 212° Fahr. (the boiling-point of water) is admitted, and the air-pump is used to exhaust any or all the water thereby converted into steam. The place of the evaporated water is simultaneously taken by the warm creosote, which of course penetrates the wood more easily than would be the case at a lower temperature, the force-pump being also finally used, if necessary.

The **Powell Process** or **Saccharisation** of timber, patented and worked by the Powell Wood-Process Syndicate (Temple Bar House, 28 Fleet Street, E.C.), consists in impregnating the woody tissue with molasses, glucose, or sugar. This darkens its colour more or less, according to the material employed and the wood operated upon, but increases its hardness and density without loss of toughness, tensile strength, or flexibility; whilst at the same time it slightly decreases its inflammability.

The *impregnating material* used consists of the following:—

(1) Low syrups or molasses.
(2) Glucose or grape-sugar, made from maize, rice, &c.
(3) Beet-sugar, raw or refined.
(4) Cane-sugar, raw or refined.

(1) *Low Syrups or Molasses*, of either beet or cane, the cheapest by-products of sugar-factories, are used for timber for unpainted work, railway-sleepers, street paving-blocks, joists and beams, &c. Beet- and cane-syrups leave the timber more or less hygroscopic, and also darken it; but they prevent the wood from drying or cracking with heat. Thus paving-blocks do not wear so rapidly or grind into fine dust in dry weather; pier-decking and platforms do not splinter and crack; paving-blocks, railway blocks, and similar timber will not shrink or expand as ordinary wood does; railway and vehicle brake-blocks maintain their power of gripping when dry. For fine timber, where whiteness and dryness of surface are essential, syrups are not used.

(2) *Glucose* or *Grape-sugar*, ordinarily cheaper and better for the purpose than beet- or cane-sugar, is non-hygroscopic, and gives a clear crystalline liquor, which leaves timber unchanged in colour and dry to the touch. In some cases, however, a mixture of glucose and cane- or beet-syrups is preferable to either alone.

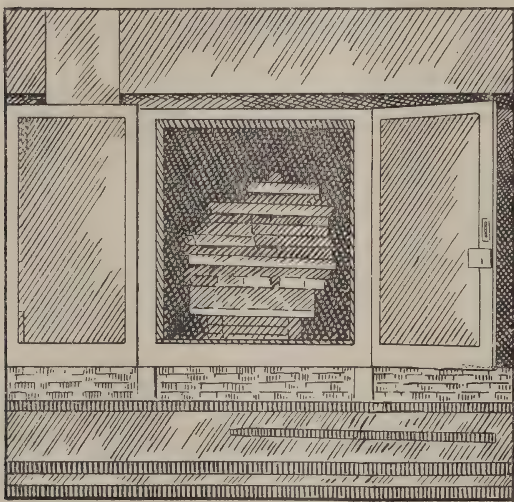
(3 and 4) Raw or refined *Cane- and Beet-sugars* are used with much the same effect as glucose, but they both (and especially the cane-sugars) have a tendency to darken the timber boiled in their solutions, and to render it more hygroscopic superficially, although it still takes paint, varnish, or polish well.

A *Solution* should be made by dissolving one of the above described syrups or sugars in water. It will be found that 4½ lb. of sugar or 6 lb. of molasses added to 1 gallon of water (10 lb.) will make a solution with a specific gravity of 1·150 (30° Twaddle) at 65° Fahr., while the same solution at 180° to 200° Fahr. will have a specific gravity of 1·110 (22° Twaddle). Whether made from sugar or syrup, the solution may be used continuously, as it does not rapidly deteriorate, and any weakening of the syrup by the boiling out of sap in new timber may be remedied by adding sugar or syrup to bring the solution up to the right strength. Timber like Oak or Walnut darken the solution so much, that it becomes useless afterwards for processing any white wood where colour is of moment. Hence, in works where several kinds of timber are to be processed, storage tanks should be provided for keeping the various solutions separate, the clear and new liquor being used for the whitest and highest class of timber, and, when discoloured, passed on for the commoner or darker woods.

Storage Tanks are required for preparing and storing the solution. Those in use at the Powell works consist of four 5000 gallon tanks 20 ft. long × 9½ ft. wide × 5 ft. deep, and are sufficient to keep a large installation going.

Trollies and Loading.—The timber should be classified as to size and quality, and so loaded on the trollies as to facilitate both saturation and drying. In loading, a space of about 2 in. should be allowed between the various pieces to secure free passage of the solution and circulation of the hot air in the drying-rooms. For small pieces, the trollies are furnished with a cage to keep the wood in place and to prevent it from floating in the liquor, while heavy timber is securely fastened to the trollies. After being once loaded, the timber does not require further handling until the process is complete. Trollies about 6 ft. long by 4 ft. wide are best. These are lengthened for carrying long planks or boards by steel rails of varying lengths resting on the framework.

Fig. 261.



Drying-Room showing loaded trolly in place ready for drying.

Processing Tank.—A closable cylinder was first used in this process, but an open rectangular tank is now preferred. For treating 30 to 40 loads of timber daily an iron tank is needed about 30 ft. long × 9¾ ft. wide × 6 ft. deep, divided down the centre lengthwise by an iron partition, practically making it into two long tanks over 4½ ft. wide. Along the sides and bottom of this pair of tanks is a series of pipes (fitted with the necessary valve connections), used first for boiling the liquor by the aid of steam, and afterwards for cooling it by the circulation of cold water. Raised flat plates are laid at the bottom of the tanks for supporting the wheels of the timber trollies.

The loaded *Trollies* are raised from the ground by a lift attached to overhead trolly-ways, and run over to the right position for being dropped into the tank. A chain or wire-rope is then fastened to the lower part of the trolly. This rope passes round two wheels at the bottom of the tank, and is attached to a shaft running the whole length of the side of the tank ; and by its means the trolly is drawn down into the tank and held firmly during processing.

When the tanks are loaded and sufficient liquor is run in to cover the timber well, steam is admitted into the circulating pipes, and the liquor is rapidly raised to the boiling-point (212° Fahr.), at which it is kept until sufficient air is extracted and the timber is ready for saturation. The time required for boiling, as also for the subsequent saturation, depends on the size and quality of the timber. Loss by evaporation during the boiling stage should be made up by adding water occasionally. The steam is then turned off and cold water circulated through the pipes to rapidly cool the liquor, care being taken to add fresh liquor so as to keep the timber well covered during the time it is absorbing the solution. The liquor is cooled to 70° Fahr., and the timber left in for several hours (according to the kind of wood) after reaching this point, so that the timber itself may be cooled from the centre and thus be prepared for absorbing the solution.

For large works two or more sets of process tanks are needed, so that the timber when ready, can be taken out of the hot liquor, in which it has been boiled, and dropped into a tank containing cold liquor instead of heating and cooling the same liquor alternately. This expedites the saturation of the timber without injuring it, and several charges can then in twenty-four hours be treated and made ready for drying. When absorption is completed, the timber is taken out of the tanks and passed on to the drying-room.

Drying-Rooms (Fig. 261) are needed to the extent of at least ten or twelve times the capacity of the process-tanks, if the plant is to be kept fully employed. The height and width should be only slightly in excess of the height and width of the loaded trollies, so as to leave as little space as possible between the timber and the walls of the drying-chamber, and to prevent the hot air in the rooms from passing round, instead of through, the trollies. The length of the drying-rooms is immaterial, provided that they can accommodate the timber to be dried. Each room is fitted with a fan for circulating the hot air, forced into the chamber by a special fan. The temperature can be raised to 250°-300° Fahr., and the air can be changed when saturated with moisture.

The *Drying and Seasoning* after immersion must be done slowly to secure the full advantage of the process. From 2 to 6 or 8 hours (according to the softness and porosity, or the hardness and density) are required per inch of the least dimension of the wood to raise the temperature from the starting-point to the maximum, then ten times such number of hours for drying at the maximum (250°), and finally from 2 to 6 or 8 hours per inch to cool it down to about 65° Fahr. The woods which absorb most liquor of course take longest to dry; thus Poplar takes three or four times as long as Pine or Spruce.

The *Absorptive Power* of the timber while cooling varies greatly even for any one kind of wood; but the following is the average quantity of *saccharine matter* (and not merely of the *solution*) retained by different classes of our common woods after being dried—the amount of sugar retained being about one-third of the solution at first absorbed :—

Kind of wood.	Lb. sugar per cubic foot.
Poplar	9½ lb.
Beech	7½ ,,
Birch, Cherry, Elm, and Sycamore	6 ,,
Ash	5½ ,,
Willow	5 ,,
Oak, Larch, and Walnut	4 ,,
Scots and Weymouth Pine, Spruce, Silver Fir, Douglas Fir	3½ ,,

It is noteworthy that Larch and Spruce, which are hard to creosote or naphthaline (see pp. 554, 560), appear to be as easily saccharised as Scots Pine.

Details are not available regarding the cost of this process. But the plant for treating charges of 700 ft., and drying same, costs about £1500, exclusive of engine and boiler, and the cost for processing ordinary timber in large quantity is said to be about the same as that of creosoting.

Powellised timber may at the same time be rendered *fire-resisting* and *non-flammable* by the addition to the saccharine solution of certain chemicals (see p. 563).

The cost of making timber non-flammable varies considerably according to the amount of solution absorbed and the time occupied in the treatment, but is said to bear favourable comparison with other methods.

3. **Hydrostatic pressure** was first employed by Boucherie in France (1857), who found that a pressure varying from 1 to 2 atmospheres, or 14 to 28 lb. per square inch, applied to the thick end of a cross-cut stem, fully covered with its bark, and lying almost horizontally, was sufficient to force out the sap from the lower end, so that it may be replaced by some antiseptic fluid.[1] One end of the log is firmly closed by a cap consisting of a flat wooden board clamped and screwed tightly down on both sides against a ring of greased rope or of caoutchouc, fitting round the edge of the stem-section. Into the narrow water-tight chamber thus formed at the end of the log an auger-hole is bored obliquely down from the top; and into this is inserted the nozzle of a gutta-percha tube, which conducts a 1 per cent solution of sulphate of copper (10 oz. to every gallon of water; or $2\frac{1}{2}$ lb. to 4 gallons, 250 lb.) from tank placed at a height of 28 ft. or more (but usually about 30 to 33 ft.) to supply a sufficient pressure (of over 1 atmosphere, or 14·2 lb. per square inch) on the surface of the stem. By means of this pressure the sap is expelled and its place is taken by the sulphate of copper solution, which forms an insoluble combination with the nitrogenous substances remaining in the cells, and impregnates the woody tissue itself.

The sap begins to ooze out of the free end of the log within a few minutes of the hydrostatic pressure being applied, and gradually this becomes mixed with the copper solution. When the exuding fluid shows 0·75 per cent of sulphate of copper, the vat of 1 per cent solution is weakened to 0·5 per cent, for the purpose of washing out the sulphurous acid set free by the elimination of hydroxide of copper. When the fluid issuing no longer shows any acid reaction, the impregnation is complete, the cap can be removed from the front end of the log, and the stem barked and dried in the air. The length of time taken for impregnation varies from 2 to 4 days, according to the kind of wood, time of felling, and length and thickness of the log; but it takes about 3 days, or 72 hours on the average. To carry out operations on any large scale a considerable ground-area is therefore needed.

The sap issuing first of all from the log is of no value; but when it begins to consist partly of the copper solution, it is run off in a wooden gutter and collected in a reservoir. When this solution contains less than 0·5 per cent of sulphate of copper, the copper can be precipitated by iron; and that containing 0·5 per cent or more is filtered through fine sand, and brought up again to 1 per cent for future use by adding copper vitriol.

By this method winter-felled wood is more easily impregnated than that felled in summer; but the most difficult of all to impregnate is that felled in April and May, while the sap is in strongest flow. Freshly-felled wood is

[1] Another hydrostatic process of Boucherie's, which was soon abandoned, was to utilise the natural osmotic force of the living tree to raise up towards the foliage a weak solution of antiseptic fluid, introduced through gutta-percha tubing into holes bored into the stem close to the ground. The stem then becomes to a certain extent impregnated with the fluid thus artificially introduced in place of the sap imbibed nominally through the root-system. But the results were of course found very incomplete, this natural osmotic force of the tree not being sufficient to secure satisfactory impregnation even in the sapwood, and especially in the upper portion of the stem.

more easily operated on than logs that have been lying seasoning for some time, because then, and especially during the summer, the sap becomes slimy and more difficult to expel from the log. If logs cannot be impregnated at once, it is therefore best to store them in running water meanwhile. Spruce, Silver Fir, Beech, and softwoods (trees without any true heartwood) are much more thoroughly impregnated than Pine, Larch, Oak, Elm, or other trees with a distinct heartwood, in which only the sapwood (and not the hard kern) gets properly injected. Among Conifers, the more resinous the wood, the less thorough is the impregnation.

Further drawbacks to this method are (1) that logs with damaged bark cannot be treated thoroughly, and (2) that it is only suitable for telegraph and scaffolding poles, &c., which are to be used in the round, otherwise there is a decided loss in impregnating wood that falls into the slabs, which is at the same time the portion most thoroughly impregnated.

A variation of this method, customary in France for treating long logs, consists in sawing through most of the log at the middle, levering up the sawn part carefully, inserting a wedge-shaped horse-shoe-like band of caoutchouc or greased hemp, then letting the log down again to close on this firmly, and boring an auger-hole obliquely into the narrow chamber thus formed. On the nozzle of the gutta-percha tube from the vat being fixed in this hole and the impregnating fluid turned on, the pressure is exerted equally on both of the surfaces at each side of the narrow water-tight chamber formed, and simultaneous impregnation to right and left takes place more rapidly than if the long log were operated on from one end only.

Pfister's Process, patented in 1889, but really already discovered and applied by Rheinhard in 1884, is an Austrian modification of Boucherie's method, stronger pressure being obtained by the use of a force-pump.

The timber is impregnated in the forest as soon as possible after it is felled. The zinc chloride solution has a specific gravity of 1·01, and is forced into the thick end of the log by a force-pump. For this purpose an iron disc of suitable diameter (adjustable for various sizes of logs, and furnished with a cutting rim) is forced into the end of the log and secured by clamps and screws. The time required for this preliminary work is only 3 or 4 minutes for each log. The force-pump is connected by gutta-percha tubing with a vat on the ground containing the chloride of zinc solution. The pump is mounted on a movable framework, and can supply a pressure up to 10 atmospheres, or 142 lb. per square inch. After a pressure of 2 to 3 atmospheres has been maintained at the thick end of the log for a few minutes, the sap begins to exude at the opposite end; and finally a weak solution of zinc chloride comes through, showing that the operation has been completed. About 2¼ gallons of the solution are required per cubic foot of timber treated.

The process is rapid, being accomplished within from a few minutes up to 2 hours, according to the kind and size of log, but the solution does not appear to be so uniformly distributed as in the French method. Besides its rapidity, however, it has the additional advantages—(1) that the wood can be impregnated in the forest as soon as felled, before there is any chance of damaging the bark during transport, or of the sap becoming thick and slimy; (2) that with the much greater pressure obtainable, it is immaterial whether the timber be felled in winter, spring, or summer; and (3) that it is much cheaper for working on a large scale.

Buchner's method is more recent still. The wood is first boiled under pressure to get rid of resin and soluble constituents, then treated with a solution of chromic oxide salts, which both hardens and tans the woody fibres, and thus renders them immune from fungous attacks.

Chromic oxide or chrome green (Cr_2O_3), when strongly heated, becomes incandescent and turns into chromic acid or anhydride (CrO_3), which forms several classes of salts—(1) *chromates* (*e.g.*, chromate of lead, $PbCrO_3$), and (2) *bichromates* (*e.g.*, bichromate of potash, $K_2Cr_2O_7$). Chromic acid salts are all more or less poisonous, owing to their corrosive and oxidising action on organic tissues ; and this latter property is utilised in Buchner's method—just as it is likewise used in tanning leather.

4. **Electricity** has also been applied in a process invented by Nodon and Bretonneau, and known as **Senilising** or **Rapid-Ageing of Wood**, which is practised at Aubervilliers, in France. Impregnation takes place with a 20 per cent solution of magnesium sulphate, warmed to a temperature of 30° to 35° C. (86° to 95° Fahr.), and passed into the wood by means of an electric current, continued for from 7 to 14 hours, with a strength varying from 4 to 6 ampères, after which the wood is dried in the open air.

Another similar method, also used in France, and likewise known as **Senilising**, consists of a solution of 10 per cent borax and 5 per cent resin-soap, in place of the 20 per cent solution of magnesium sulphate. It is as yet too early for the results of these processes to have been properly tested.

Nodon and Bretonneau's process is simple. Vats of cement or wood are filled with the 20 per cent solution of crystallised magnesium sulphate ($MnSO_4$; 1 part sulphate of magnesium to 4 parts water), heated to from 86° to 95° Fahr., in which the wood is immersed. This bath may be used indefinitely, if strengthened with sufficient sulphate of magnesium. About once a month the bath is brought to the boiling-point in order to coagulate and separate the organic matter coming from the wood.

Before the solution of magnesium sulphate was employed, other baths experimented with were abandoned on account of the deposit of resinous matter on the surface of the wood, which had to be removed by scraping and washing, or on the fibre itself, which quickly blunted the wood-working tools.

In treating with magnesium sulphate, a continuous electric current of 110 volts is employed ; but instead of being directed through the wood always in the same direction, a change is made every hour or every two hours, or only half the necessary amount of electric power is passed from the top to the bottom, and then the other half from the bottom to the top.

The time taken in treatment varies from 7 to 14 hours, according to the nature, thickness, humidity, and resistance of the wood. But recently felled timber, in which the sap has not undergone modification, is easiest treated.

For this process it is claimed that under the action of the electric current new and sterilised mineral compounds are formed in the wood, and this in a way much more complete than by any other process, preventing the ulterior development of the germs which cause decomposition. Microscopic tests and analyses are also said to show that the action penetrates to the heart of the wood. The natural colour of the wood is not changed, but its resonance is said to be increased, so as to make it more suitable for musical instruments. By the electric treatment wood may be rendered non-inflammable if impregnated with ammoniacal salts in place of magnesium sulphate (see p. 563).

Comparative Cost and Results of the Different Methods of Impregnation.—No complete data appear to be available as to the relative cost of impregnation and the increase in durability obtainable by each different method. As regards the actual **Quantity of Antiseptic fluid absorbed**, when practised on any very large scale, this varies greatly according to the kind of wood, and its age and soundness. The more porous and the sounder a wood, the more of the impregnating substance it can absorb, because only sound fibres can be injected. But there exists a great difference between the quantity of antiseptic considered as forming a good practical impregnation and the furthest limit of absorption of which a piece of wood is capable under extraordinary pressure. Thus, sleepers of Beech have been known to absorb over 25 lb. and of Scots Pine over 22 lb. of creosote per cubic foot, which is far in excess of anything that is considered necessary in common practice. For *kyanising* with corrosive sublimate it takes 15 gallons of 10 per cent solution (*i.e.*, $1\frac{1}{2}$ lb. of chloride of mercury to 15 gallons of water, the strongest solution used) to impregnate 50 cub. ft. of wood, while for *creosoting* the same quantity 50 gallons of creosote (weighing 11 lb. a gallon) are required—*i.e.*, 1 gallon (or 11 lb.) is needed per cubic foot (though it can easily take up to 12 lb., according to Boulton). But these are of course only rough averages, because in Britain $2\frac{1}{2}$ gallons (or $27\frac{1}{2}$ lb.) of creosote are considered enough for an ordinary Scots Pine sleeper (9 ft. $\times$ 10 in. $\times$ 5 in. $= 3\frac{1}{8}$ cub. ft.), and this works out to $8\frac{4}{5}$ lb. per cubic foot. To give general averages, it may be said that Scots Pine for sleepers, fencing, and ordinary outdoor construction is sufficiently creosoted with from 8 to 10 lb. of the oil per cubic foot, while from 10 to 12 lb. or more are needed for bridge-piles and other wood to be used in water.

The statistics of Continental railways show great variations, classifiable as under for the three chief woods used as sleepers (of $3\frac{1}{2}$ cub. ft. each), and the two chief methods of impregnation :—

Sleepers of	Chloride of zinc solution.		Creosote.	
	Per sleeper.	Per cub. ft.	Per sleeper.	Per cubic foot.
	lb.	lb.	lb.	lb.
Oak	$16\frac{1}{2}$-26	5-$7\frac{1}{2}$	13-20	4-6
Beech	42-66	12-19	33-44	9-$12\frac{1}{2}$
Scots Pine . .	42-66	12-19	44-55	$12\frac{1}{2}$-$15\frac{1}{2}$
	Sulphate of copper solution.			
	Per sleeper.	Per cub. ft.		
Beech . . .	66 lb. of $1\frac{1}{2}$ per cent solution = 1 lb. sulphate of copper.	19 lb. of $1\frac{1}{2}$ per cent solution = $4\frac{1}{2}$ oz. sulphate of copper.	Some railway companies are satisfied with about 4 lb. of creosote per cubic foot, while others specify at least 5 to 6 lb. for Oak.	

The two kinds of wood which, owing to their structure, take creosote worst of all are Spruce and Larch; and this prevents the former being used as telegraph-posts.

If Norway Spruce could be creosoted it would be particularly suitable for telegraph poles, as it is usually very straight and shapely, and we have consequently from time to time endeavoured to creosote it; but even when the timber has been seasoned many months and put under the greatest obtainable pressure (say, 80 lb. to the square inch), the creosote has not penetrated more than half an inch below the surface of the wood. Mr. Havelock says, "Spruce takes the creosote worse than any timber I know," and by this I understand that his experience is the same as my own—viz., that the creosote can only be injected to a very limited extent. Spruce so creosoted would be more durable than untreated timber, but it would have a very short life as compared with properly creosoted redwood (*i.e.*, Scots Pine). . . . To satisfactorily creosote timber, about 10 lb. of oil per cubic foot should be injected ; Oak and Red Fir will very readily take this quantity, or a much larger quantity ; whereas Larch and Spruce, which will only absorb creosote to a depth of about half an inch, will take from 2½ to 6 lb. of oil per cubic foot, according to the age of the tree and the structure of the wood, and this quantity is insufficient to thoroughly preserve it (M. F. Roberts, G.P.O., London, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xviii., 1905, p. 224).

The remark made about Spruce in the above refers to tests made by Mr. Havelock, forester to the Earl of Yarborough, Brocklesby Park, Lincoln, to ascertain the absorption of creosote by different kinds of home-grown wood, naturally seasoned and injected under a pressure of 70 to 80 lb. per square inch (5 to 5½ atmospheres) for 3 to 4 hours. The creosote (sp. gr. 1·040, costing 2¼d. to 3½d. a gallon delivered at nearest station) was warmed by steam during use, and a vacuum of about 9 lb. was obtained in the cylinder before the oil was injected. The results of the tests on *posts*, which I have here worked out to show the absorption of creosote per cubic foot of the wood impregnated, were as follows :—

Posts of	Size of posts.	Weight before creosoting.	Weight after creosoting.	Total increase in weight.	Contents of each piece.	Weight of creosote absorbed by each piece.	Per cubic foot.	Kind of posts.
	ft. in. in.	lb.	lb.	lb.	cub. ft.	lb.	lb.	
10 Scots Pine . . .		366	531	165		16½	12·22	Scots Pine.
15 Spruce		504	678	174		$11\frac{6}{10}$	8·59	Spruce.
96 Larch (young trees)		2014	2749	735		$7\frac{6}{10}$	5·63	Larch.
4 Larch (older trees) .	6½ × 6 × 5	112	132	20	1·35	5	3·70	Larch.
7 Hornbeam . . .		259	350	91		13	9·63	Hornbeam.
14 Silver Fir		502	681	179		$12\frac{11}{14}$	9·43	Silver Fir.
18 Hornbeam . . .	5 × 6 × 4	624	853	229	⅝	12½	15·00	Hornbeam.
21 Silver Fir		1040	1186	146		7	3·60	Silver Fir.
30 Spruce	8 × 7 × 5	1290	1470	180	1·94	6	3·09	Spruce.
75 Larch		2823	3255	432		5¾	2·96	Larch.
3 Oak (sappy) . . .		205	234	29		10	5·15	Oak (sappy).

As regards **Cost of Impregnation**, the only comparative data on any large scale which are at hand are the statistics of German railway companies showing the average cost of treating sleepers (of 3½ cub. ft. each) to be (*in pence*) as follows (Schwackhöfer, *op. cit.*, p. 312) :—

Sleepers of	Sulphate o copper.		Chloride of zinc.		Chloride of mercury.		Chloride of zinc and creosote.		Creosote.	
	Per sleeper.	Per cub. ft.	Per sleeper.	Per cub. ft.	Per sleeper.	Per cub. ft.	Per sleeper.	Per cub. ft.	Per sleeper.	Per cub. ft.
	d.	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*	*d.*
Oak	...	...	5·16	1·47	4·80	1·37	...	...	11·16	3·29
Beech	4·08	1·16	6·36	1·82	7·20	2·05	10·80	3·08	...	...
Scots Pine .	...	...	...		...	...	...	...	...	...
Spruce and Silver Fir	2·76	0·79	3·0[illegible]	1·71	6·24	1·78	8·28	2·37	18·00	5·14
For cost of Naphthaline Process, see p. 560.										

As regards **Increased Durability**, this also varies largely—on the one hand, according to the impregnating substance, and to the pressure under which and

Fig. 262.

Transverse Section of Creosoted Scots Pine Wood-paving Block (Bethellised).

The blurred appearance is due to the creosote pressed into the tissue. The medullary rays and the resin-ducts are completely filled with creosote and resin.

Fig. 263.

Longitudinal Radial Section of same Block.

Showing the tissue, the medullary rays (filled with creosote), the autumn zone, and the bordered pits peculiar to the wood of the Pine.

the extent and depth to which it has been injected into the wood; and, on the other hand, according to the mechanical wear and tear, the variations in temperature and moisture to which it has been exposed, and the kind of soil or other substance in which it has been used (decay taking place much sooner in porous sand than in stiff clay or lime). Fair comparisons are therefore difficult to make. In the South of England, Scots Pine telegraph-posts impregnated with chloride of zinc, and erected in 1844, had all to be renewed by 1871, or within 27 years, while over 99 per cent of creosoted poles erected in 1848 were still serviceable in 1883, after 35 years' use (Preece). German and Austrian railway statistics give the following details for sleepers :—

Sleepers of	Not impregnated.	Impregnated with chloride of zinc.	Impregnated with creosote.		
			On main lines.	On sidings.	Total.
	Years.	Years.	Years.	Years.	Years.
Oak	12	17	18	7	25
Beech	3	7	20	10	30
Scots Pine . / Larch . . . (	6	16	15	5	20
In France, Beech sleepers treated with creosote are found to last for about 30 years.					

For *estate purposes* the durability of fencing-wood, &c., is increased at least threefold, and there is the other great advantage that softwoods of all kinds (Birch, Pine, Fir) can thus be utilised every bit as well as the more valuable hardwoods (Oak, Larch).

Details concerning British Creosote and Naphthaline Processes.

For estate purposes, in which the impregnation of the timber is in the hands of the forester, and is carried out with the aid of plant also used for saw-mill or other yard work, there can be no doubt that the simplest, most convenient, and most effective processes are injection with **creosote** or with **naphthaline** at a high temperature. And if the operations are extensive enough to make the extra expense profitable, it is useful to have a drying-chamber to dry the wood thoroughly immediately before injection.

By impregnating with either of these substances the durability of Scots Pine and of softwoods is increased at least threefold for fence and other posts, and for outside use generally (Figs. 262, 263). Uncreosoted Scots Pine fence-posts have only a life of about 5 to 7 years, but creosoted posts have often, in different parts of England and Scotland, been found to be still sound and serviceable after being from 15 to 20 years in use. And whereas small 3 × 3 in. posts of non-impregnated Beech will decay in 2, or at most 3 years, creosoted fence-stobs have in Scotland been found to be still almost perfect after 15 years. That *naphthaline* appears to be equally effective with *creosote* as an antiseptic (see p. 541) was proved by exhibits of Scots Pine, Spruce, Beech, and Birch, at the Royal Agricultural Society of England's

Show in 1904, which all appeared perfectly sound after having been in use for 8 to 14½ years.[1]

For creosoting, the plant required of course varies according to the quantity of wood to be treated. For small quantities of fencing material, &c., *immersion in tanks or open boilers* is sufficient; while for impregnating the larger quantities of wood required on great estates, or for work on a large commercial scale (such as pitwood, sleepers, &c.), *injection under pressure in closed cylinders* is necessary, with a much more expensive plant, in order to obtain deeper and more thorough impregnation.

1. **Creosoting by Immersion in Open Tanks or Boilers.**—For small quantities of wood the simplest and cheapest method is to immerse the timber (preferably just after it has been warmed, if convenient, to expel as much of the moisture as practicable) into an open iron tank containing hot creosote (kept well below its boiling-point, 365° Fahr.). Treated thus, Scots Pine and softwoods will absorb about 8 to 9 lb. of creosote per cubic foot, which is sufficient to act as a good preservative.

While the simplest form of an open tank with a fire below is mostly in use for such rough material as hop-poles and hurdle-wood, improved forms of open boiler and furnace are preferable for treating converted timber. The construction and working of such a small, inexpensive creosoting plant in Ayrshire is described by Mr. G. Leven, forester on the Auchencruive estate, in *Trans. Roy. Scot. Arbor. Socy.*, vol. xvii. part i., 1903, pp. 93–98 (see Figs. 264, 265).

In this particular case, advantage being taken of a chimney-stalk erected in connection with a saw-mill, a second-hand egg-end boiler, about 24 ft. long by 3½ ft. in diameter, with an opening cut along the upper side, was built up with firebricks and fireclay, with a cement coping to within 1 ft. of the opening. The boiler rests on two butts or bridges, with a furnace and flue running underneath, and the draught is regulated by a damper at the foot of the chimney-stalk. The furnace is 6 ft. long, so as to burn slabs and other rough wood. At the end opposite the furnace, and from the lowest point of the boiler, a pipe with valve attached discharges surplus oil into two cow-boilers (of 200 gallons capacity each), connected by a syphon and surmounted with a hand-pump to return the oil to the boiler. The cost of the plant, including all material and labour, was £55.

The process consists of placing the timber in the boiler, covering it with creosote, raising the temperature slowly to a little over 212° Fahr. (the boiling-point of water), and keeping up that heat for 48 hours, when the fire is extinguished and the oil is run off while hot, in order to dry up what adheres to the surface of the wood. The timber is removed when cool enough to handle.

Most of the wood creosoted consists of fencing-posts and palings, all kinds of wood being used for this purpose. Fast grown, immature thinnings thus become practically as useful as good Larch. All kinds of wood, except Larch, are creosoted, though of course the different kinds do not absorb the oil to the same extent. Beech takes much more than any other kind, while practically the whole of the other broad-leaved kinds absorb less than the Conifers. Open-grained wood

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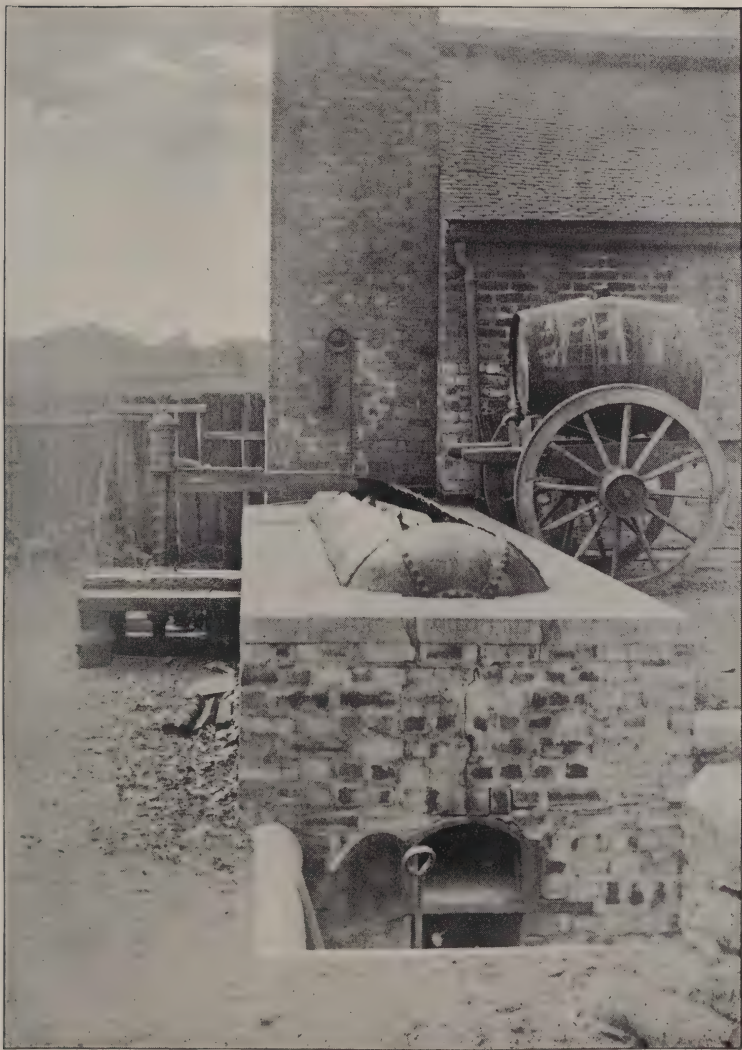
[1] Stobs preserved by the Naphthaline process on the Duke of Buccleuch's Drumlanrig estate, Dumfriesshire:—

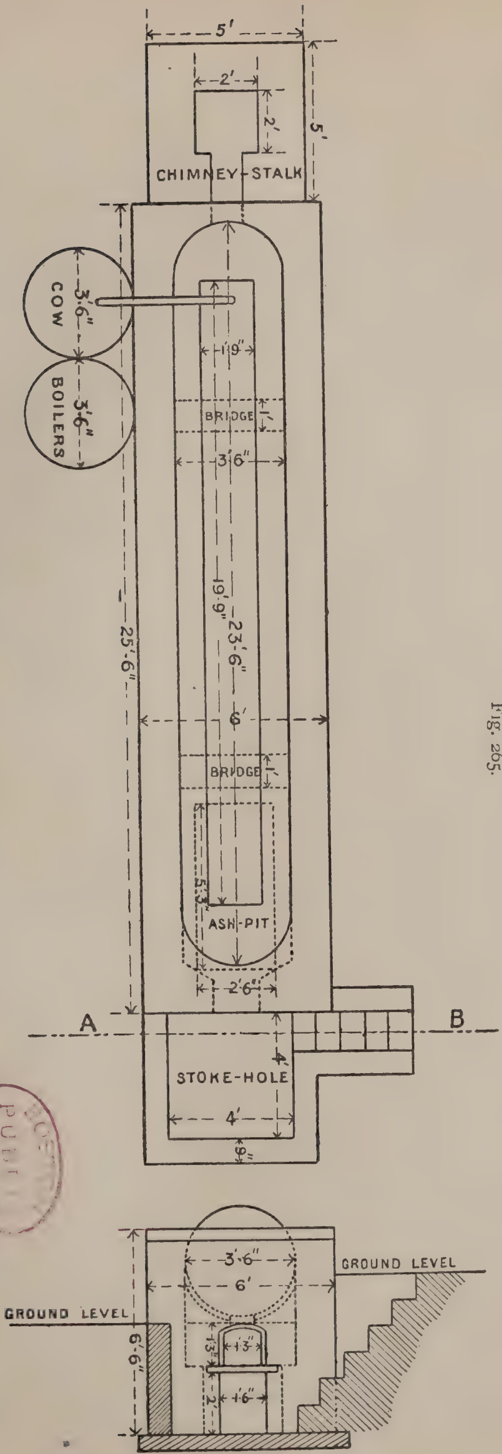
(1) Six Birch stobs, 14½ years in use, taken from fence erected in October 1889.
(2) Four Scots Pine stobs, 10 years in use, ,, ,, May 1894.
(3) Four Spruce stobs, ,, ,, ,, ,, ,, ,,
(4) Four Beech stobs, 8 years in use, ,, ,, ,, 1896.

Fig. 264.



Photograph of the Open-Boiler Creosoting Plant shown on accompanying Plan.

Fig. 265.



SECTION ON A..B.

SCALE 1 INCH = 6 FT.

Plan of cheap and simple Creosoting Plant for Estate purposes.

of quick growth can sometimes absorb twice as much as close-grained, slow-grown wood. The degree of seasoning also affects absorption in most kinds of wood; but thorough seasoning has not been found essential.

The creosote costs 2¾d. per gallon at the tar-distilling works, and is brought in a barrel mounted on wheels. The sawn stobs and palings, seasoned as far as circumstances permit, are stacked near the boiler and treated in succession, wood being packed as closely as possible into the boiler, and covered with creosote. The fire is then started and kept going until the temperature reaches a little above 212° F., when the moisture in the timber is driven off in the form of vapour, and creosote takes its place in the wood-tissues.

Here, assuming a uniform absorption of one gallon (or 10 to 11 lb.) per cubic foot of wood, the cost of treatment, with creosote at 2¾d. per gallon, amounts to about 1d. per stob of 4½ ft. × 3 in. × 3 in. ($=\frac{9}{32}$ cub. foot.—*i.e.*, just under 4d. per cubic foot), and to somewhat under 9d. per 100 lineal feet of paling rails, 4 in. × 1 in. But absorption is not uniform. It varies with the kind and quality of the wood, so that the average cost works out at 1½d. per stob-fence (or nearly 6d. per cubic foot), and 1s. 3d. per 100 ft. of paling, including the whole expense of fuel, labour, and plant.

On the Sundrum estate, in Ayrshire, the results obtained by a similar process usually employed for impregnating stobs show that green Beechwood becomes fully impregnated to the centre. But the result is much less satisfactory with dry Beech, which after impregnation becomes hard and brittle; while Spruce, seasoned for at least a year, is much better than dry Spruce. Larch and Oak do not absorb the oil well, but are very durable without treatment. Creosoted Beech stobs will last 20 years, and are as good as Larch; but untreated Beech will not last for more than 2 years. Four barrels, each holding 120 lb. of creosote, costing 4d. a gallon, will suffice for 750 stobs (of 5 ft. × 3 in. × 3 in. $=\frac{5}{16}$ cub. ft. each); each therefore absorbs about 0·65 gallons of oil, costing about 2½d. Fuel and labour are about 1d., and bring the total per stob to 3½d., exclusive of interest on and wear and tear of the plant, costing about £50 (*Trans. Roy. Scot. Arbor. Socy.*, 1901, p. 525).

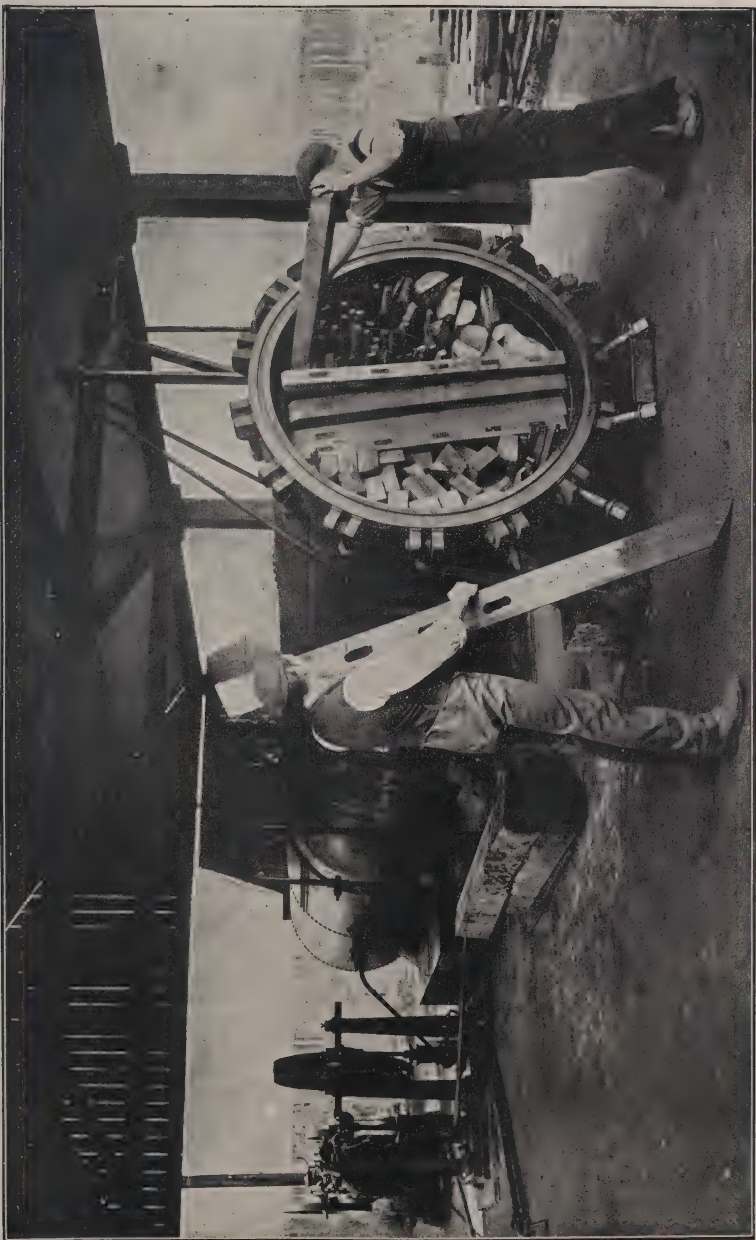
2. **Creosoting in Closed Cylinders, with Injection under Pressure,** is necessary to ensure thorough impregnation of hardwoods, and to enable as much as 10 to 12 lb. per cubic foot of the oil to be injected into softwoods.

In this case the creosoted timber is packed as closely as possible in an iron cylinder with closed ends, the air is exhausted by an air-pump, and creosote heated to 120° Fahr. is admitted and injected into the wood under a pressure of 10 to 15 atmospheres (142 to 210 lb. per square inch) by the use of a forcing-pump (see p. 545), until the required quantity has been absorbed, as can be ascertained by a gauge attached to the creosote-tank.

Such a process, the most suitable for large estates, requires a special plant costing about £300. That in use on the Duke of Portland's Welbeck estate (Fig. 266) consists of a pressure-cylinder 30 ft. long and 4 ft. 8 in. diameter, containing a charge of about 450 cub. ft. of timber, and a set of self-contained pumps. As the cost of the cylinder and pumps was £250, the whole first cost of a similar plant would probably, including erection, be about £300. Its working is as follows:—

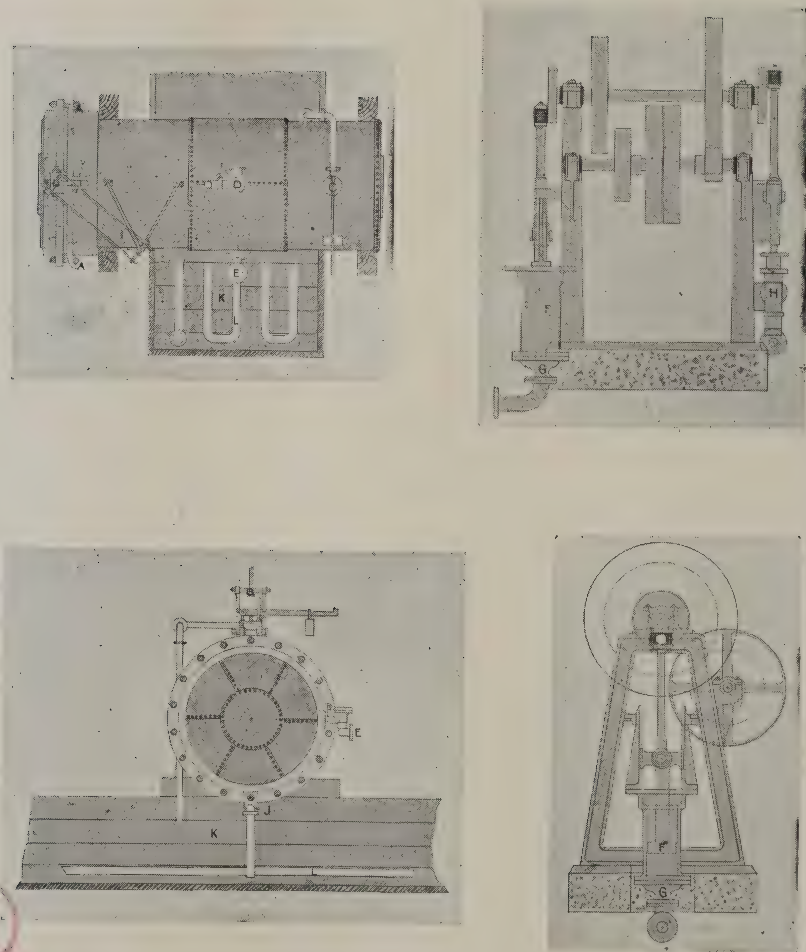
The timber being admitted and the door closed, the air is exhausted and the oil forced in. A small 2½ horse-power portable engine is used, and pumping is continued until the gauge registers 100 lb. pressure to the square inch, which will be in about three hours. When the door is unscrewed the superfluous creosote drains out into the storage tank. The timber is taken out next day, by which time it will be better to handle. Mr. Michie,

Fig. 266.



Creosoting Plant in use on the Duke of Portland's Estate at Welbeck.

Fig. 267.



Creosoting Plant for Large Estates.

the forester at Welbeck, informs me that the cost of creosoting 600 fencing-rails, 9 ft. long, is £2, 4s. 6d., allowing for 90 gallons of creosote at 3d. and all labour, but taking no account of the original cost of the plant. In the case of very soft woods as many as 140 gallons might be required (R. Anderson, in *Jour. Roy. Agric. Socy. of Eng.*, vol. lxiv., 1903).

In actual practice the total cost of creosoting in closed cylinders containing from 300 to 450 cub. ft. of converted timber varies from below 3d. to about 4d. per cubic foot, according to kind and quality of wood treated. Where creosoting is done on a large scale, an allowance of 3d. to 4d. per cubic foot gives a margin of profit, and this is the usual charge for treating customers' wood at large works.

Any one desirous of detailed information regarding the cost of plant for creosoting any given amount of timber at each charge of the cylinder should of course apply to such engineers as Mr. R. G. Morton of Errol, Mr. R. Melvin of Alloa, or other firms making this a specialty. But it may perhaps be of use to note here that in the *Trans. of High. and Agric. Socy. of Scot.* for 1898, Mr. D. F. Mackenzie gives the following specification of a creosoting plant for estate purposes on a large scale (Fig. 267):—Including receiver and its fittings, air- and-force-pumps, steam-coil, and all connections fitted up complete, the plant costs about £280—exclusive of cartage from nearest railway station, manual labour for lifting and handling, and timber for the supporting blocks and the creosote-tank, and also exclusive of the cost of any necessary alterations to existing buildings or to any 8 to 10 horse-power estate saw-mill or farm steam-engine in connection with which it is intended to be used. But the driving-power can be quite as well provided by a travelling steam-engine, or water-power can be utilised to drive the air- and force-pumps. The closed cylinder is 18 ft. long (19 ft. over ends), and 5½ ft. in diameter, so that it will contain about 300 cub. ft. of timber at each charge, and take in timber nearly 18 ft. long. It requires 2 men, who can easily work one charge each day, so that it could creosote up to about 90 to 95,000 cub. ft. annually if in constant use. The shells of the cylinder should be of riveted steel plates, and the door-joint formed of two heavy cast-iron rings riveted to the barrel, with a projecting fillet on the face of the end-ring fitting into a groove in the face of the other, to form a tight joint. When the door is closed, these rings are drawn tight by eighteen steel bolts, with an eye in the end, and having cross-pins fitted into snags (A) cast on the barrel-ring. The door is carried by a crane (I) fixed to the side of the shell, stepped into a stone in the ground, and stayed at the top to the cylinder. The fittings of the cylinder consist of a lever safety-valve (C), with a connection for returning overflow oil into the creosote-tank, a vacuum-gauge, a pressure-gauge, and a draining-cock with a pipe (J) from the bottom of the cylinder of the tank (K). The valve of the air exhaust-pipe (D) is placed at the top of the cylinder, and the pipe is carried up about 4 ft. to prevent creosote being drawn into the air-pump. The charge-pipe from the force-pump is connected to a valve (E) fixed on the side of the cylinder. The air- and force-pumps and the gearing are driven by a belt and pulleys. The cast-iron chamber of the air-pump (F) should be 8 in. diameter, and allow of a 10 in. stroke, and the bucket should be fitted with a brass valve and seat. The foot-valve (G) of the air-pump should also be of brass, but set in a separate casting to be easily accessible. The force-pump (H) should be 2½ in. diameter, and have a 10-in. stroke, with a solid cast-iron plunger and brass valves. Both pumps should be fixed to cast-iron frames secured with a cast-iron sole-plate ; and the frames should also carry the guides for the pumps and the plummer-blocks for the gearing-shafts. The pumps are intended to be driven from the main-shaft on the top of the frames, which would be driven by spur-wheels and pinions from the counter-shaft carrying the driving-pulleys ; and each pump can be ungeared as required. The cylinder should be supported by blocks of timber at the required height, and the wooden creosote-tank (K) sunk in the ground below it. In the tank there should be a coil of 3-inch steam-piping (L) with inlet and blow-through cocks to heat the creosote and make it quite fluid.

The Naphthaline Process was invented and patented by the late Mr. Henry Darroch, coalmaster, Falkirk, and was first used in connection with his collieries. Naphthaline ($C_{10}H_8$) is a transparent, unctuous, solid substance obtained from coal-tar. It melts at 176°, and boils at 422° Fahr., but sublimes readily at a much lower temperature. It was first used for impregnating in 1882, and is now employed with excellent results on several large Scottish estates (see pp. 544 and 546). The following description of the process is based on notes kindly supplied to me by Mr. A. Menzies of the Drumlanrig estate (see Fig. 268):—

The **Crude Naphthaline**, also known as **Creosote Salts**, is put in bags into a tank, 21 ft. long by 5 ft. diameter, which is heated with steam conveyed by a pipe from a small boiler about 20 yards off. Great care is necessary owing to the high inflammability of the naphthaline. Not only is the boiler kept well away from the tank, but the stove for heating the boiler is carefully isolated. All kinds of wood are treated, but chiefly the less durable kinds, such as Scots Pine, Birch, Spruce, Alder, Lime, Silver Fir, &c. The wood must be thoroughly seasoned; and the drier the timber, the better is the result of the treatment.

The tank is packed with fence-stobs along with about 2 tons of naphthaline, and steam is applied to raise the heat of the tank to over 212°. It is kept at this temperature for 24 hours and then allowed to cool slightly, so that the stobs can be taken out. A fresh lot is then put in, along with a few hundredweights of naphthaline to replace the quantity already absorbed. Then the process of superheating is repeated for 24 hours, and so on.

The cost of a tank and boiler is about £120—more or less, according to size; while the average cost of impregnating tank-loads of stobs of mixed hard and soft woods comes to about 3d. per cubic foot. The crude naphthaline costs 35s. a ton delivered at the nearest railway station.

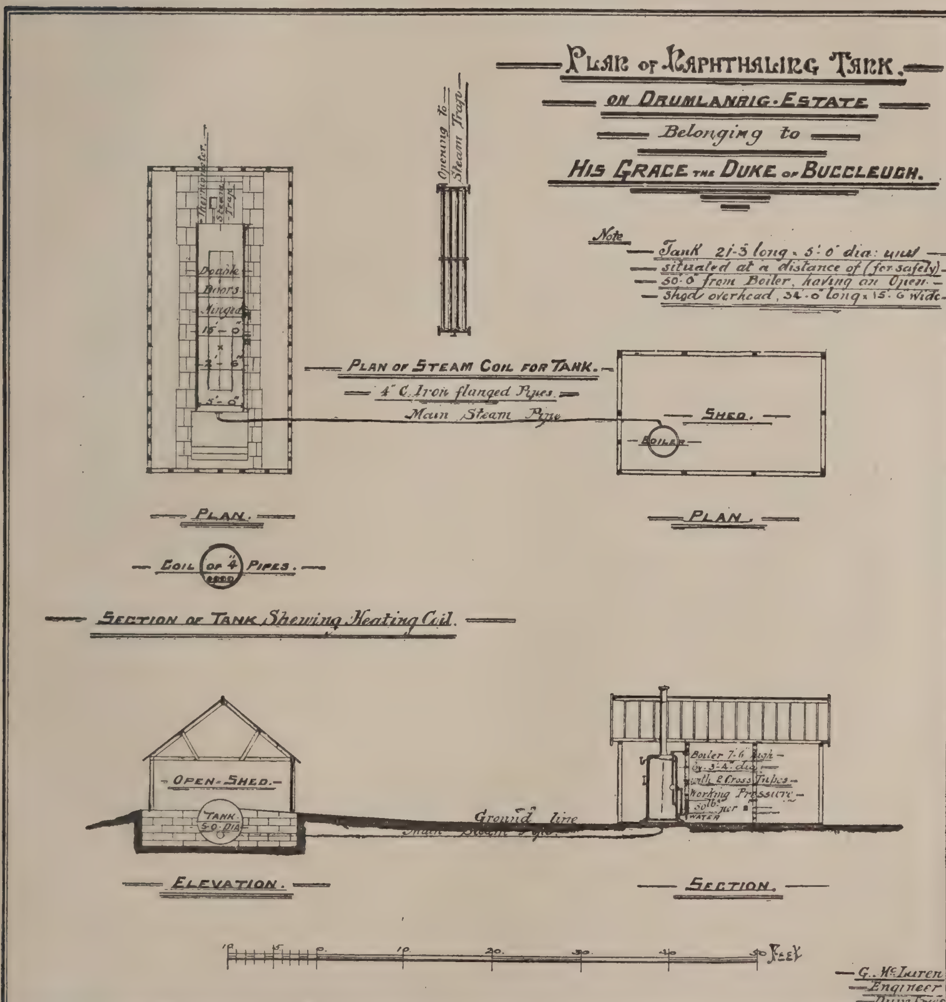
The absorptive power of the dry wood varies considerably, being greatest in Scots Pine, Beech, Birch, Alder, and Lime, and least in Oak, Elm, Spruce, Silver Fir, and Larch. In January 1905, Mr. Menzies kindly weighed for me eleven well-seasoned stobs (5 ft. × 3 in. × 3 in. = $\frac{5}{16}$, or 0·3125 cub. ft. each) of different kinds of wood before and after treatment, and the results therefrom deducible are as follows:—

Kind of wood.	Weight before treatment.		Weight after treatment.		Quantity of naphthaline absorbed.		
					Per stob.	Per cub. ft.	Percentage of original dry weight.
	lb.	Sp. gr.	lb.	Sp. gr.	lb.	lb.	Per cent.
Scots Pine . .	12	0·61	18½	0·94	6½	20·8	54
Beech . . .	14½	0·74	19½	1·00	5	16·0	34½
Birch . . .	13	0·66	17½	0·89	4½	14·4	34½
Alder . . .	12	0·61	16	0·81	4	12·8	33⅓
Douglas Fir . .	8½	0·43	12	0·61	3½	11·2	41
Ash . . .	14½	0·74	16½	0·84	2	6·4	13¾
Silver Fir . .	11	0·56	12½	0·64	1½	4·8	13⅔
Oak . . .	17	0·87	18½	0·94	1½	4·8	8¾
Spruce . .	9	0·46	10	0·51	1	3·2	11
Larch . . .	12	0·61	13	0·66	1	3·2	8⅓
Elm . . .	14	0·71	15	0·77	1	3·2	7⅐

The average actual absorption in the above cases is here about 9 lb. per cubic foot.

The fire-proofing of wood is also carried out by means of impregnation. No process has yet been discovered for rendering wood *incombustible*, but at any rate it can be made *non-inflammable.* If no oxygen be allowed to come in contact with it, all wood becomes carbonised at a temperature of 300° C. (572° F.); and the presence of borates, silicates, &c., imparts to the wood the property of only smouldering, and not breaking out into flame; while such non-inflammable tendency is increased if volatile salts (such as certain ammoni-

Fig. 268.



acal salts) decomposable by heat but not combustible, be mingled in sufficient proportion with other gases which do not burn easily, in such a way that the wood is calcined without bursting into flame.

Numerous processes have been recommended for rendering wood non-inflammable, some consisting in external applications, and others in injection of saline solutions under pressure. Superficial applications are at best only a slight preservative from flame, and their power of resistance to fire is only of short duration, as they scale off or are rapidly reduced to ashes.

The fire-proofing may take place under one or other of four different kinds of processes—(1) by *coating superficially*, like paint; (2) by *immersion* and imbibition; (3) by *impregnating under pressure;* and (4) by *electricity*.

1. **For coating superficially** three of the best compositions are—(1) a mixture of 2 parts hot sodium silicate to 1 part Spanish white and 2 parts glue; (2) for *first coat*, 1 part aluminium sulphate and 5 parts hot water; and for *second coat*, 1 part liquid sodium silicate and 2 parts hot water; (3) *first application*, two coats hot of 1 part sodium silicate and 2 parts water; *second application*, two coatings of 8 parts gelatine white and 3 parts boiling water; work up with 5 parts asbestos, 3 parts borax, and 1 part boracic acid.

Alkali-Silicate is often used for fire-proofing wood. The silicate, which is soluble in boiling water, is usually sold in 33 and 66 per cent solutions. Five or six coats of it are required, beginning with a 15 per cent solution, and ending with the full strength of 66 per cent, each coating being applied after the previous one has dried thoroughly. It dries quickly, and produces a glass-like surface; but though it prevents the wood from bursting into flame, and retards even the process of charring, yet it has no antiseptic action preserving wood from decomposition, decay, and rot. In fact, through its strong alkaline reaction it weakens the woody-fibres; and it has the further disadvantage of decomposing easily under the action of the carbonic acid in the air, alkali-carbonate being formed which is very soluble in water. The process is therefore unsuitable for outdoor woodwork; and even on interior work the glassy coating gradually becomes rough, scales off, and is then ineffective from the above cause. Besides alkali-silicate, various other substances (silicates and borates) are also used to render woodwork fire-proof, but most of them have the drawback of being hygroscopic, and of gradually being eliminated from the wood treated with them.

Oil paint is made non-inflammable by adding phosphate of ammonia and borax in the form of impalpable powders; while asbestos paint and mortar made of plaster and asbestos are also used, and give limited security from fire.

2. For immersion or imbibition a good solution is ammonium phosphate 4 oz., and boracic acid $\frac{2}{5}$ oz. per quart of water; or ammonium sulphate $5\frac{1}{2}$ oz., sodium borate $\frac{1}{2}$ oz., and boracic acid $\frac{1}{4}$ oz. per quart. This can also be used superficially, and for each of these formulæ two coats are necessary.

3. **Impregnation under strong pressure** has been tried with various preserving solutions, but has still the drawback of fire-proofing only the outer part of the wood to a limited depth. The process consists in removing as much of the sap as possible under steam pressure, and then injecting with a force-pump non-inflammable solutions, generally composed of sulphate or phosphate of ammonia, boracic acid, or alkaline borate.

Payne's Process is one of the best of these methods. It consists in first of all impregnating the wood while in a vacuum with a strong sulphate of iron solution, then injecting it under pressure with a solution of sulphate of lime or some alkaline carbonate to make the iron insoluble.

Timber treated by **Powell's Saccharine Process** (see p. 547) can also be rendered non-flammable and fire-resisting, by the addition of certain substances to the saccharine matter used for impregnating. These additional substances are a trade secret; but alum is probably one of them.

4. **Fire-proofing by Electricity.**—For Nodon and Bretonneau's electric process it is claimed that fire-proofing is much more regular throughout the whole of the wood than by injection under pressure. The extent of the fire-proofing depends on the strength of the bath and the duration of treatment.

The process of impregnating the wood with the fire-proofing salts is much the same as that already described for senilising or rapid-ageing (see p. 552), the only real difference being that ammoniacal salts are here used in place of sulphate of magnesium. The wood to be treated should be green, and not too hard.

The whole process lasts 48 hours, but at the end of the first 24 hours the wood is turned upside down to reverse the current. After the full 24 hours' treatment the wood will have absorbed from 15 to 20 per cent of its weight of the ammoniacal salts into its tissues. If, after drying, the wood is submitted to the action of fire, the ammoniacal salts melt, and as the heat increases, the fibres carbonise slowly, while the gases produced by the decomposition of the salts prevent the fibres bursting into flame.

Wood thus treated can be easily worked, glued, painted, or varnished to keep out moisture and prevent the ammoniacal salts decomposing.

The cost is said to be less than that of other methods of fire-proofing, and the wood treated can be employed for numerous purposes, especially on war-ships, where metal has hitherto been used.

CHAPTER V.

WOODLAND INDUSTRIES: ESTATE SAW-MILLS, PREPARATION OF WOOD-PULP AND CELLULOSE, CHARCOAL-MAKING, RESIN-TAPPING, &c.

In countries where there are very extensive forests, many important industries have sprung up which require woodland produce for their raw material. And even though the British forester will usually only be called on to work small saw-mills for supplying estate timber and other local requirements, or for conversion so as to reduce the cost of transport to the nearest available timber market, yet it is desirable that he should also know something about the other woodland industries, so that he may turn such knowledge to practical use should occasion perhaps offer—such as in dealing with extensive windfalls, or with large thinnings of small dimensions, &c., for which, in their rough and raw condition, no local demand exists. These woodland industries will therefore be considered in the following order:—(1) *Estate Saw-mills*, (2) *Preparation of Wood-pulp and Cellulose*, (3) *Charcoal-making*, (4) *Utilisation of small Waste-wood and Sawdust*, (5) *making Potashes, and* (6) *Resin-tapping*.

I. **Estate Saw-mills.**[1]—Wherever there are large woodlands it will usually be found profitable to reduce the bulk of the logs for transport by conversion to a greater or less extent, even if it goes no further than cross-cutting to standard lengths (*e.g.*, as in pitwood). The right of converting on the spot, with a small temporary saw-mill worked by a portable steam-engine, is indeed sometimes made a condition of purchase by the buyer, who is thus able to get rid of comparatively useless slabs, &c. And if these latter are marketable locally, this increases the possible margin of his profit, and he can then afford to give a better price for the wood.

On most large properties it is generally found profitable to have a permanent estate saw-mill located at some convenient centre, although even on large estates there will rarely be either a sufficient supply of home-grown wood, or a sufficient demand throughout the estate itself to keep any large saw-mill at work all the year round. Such estate mills, however, often supply other than merely estate requirements in rural districts distant from ordinary commercial saw-mills. And if this combination of converting as well as growing the timber were further developed in rural districts not well served by

[1] Those specially interested in timber-conversion should consult *English Timber and its Economical Conversion*, by "Acorn"; *Handbook of Saw-Mill and Wood-Converting Machinery*, by M. P. Bale; and *Modern Wood-Working Machinery*, by J. S. Ransome.

saw-mills, it would be to the advantage of both the landowner and his tenants, and of the whole country-side. Timber-growing landowners who establish permanent saw-mills with good modern machinery generally find their enterprise profitable and the benefits appreciated by the surrounding population, and in such cases the main inconvenience felt is that sufficient supplies of home-grown wood are not obtainable locally to keep the mill continuously at work up to its full capacity. But even simple, old-fashioned saw-mills worked by water-power, or in connection with a portable steam-engine used for other estate purposes, can be used with profit and advantage.

Whether it is better for the timber-grower to be his own manufacturer is another question, which admits of no general answer. Whether, and to what extent, conversion may prove profitable often mainly depends on the man in charge of the business; and it is therefore fairest that he should be allowed, over and above his regular salary, a bonus of a certain small percentage on the net profit earned after payment of all expenses, including a fair allowance for wear and tear of machinery. When there has been heavy windfall among Conifers, speedy conversion by one means or another is often the only way of averting a heavy loss. But, on the other hand, it will seldom prove profitable to make falls of timber in the woods simply for the express purpose of supplying the saw-mill, and merely to keep it uninterruptedly at work. It is not true economy to manage the woods in the interests of the saw-mill; and the work of conversion should be subordinated to the more important considerations affecting the capital locked up in the woodlands.

Estate saw-mills are usually worked either by water-power or by steam, as electricity is as yet neither cheap enough nor sufficiently simple. Where sufficient water-power is obtainable, this is the cheapest and simplest method of conversion. In this case, the saw-mill is located wherever the water-power can be best utilised; but otherwise it is placed, for convenience, near the home-farm workshops, where the mill can be driven either by a stationary steam-engine used for other yard-work (pumping water, generating electricity, threshing, chaff-cutting, &c.), or by a traction-engine, which can also be used to move the sawing-machinery from place to place as required, and to transport the sawn timber after conversion. Due regard has of course to be given not only to the supply of the rough logs, but also to the removal of the sawn timber after conversion.

Where sufficient wood can be supplied from a reasonable distance a stationary saw-mill is best, because this gives the fullest opportunities of converting slabs, tops and ends, and other small refuse into small staves, boards for packing-boxes, railway keys, and any other articles of small dimensions which can be disposed of locally with profit. The best chance is here also given of disposing of firewood, or for dry distillation, or for using the sawdust as litter and manure, &c. But where the woods are distant and comparatively small, the use of a traction-engine (see p. 575) and a portable saw-bench may be the cheapest, and in fact the only profitable, way of converting. It is simply a question as to whether it is better to bring the timber to the mill, or to take the machinery to where the timber is; and that depends entirely on local circumstances in each case. In general, a stationary saw-mill worked by water or by steam is the more profitable, if the logs can be supplied from within about 2 miles; but otherwise portable machinery is usually preferable, even though it is more liable to get out of order than fixed machinery.

The saving that can thus be effected in the haulage of the dead-weight of green timber may easily be roughly estimated from the data given elsewhere (pp. 436-439, and 511); and unless the stems can be stripped for tanning-bark, the weight of the rough, thick bark of trees comes when green to from $1\frac{1}{2}$ to $2\frac{1}{2}$ cwt. per ton of gross weight, or about 10-15 per cent of the whole weight of the timber in log; while the actual wood amounts to from $17\frac{1}{2}$ to $18\frac{1}{2}$ cwt., or about 85-90 per cent, and a considerable proportion of this is sapwood, the least durable and useful part of the log. Hence the desirability of economy in transport.

As regards the question of profit on conversion, it must be recollected that the loss by wastage usually varies from about 30 to 40, and sometimes even 50 per cent.[1] Thus, whatever price is obtainable for the timber on the fall, will have to be increased by about one-third or more for each cubic foot of converted timber, *merely in order to avoid a loss*, owing to the extra cost of transport, handling, sawing, wear and tear of machinery, &c., on the one hand, and of loss in conversion on the other—and this latter, notwithstanding the fact that log-measurement (square-of-quarter-girth) expressly allows $21\frac{1}{2}$ per cent for wastage, while converted wood is sold by actual cubic contents. It does not therefore follow that conversion is profitable merely because 1s. 6d. per cubic foot can be obtained, say, for converted Larch at the saw-mill, while only 1s. is obtainable for the logs on the fall. Thus, if local experience shows that every 150 cub. ft. log-measurement of timber, saleable on the fall at 1s. per cubic foot, yield, say, about 120 cub. ft. of planks, &c., converted at a total average outlay of perhaps 40s. for carting, handling, conversion, and mill-sundries, then 1s. 7d. per cubic foot for the converted timber will simply equalise matters, without showing any profit, and only the slabs and waste wood will be on hand for the extra trouble and expense; but anything beyond 1s. 7d. per cubic foot, as well as anything obtainable by the sale, conversion, or use of the slabs, as firewood, &c., will represent payment for the extra trouble, and profit on the transaction.

Saw-mills and saws may vary from very simple contrivances to complicated and very powerful machinery. The motive-force may either be—(1) **water-power**, driving (*a*) ordinary *vertical water-wheels*, or (*b*) *horizontal water-wheels* (*turbines*), or else (2) **steam-power**; and the sawing-machinery thereby set in motion may control either (*a*) *vertical frame-saws*, (*b*) *circular saws*, (*c*) *horizontal saws*, (*d*) *continuous endless band-saws*, or (*e*) *cylindrical* or *barrel-shaped saws*. **Vertical water-wheels** are called *overshot* or *undershot*, according as the water-pressure is applied *above* or *below* the middle of the wheel, while *breast-wheels* receive it at about the middle of the wheel. **Turbines** are horizontal water-wheels with vertical axes, which receive and discharge the water round their circumference. The best turbines can

[1] In supplying contracts for many hundreds of thousands of narrow-gauge railway sleepers from exceptionally fine, round, large *Pyingado* (ironwood) logs in Burma, I found the average out-turn in sleepers to be about 66 per cent of the total actual contents (length × mean superficies), with many fair-sized slabs left on hand.

utilise the water-power up to a maximum of 80 per cent (Unwin) in normal conditions of working.

With a fall varying from 10 to 70 ft., and giving 3 to 25 cub. ft. of water per second, a wheel can be made to act by the mere weight of the water. If the variation of head-water does not exceed 2 ft., an overshot wheel can be used; but with a greater variation of head-water level, a pitch-back or high-breast wheel is better. The ordinary undershot wheel develops only about 2 per cent of the work of the water. For woodland saw-mills the choice usually lies only between *overshot-wheels,* where there is plenty of water, and *turbines,* where the quantity of water is limited, but a good fall can be provided to increase its force.

The sawing of timber by hand must, like charcoal-burning, be one of the very oldest of woodland industries. Saws were run by windmill-power as early as the thirteenth century; and the use of water-power soon followed, as water-power saw-mills are known to have been employed in Germany in 1322. The first British saw-mill that is known was erected in 1634 in America (then a colony), at the falls of the Piscataqua (between Maine and New Hampshire). An attempt was made to establish one in England in 1663, but had to be abandoned owing to the opposition of the hand-sawyers; and when the first was afterwards erected at Limehouse in 1768, it was soon destroyed by a mob. As our American colonies then supplied England with much of the timber already even then required to be imported, saw-milling soon there became an important industry. The original, simple form of mill worked by water-power consisted in a single saw attached by a long arm (*pitman*) to a crank on the wheel-shaft at the lower end, and by a heavy frame (*gate*) above, running in wooden slides upon two stout posts crossed above by a beam connecting the two sides of the mill-frame. At each turn of the mill-wheel the saw made a downward and an upward stroke, each varying very slightly from the vertical. The saw was set with teeth pointing downwards, and the downward stroke, which brought the saw slightly forward, was that which cut and tore the particles of wood resisting the passage of the saw. During the upward stroke the saw was carried slightly backwards, and in the meantime the log (held firmly in position by a *dog* or clamp on each side) was pushed forward a little in readiness to meet the cutting-edge of the saw with a fresh point of contact. By the slope thus given to the saw, the work of cutting was distributed all over its face in place of being confined to the first teeth coming in contact with the wood, as would be the case if the saw simply moved up and down perpendicularly. The mill-carriage (*travelling table*) on which the log lay was moved forward towards the saw by a rack and pinion worked by a feed-wheel, and the daily conversion was 500 to 1500 superficial feet.

The first great advance was to introduce a *gang* of two or more saws in the frame, and after that improvements have ever since been gradually introduced into the form, size, and mechanism of the saws and mode of suspending them, and into the driving-power and cutting-capacity of the machinery. Just as the single *frame-* or *gate-saw* worked by simple machinery was a decided advance on the older *pit-saw* worked by hand, so too a further improvement was made by the introduction of the *gang-saw* or modern *frame-saw* fitted with *multiple saws,* having shorter and thinner blades, which work more quickly, though with a shorter stroke, and cause less wastage in sawdust. A later improvement was the *muley-saw,* suspended without strain upon a "pitman" beneath, having its upper end hung in slides pendant from a heavy beam above, thus dispensing with the heavy gate and posts of the older saw-frame. But the muley has now in turn given place to the quicker-working circular saw where very large quantities of timber have to be converted; and in many large lumbering districts the endless band-saw is preferred even to the circular saw. A great impulse was of course given towards improvements after the introduction of steam as a motive-power (about 1855) and of iron for constructive purposes. A good account of saw-mills up to 1886 is given by Hotchkiss in an article on *Saws* in *Encyc. Brit.,* 9th edit., 1886, vol. xxi. p. 344; but the modern development of horizontal frame-saws and endless vertical and horizontal band-saws has taken place chiefly within these last twenty years.

Mill-saws may vary considerably in diameter, thickness, and quality. They must be strong to stand the heavy thrust they sustain, and their thickness or

gauge is classed according to the different sizes of wire; thus a 10-gauge (10 B.W.G.) is thicker than a 12-gauge (12 B.W.G.). In large saw-mills gang- or multiple-saws are seldom thicker than 14-gauge, and can even be successfully worked as thin as 18-gauge (with a saw-kerf wastage of only $\frac{1}{8}$ in.), while the best thickness for circular saws is usually from 13- to 16-gauge.

Cross-cut Saws, for cutting across the grain of the wood, belong to the reciprocating class. The cutting-edge strikes the fibres at right angles to its length, and while its pitch is slight (if any), it must sever from each side before dislodging the sawdust. **Slitting-** or **ripping-saws** have the cutting-edge at about a right angle to the wood-fibres, and sever them in one piece, which the throat of the tooth wedges out. **Circular Saws**, in use among watchmakers and fine metal-workers since 1790 (invented by Bennel), were only applied after the introduction of steam-power to saw-milling about 1855, though they can also quite easily be worked by water-power; but now they are much more largely employed than any other kind of saws, although they require to be stronger and thicker, and therefore cause more wastage than either frame-saws or band-saws. In large mills circular saws of 60 in. diameter are in common use, and can per diem of 12 hours (according to the horse-power) cut out from 20,000 to 60,000 superficial feet of 1 in. boards, as compared with 5000-8000 ft. sawn by a straight muley- or gate-saw. Saws of 8 ft. diameter are sometimes in use in California. They cannot be set in gangs close together, as in frame-saws, for sawing thin boards simultaneously; but two saws of 3-6 in. diameter, or from three to five of smaller diameter, can be set on one shaft, and simultaneously used to divide or trim the planks cut from a log. **Horizontal Saws**, working rapidly from side to side between supports adjustable to suit the log, have recently been introduced, and prove successful even in small estate-mills, both for breaking down timber and for re-sawing the broken-down pieces into flitches of different sizes. As thin saws of 17- to 19-gauge can be used for sawing thin boards, the wastage is less than in sawing in ordinary vertical log-frames or with circular saws. Endless **Band-saws**, at first used for fine work, and only introduced about twenty years ago for timber-sawing, but now largely used for breaking down logs into squares, consist of a continuous ribbon-like blade running over two pulleys, placed either vertically or horizontally with reference to each other, according as the cut is to be made vertically or horizontally. They vary from about $1\frac{1}{2}$ to $2\frac{1}{2}$ up to 9 in. in width, and have a cutting capacity of 30,000 to 40,000 superficial feet per diem of 12 hours, with an expenditure of from 25 to 40 per cent less driving power than is needed for the same out-turn from a circular saw. As they are usually only from 16- to 19-gauge, according to the kind of wood sawn, the wastage is smaller than with ordinary vertical or circular saws about 14- to 16-gauge. **Cylindrical** or **barrel-shaped Saws** are only used for cutting rounded staves for barrels, tubs, pails, &c.

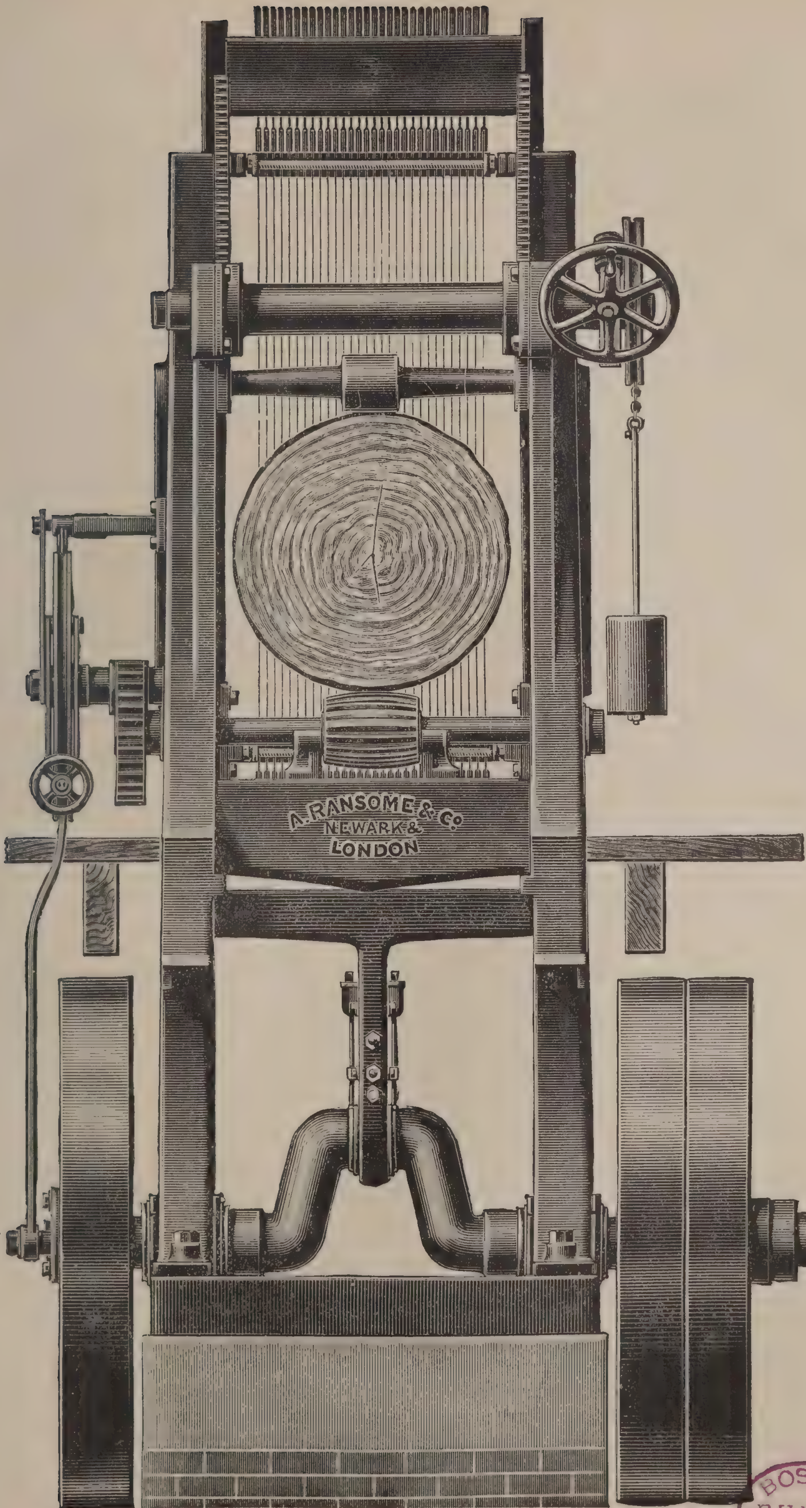
Typical illustrations of some of the higher classes of vertical, circular, and horizontal frame-saws, and of a horizontal band-saw, are shown in Figs. 269 to 272.

Vertical Frame-Saw with Gang of Multiple-Saws (Fig. 269) for sawing logs or squares into boards or planks. The logs are fed up to the saws by revolving rollers, with a rate of feed varying up to 4 ft. a minute, according to the kind of wood and the number of saws.

The pressure gear is so arranged that, by turning a hand-wheel, the rollers can be raised or lowered to suit any inequalities in the log, and thus obviate overhead levers and weights, besides leaving the top of the swing frame clear for keying-up and adjusting the saws. The swing frame is connected with the crank-shaft by two rods, one on each side of the frame, to reduce the distance between the floor-line and the foundation as much as possible, and the whole machine is bolted to a massive cast-iron bed-plate, into which the bearings for the crank-shaft are fitted.

The ends of the log that is being sawn are carried on strong iron carriages running on rails, and fitted with screw dogs, which grip the timber and have a lateral motion, enabling the saws to follow the curve of a crooked log. The swing frame, connecting

Fig. 269.



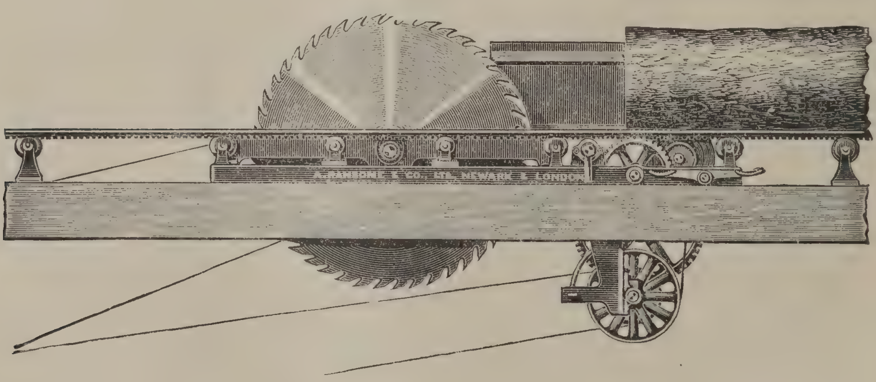
rods, crank and crank-shaft are made of the best steel, so as to combine strength with comparative lightness.

Circular Saw with Steel Travelling Table for breaking down logs of round or square timber into scantlings, &c. The timber is carried to the saw upon a steel bed, running on rollers with iron spindles, at rates varying from 12 ft. to 40 ft. a minute ; and the table has a quick return motion of 150 ft. a minute. The travelling bed is fixed nearly level with the floor of the mill, so that the timber may be readily placed on it. The log needs no fixing, as its weight keeps it steady upon the table. All the gearing connected with the feed and return motions of the table is attached to the main bed of the machine, thus making the machine entirely self-contained (Fig. 270).

Horizontal Frame-Saw.—The timber is carried on iron transoms bolted to steel joists, and provided with dogs or clips at suitable intervals. The saws and their driving gear can be raised or lowered to save time lost in adjusting the machine after each cut, and the whole of the driving gear for the saws is attached to one saddle. The connecting rod is attached to the swing frame in the middle instead of at the end to reduce the space taken up. The feed has several changes of speed, and is driven directly from the crank-shaft (Fig. 271).

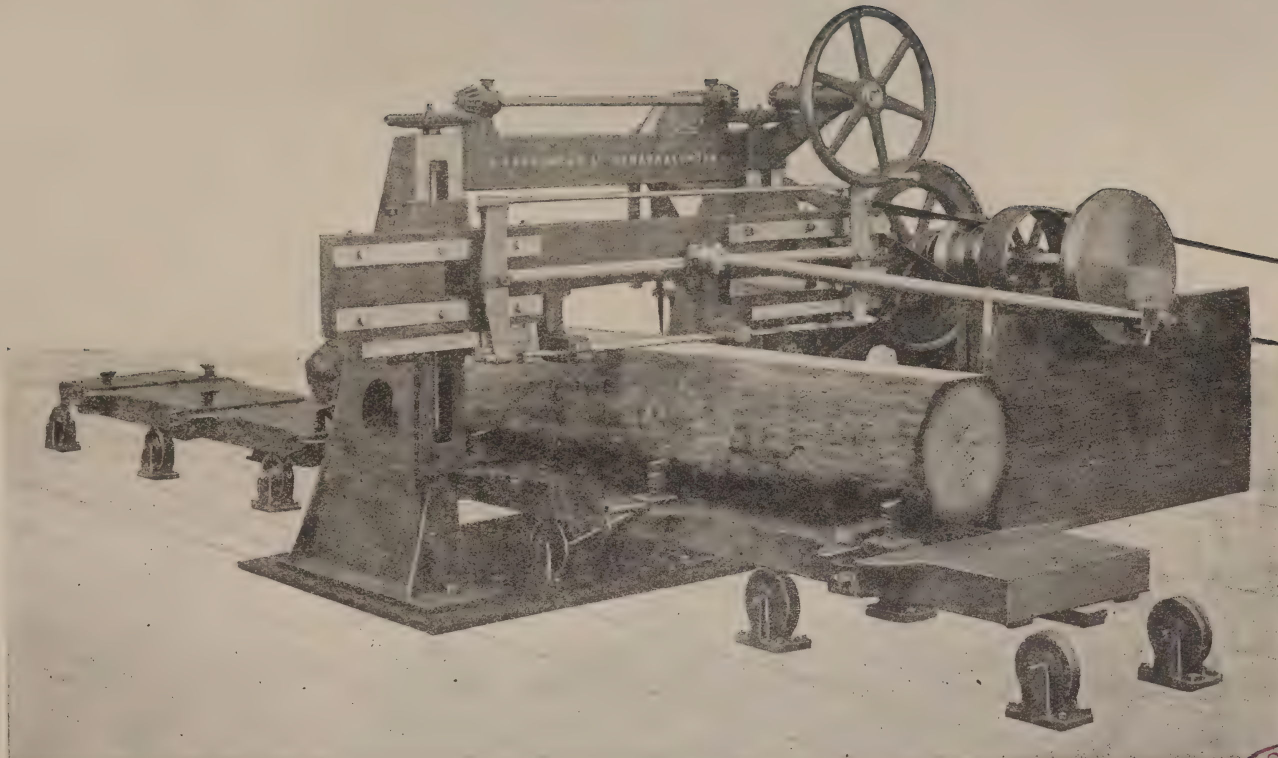
Horizontal Endless Band-Saw.—This saw, protected by the Landis and Ransome patents, represents the highest development of timber-sawing machinery in Britain at

Fig. 270.



present. It can be used both for slabbing or breaking down logs, and for cutting boards or scantlings ; and it can make a true cut through the centre of an Elm log 20 ft. long by 3 ft. in diameter in less than a minute. As only two belts are required to work all its motions, it can be driven by a portable engine for sawing large timber in the forest. It is constructed entirely of metal, and is fixed on a ground-level bed of concrete, without excavation. The saw-blade runs at a speed of about 7000 ft. a minute, and is carried on a pair of large, well-balanced steel pulleys, the saw-blade running on the metal rim with the teeth projecting sufficiently beyond the edge to clear the set. The saw is supported close on each side of the log by passing through adjustable hardwood guides, which can be instantly moved nearer or farther apart, to suit logs of varying widths, by turning two small hand-wheels carrying pinions gearing into horizontal racks on the main saw carriage. The feed ranges from 4 to 80 ft. a minute, and is driven by a simple friction gear, controlled by a switch-handle, by which the rate of advance can instantly be varied. The backward motion of the carriage is 400 ft. a minute, and is also worked by friction gear operated by another lever, which enables the sawyer to start, stop, or reverse it at once. The sawyer directly controls the whole machine. On his left is a hand-wheel with indicating disc, by which the thickness of the board to be sawn is regulated, and at his right hand, arranged in a switch rack, are four levers which respectively (1) start and stop the saw ; (2) start, stop, and reverse the timber carriage ; (3) work the self-acting rising motion of the saw ; and (4) vary the rate of feed. The travelling-carriage for the log consists entirely of metal, the main sides being rolled steel girders connected by

Fig. 271.



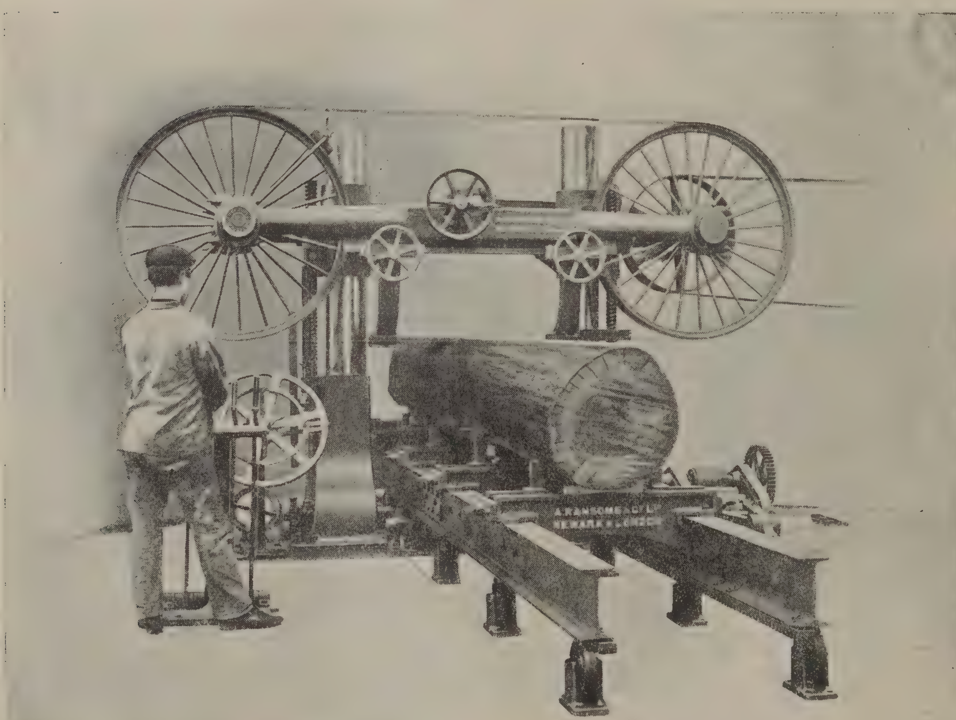
Horizontal Frame-Saw.

cast-iron stretchers. It is accurately planed on both upper and under surfaces, and runs on a series of turned rollers revolving in carriages bolted to the floor. Each of the cast-iron stretchers has an adjustable wrought-steel dog-cramp worked by screws from either side of the carriage. The carriage is moved backwards and forwards by means of two steel pinions working into corresponding racks under each main side girder.

Fig. 272 represents a new type of single blade, 18 in. horizontal log frame, for small saw-mills. It is specially designed to resist the strain due to the reciprocation of the saw-frame ; consequently a greater number of strokes can be made per minute, and a larger amount of sawing done.

The framework is on a cast-iron bedplate, and the saw-frame carriage rises and falls on two strong cast-iron standards, having planed faces and adjustable strips for taking up

Fig. 272.



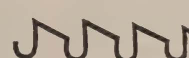
Horizontal Endless Band-Saw.

wear. The saw carriage rises and falls by means of two screws worked by a large hand-wheel. The swing-frame crossheads slide between gun-metal strips adjustable for wear, the thrust of the cut being taken by strong thrust-blocks. The saw is steadied by guides placed immediately each side of the timber. The crank-shaft, fitted with a pair of fast and loose pulleys, is mounted on two strong cast-iron standards, and the shaft runs on two long bearings of hard gun-metal, adjustable for wear. While being sawn, the timber is held down on the travelling-carriage by adjustable steel dogs.

It is not here necessary to give full descriptions of these, or of other very expensive and powerful sawing machinery for large timber mills, because precise details regarding such important points as price, size, weight, horse-power, diameter of driving-pulley, speed of crank-shaft and saw, length of travelling bed, dimensions of logs that can be slabbed, broken down, or sawn up, &c., are easily obtainable in full in the catalogues of firms making a specialty of this class of machinery—*e.g.*, Messrs. A. Ransome & Co., Newark-on-Trent and Chelsea (who have kindly enabled me to reproduce Figs. 269 to 272); Messrs. T. Robinson & Son, Rochdale; and several others both in Scotland and England. And in such catalogues will also be found ample details regarding saws, and the machinery for stripping, re-setting, sharpening, brazing, and mending mill-saws of all kinds by machinery, together with various kinds of labour-saving appliances, such as hauling-apparatus, log-turners, overhead travelling crabs and cranes, &c.

For ordinary estate purposes, however, machinery of the above kinds is mostly too expensive, although where there is the prospect of converting continuously on anything like a large scale it is always economy to get the very best class of machinery, even though it may cost a larger capital outlay to start business operations. Such machinery will, however, always need to be in charge of an experienced engineer, and the simpler class of saw-mills that may usually be worked under the direct supervision of the forester will consist of vertical frame-saws or of circular saws driven either (1) by an overshot water-wheel, or (2) by light steam-power provided by a small stationary yard-engine, a portable engine, or a traction-engine in the charge of a trained hand. Given a favourable supply of water, water-power is by far the cheapest method of conversion, but it is only by the use of a portable or a traction-engine that a saw-mill can be moved from place to place in or near the woodlands. The cost of erecting a small mill with a full complement of simple but good workable machinery may vary from about £300 to £500 up to £1000 or more, according to its class, working-capacity, and quality. The initial cost of a small mill, purely for estate purposes, is of course greater when a traction-engine is required.

Mill-saws act on timber in similar manner to hand-saws, though of course at a very different rate, so that what has elsewhere been said about these (see p. 468) also applies generally to the former. But the shape of the teeth is usually different, and the saws have to be made of the very best steel, a very high quality being more especially important for all frame, circular, or band-saws driven by steam machinery at a great rate of speed. For frame-saws the teeth are generally somewhat J-shaped on their face, thus—



the sharp, slightly hooked points facing in the cutting direction. The teeth of circular ripping-saws (see Fig. 280, p. 576) are more or less hooked at an angle varying from 20° to 30° from the radius of the circular saw, the amount of hook being greater for soft than for hard timber. The teeth of cross-cutting saws are made without hook, being usually of an arrow-head shape rising from a broad base. The **pitch** of the saw, or distance from tooth to tooth, is also greater in circular ripping-saws than in cross-cutting saws, and may vary, according to the diameter of the saw, from about $1\frac{1}{2}$ to 2 in. in the latter to $1\frac{3}{4}$ to $2\frac{1}{2}$ in. in the former, saws for softwoods requiring more pitch than those for hardwoods (see Fig. 280). The shape and the pitch of the teeth of course regulate the proportion between the tooth-area and the kerf for holding and extracting the sawdust, which ratio generally varies from about 1 : 2 for hardwoods and 1 : 3 for softwoods. So, too, the **set** of the teeth to each side alternately is greater for soft than for hard wood. The teeth of band-saws are usually shaped differently from either of the above, thus—

Mill-saws should be made of the finest cast steel, and their thickness and size should be proportionate to the class of work they are intended to perform. The thinner the saw, the easier it is to drive, and the less wastage there is as sawdust; but when worked at high speed the tension becomes greatly increased, and too thin a saw will not cut true and straight, while it may easily buckle or break. The gauge will therefore vary from 12 to 16 according to circumstances. Thus, thinner saws of higher gauge will suffice for softwoods and non-resinous Conifers than are needed for hardwoods and resinous Conifers, and frame-saws need not be as thick as circular saws.

1. **Saw-mills driven by Water-wheels** can work several vertical saws set in a frame, but their rate of progress and output is nothing like so great as that of machinery driven by steam-power. The manner of working is still very much the same as already described for the primitive forms of mill, and the chief improvements have consisted in shortening the crank which works the saw-frame up and down (twice the length of the crank of course forming the full stroke or play of the saw) and increasing the rate of its revolution ; because, the shorter the saw-blade, the more rigid it remains, and the cleaner the cut it makes. But, to evacuate all the sawdust from the kerfs or vacant spaces between the teeth of the saw, the blade must of course be at least twice as long as the diameter of the log sawn.

The motive-power obtained from the water-wheel is communicated by its axle to a heavy, regulating fly-wheel made of iron and to the crank attached at the end of the axle, which works the pitman attached to the base of the saw-frame, so that this moves up and down nearly vertically within grooves in the sides of the frame. Each revolution of the crank makes both a downward or cutting stroke and also an upward or release stroke, during which the travelling-carriage supporting the firmly fixed ends of the log to be sawn moves automatically forward by the breadth of each cut made. The log is held in place by dogs or clamps at the ends of the long, narrow, travelling-carriage, which moves on rollers so as to feed the log up to the saw by means of a rack driven by the pinion of a cog-wheel, itself turned by the pinion of a smaller cog-wheel, with backward sloping teeth, that is worked automatically by a ratchet. This ratchet is attached by a jointed rod to the top of the saw-frame, and therefore rises, falls, and pushes round the small driving-cog as each revolution of the crank produces a downward and upward stroke of the saw-frame. The size of the teeth in the smaller primary cog acted on directly by the ratchet is adjusted so as to regulate the rate of feed to the cutting-power of the saw. The return of the travelling-carriage is made by pushing or winding it back to its original position for reloading or readjusting the log to be sawn. For such simple water-power mills it is self-evident that the driving-power of the mill will vary according to the diameter of the mill-wheel, the breadth and depth of the floats, and the volume and head of water, while the rapidity of sawing will of course depend on the shortness of the crank which works the saw-frame, and the number of revolutions it makes per minute. Old-fashioned mills often only gave from 60 to 120 turns a minute, while modern mills with good water-power make from 180 to 200, and sometimes more.

2. **Steam-power Saw-mills** with vertical frame-saws are more powerful than water-mills, the frame being made of iron, and containing several saws for breaking up the wood into several scantlings or boards at one operation. The heavy regulating-wheel and the motive crank are generally beneath the floor-level on which the travelling-carriage feeds the log up to the saws ; and as the log passes through the saw-frame it is borne on a revolving grooved wheel, which carries it on to the other portion of the travelling-carriage. For feeding circular saws, the travelling-carriage consists of a flat iron table or platform with an open slit running lengthways all along the middle, and of sufficient width to allow ample sideward play for the rapidly rotating saw.

For **movable saw-mills**, circular saws are the best and most economical. An excellent account of such will be found in an article on *The Conversion of Home-Grown Timber for Estate and Other Purposes*, by Mr. D. F. Mackenzie, in the *Trans. of High. and Agric. Socy. of Scot.* for 1901, pp. 134-148, from which the following extracts, with illustrations, have been kindly permitted :—

The machinery should be of a portable type, and the motive-power a 10 or 12 horse-power engine (Fig. 273), with high-pressure steam-boiler, the furnace to be so constructed

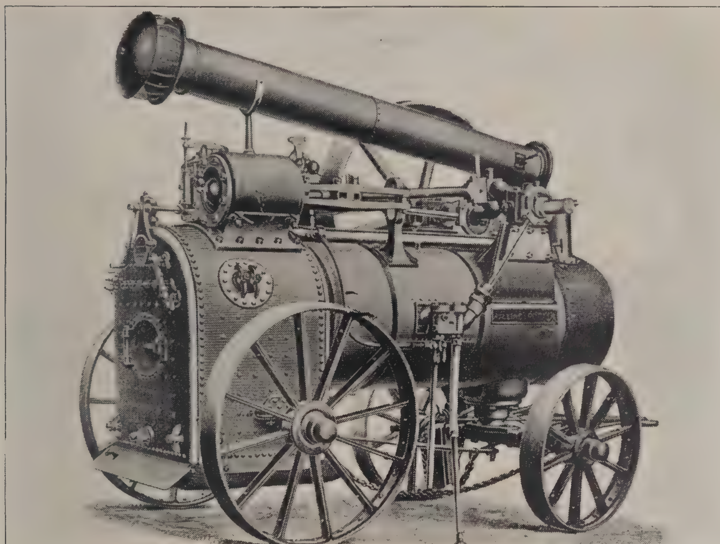


Fig. 273.—*Portable Engine.*

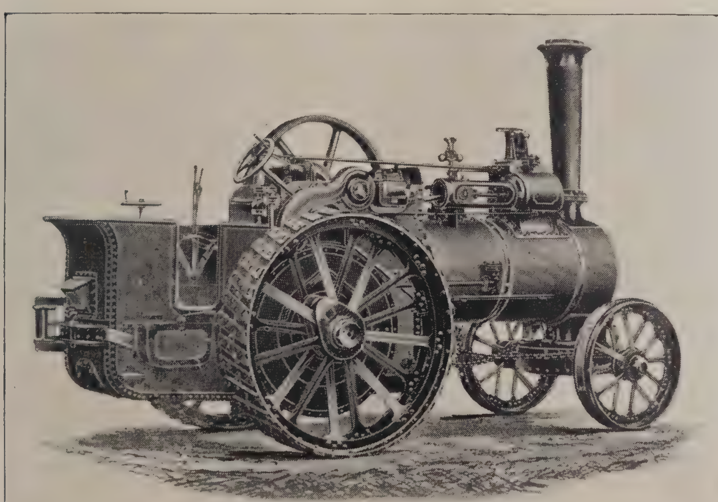


Fig. 274.—*Traction Engine.*

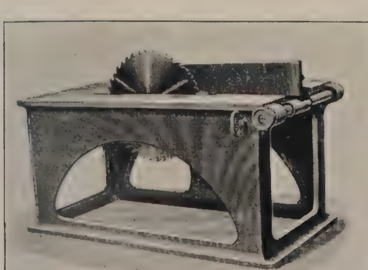


Fig. 275.—*Ripping-saw Bench.*

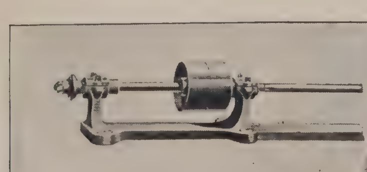


Fig. 276.—*Saw-driving Shaft, with fast and loose Pulleys.*

Fig. 277.—*Saw Bench for Staves and Pit-wood.*

Fig. 278.—*Long-saw Benches for long Logs.*

Fig. 279.—*View of small temporary Sawmill.*

as to permit of the steam being generated by the burning of the waste from the saw-mill, such as slabs and the like. Where, however, there is a fair demand for such waste, it might be found more economical to use an oil-engine of the same power. Even if there were no demand for such waste product, the oil-engine might be the more economical of the two, as the wages for tending would be almost nil. With varying results, according to the circumstances of each ease, traction-engines (Fig. 274) are often used as the motive-power for the sawing and haulage of the rough and sawn timber. It has been proved that this class of motive-power is not generally so useful for work in rough woodlands as at first sight it would seem to be, except where such may be used as a steam-roller, and for the breaking of whinstone for road-making, general estate operations, and concrete works. Under these latter circumstances, and, it might be added, where a portable threshing-mill is in use or required, this class of power will be found the most useful ; but when these requirements are absent, and the quantity of timber is limited, and the distance for cartage is under 5 miles, it is less satisfactory than horses for transport of rough timber to the saw-mill. The wages and upkeep of the traction-engine under ordinary circumstances are also greater. On the highway, however, it is possible to convey the manufactured timber cheaper by the traction-engine, provided the distances are long. In such cases the saving by this power compared with that of horses varies from 5 to 20 per cent. . . .

A 12 horse-power portable engine fitted on a multitubular boiler, with saw-benches, saws and belting, also motive drum for raising the speed, together with a proper shed or housing for mill, would cost about £330. Taking the average outlay of ten years, the upkeep of such plant, including interest on capital, tear and wear, insurance, saws, oils, files, and wages to a capable man as tenter, would cost £160 per year. An oil-engine and plant would cost 20 per cent less, and where a sufficient supply of water is not obtainable for a steam-engine, these oil-engines are to be recommended, very little water being required. A traction-engine (as in Fig. 274) would cost from £500 to £560. An engine of 12 brake-horse-power is capable of driving four circular saws, three of which would be "ripping" saws and one a "cross-cut." The latter could be fitted into a short metal bench or table fitted either "dead" or movable on rollers, but so as to be easily converted into a ripping-saw bench at pleasure (Fig. 275). This bench may be parallel to the "long bench" fitted for cutting up long timber (Figs. 277 and 278).

Both cross-cut and ripping-saw of long bench may be driven off the same shaft, the shaft to be of such length as to permit of short pitwood and fence-stobs being cut from long small timber if required, and to have bearings in the centre to prevent vibration, the shaft being fitted with fast and loose pulleys (Fig. 276). The other two ripping-saws may be fitted into two short or other benches, as is convenient, made suitable for cutting up pitwood, stobs, barrel-staves, beading, and box-wood. Both may be on one shaft, with fast and loose pulleys like the other, and all driven from a 5-ft. diameter speed-raising drum, which is driven direct from the engine fly-wheel by a 7-in. 5-ply rubber and cotton belt, wider or narrower according to the power of the engine, but of sufficient weight to prevent slipping without being unduly tight, and to secure the steady speed of the saws. The benches may be very elaborate or very simple. The simple forms are capable of producing the very best work.

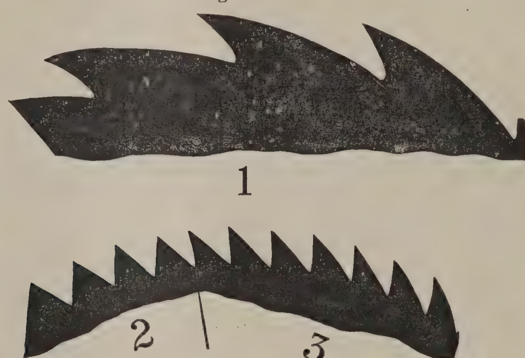
Fig. 279 shows an ordinary saw-mill built and worked upon economical principles. It consists of two long benches, two short ones, and a cross-cut saw bench, all driven by a 12 horse-power portable engine of the type of Fig. 273, with the speed-raising drum placed in the roof in the centre of the mill-shed. The engine should stand at the side of the benches, near the end.

The benches are formed of Scots Pine of the following specification : top rails 8 by 3 in., cross-pieces 7 by 3 in., bottom rails 5 by 2½ in., uprights 6 by 2½ in., rollers for moving table 7 in. diameter, with iron spindles set at 3 ft. apart, centre to centre—the rollers to have grooves to suit the "rack" and "feather" of movable top or table. The table may be propelled by hand-pinion, or direct from the speed-drum or saw-shafting. Generally speaking, the hand-motion is preferable for many reasons. Fig. 278 shows benches of this type.

As an indication of the power necessary to do a certain amount of work, the following examples may be found useful. The power required to cut a log of pinewood 32 in. deep by a circular saw 72 in. in diameter, and revolving at a speed of 500 revolutions per minute, is found, in practice, to be about 10 brake-horse-power, the same as is required to drive four 40-inch saws, each cutting a log 8 in. deep. A 60-inch saw, driven at a velocity of 600, cutting a log 26 in. deep, requires 7 horse-power. A 48-inch saw, revolving at a velocity of 800, cutting a log 20 in. deep, would require 4 horse-power ; and a 42-inch saw, revolving at a speed of 900 per minute, cutting a log 18 in. deep, would require 3 horse-power.

It will be observed that the speed at which the saw is driven is a considerable factor. Saws of a less diameter, and proportionately thinner, require comparatively less driving-power so long as the speed is high and the log is not deeper than the saw. The greater the diameter of a saw, the slower the speed should be. A saw of 24 to 30 in. in diameter could safely be driven at a speed of 1500 revolutions per minute, but a 72-inch saw would go to pieces at such a speed. There should be two saws for each bench or table, each of a different thickness and diameter. The cross-cut saw should be 3 ft. 6 in. in diameter, and No. 12 B.W.G. The saws for the long bench for cutting deals, joisting, and such-like, should also be 3 ft. 6 in. diameter, No. 13 "slack" for squaring or slabbing, and No.

Fig. 280.



Teeth of Circular Saws.

1. Wide-pitched, strongly-hooked teeth of a Ripping-saw for softwoods.
2. Triangular arrow-shaped teeth of a Cross-cut saw.
3. Slightly-hooked and less widely-pitched teeth of a Ripping-saw for hardwoods.

15 "tight" for ripping. The others should be 3 ft. in diameter, and one saw, the slabbing one, should be No. 14 or 15, and the ripping one No. 16 "tight" B.W.G. The second set should have small and "close-pitch" teeth for cutting hardwoods. It would be of great utility to have a band-saw attached to work at pleasure, and for the purpose of cutting out felloes and other irregular-sided timbers.

The quality of saws is important. They should be of the very best cast-steel plates, and of a thickness suitable for the various benches, keeping in view the work each has to do. If the blades are too thick, there is a ruinous waste of timber in sawdust ; if too thin, there is also a waste, but of a different kind, that of unequal thicknesses. Thin saws are, in the hands of an inexperienced workman, most difficult to manage. The slightest fault in the trimming causes loss of time and timber. While that is the case, thick saws also cause a very serious loss in timber, and consequently in money.

The shape and pitch of the teeth of saws are also very important. The teeth of the cross-cut saw should have no "hook," and should be shaped to a broad bevel like a spear-point. The pitch or distance of the points of the teeth apart may be from $1\frac{1}{2}$ to 2 in. All the other saws should be sharpened to a chisel-point, with very little bevel. The pitch of the teeth of the larger saws should be from 2 to $2\frac{1}{2}$ in., and those of the lesser ones from $1\frac{3}{4}$ to $2\frac{1}{4}$ in.

The saws for cutting hard dry woods may with advantage be $\frac{1}{4}$ in. less in pitch and slightly less in hook. The hook is best indicated by drawing a line from the point of the tooth through the centre of the spindle-hole in the centre of the saw. The face of the saw-tooth should be at an angle of from 20° to 30° to that line (Fig. 280). It is of great importance that the points of the teeth are absolutely the same length from the centre of the saw. To ensure this, the points of the teeth are frequently "stripped." This is done by holding a piece of hard sandstone against the points of the teeth, keeping the saw revolving at about half-speed during the operation. The teeth should then be sharpened up to the face-point—*i.e.*, all trace of stripping should be removed from each tooth, but nothing more. The blades of saws should at all times be kept at a uniform tension throughout. The uniformity of tension is sometimes destroyed in the centre by continual or frequent heating of the saw-spindle, thus causing the saw to go into the form of a shallow cup. In the outer rim the tension is disturbed by insufficient "set," by being frequently jammed by the vice-action of dried or twisted logs, by bad trimming, and by having the guides too tight, all of which tend to expand the outer edge of the saw, twisting it, and thereby causing it to cut up the logs in an erratic manner.

The cost of saws varies with the thickness, diameter, and quality of the plate. They are usually sold at so much per inch, measuring across their diameter to the points of the teeth. The catalogue prices seldom alter, but the discounts, which often exceed 50 per cent of the catalogue price, vary with every change in the cost of raw material and labour. A 42-inch circular saw, gauge 10, costs from 72s. to 75s., while it is catalogued at 180s. A 36-inch saw, gauge 11, costs 44s., while it is catalogued at 120s. Thinner saws are cheaper in proportion.

The usual thickness of saws in use in saw-mills worked by landed proprietors is between 10 and 12 B.W.G., even when of small diameter. This is because they are more rigid, and do not reflect bad trimming so readily. The proper thickness should be from 13 to 16 B.W.G. Let me give an example to illustrate what the difference would be. Two men are required to cut, say, 4000 superficial feet of 1-inch Larch boarding. The one works gauge No. 16, and the other gauge 12. To produce 4000 superficial feet with the No. 16 saw 366 ft. of rough timber is required, while the man working the No. 12 requires a little over 20 ft. more—viz., 386½ cub. ft.—being a loss of timber alone of about 6 per cent, or 20s. 6d.; then cartage of extra timber at 1d. per cubic foot, 1s. 8½d.; cross-cutting at ½d., say, 10d.; three hours more of man and machinery at 2s., equal 6s.—in all, say, a difference of 29s. on that small quantity of wood. In other words, a very handsome profit is converted into sawdust. Any one can make the calculation for himself, and he will find that the above figures are practically correct. It is to be regretted that this is so much overlooked by those in charge of estates where timber is manufactured for estate purposes.

The size of the mill and the most convenient arrangement of the machinery are matters directly affecting economical working. For the larger class of estate mills converting annually from 50,000 to 100,000 cub. ft. of timber into sleepers, pitwood, &c., under a special foreman in charge of up to about 10 men, two saws may be driven by one good portable or traction-engine standing in the middle of the shed, the one saw being used for slabbing and the other for sawing, on two home-made wooden benches up to about 40 ft. long running along each side of part of the shed. Beyond the engine, and driven by its spare fly-wheel, a cross-cut saw may be worked by the same shafting, on benches about 16 ft. long facing each other on either side of the shed, which are used for cutting pitwood, staves, and beading—the cross-cutting, slabbing, and sawing of the small-sized wood being carried on at the same time as the conversion of the large timber on the long benches. Sleepers of ordinary size (9 ft. × 10 in. × 5 in. = 3⅛ cub. ft.) can be turned out in such a mill at a total cost of about 1¼d. per sleeper.

It is only in large mills with strong driving-power that additional machinery can be added in the form of a band-saw, mortising machine, lathe, planing machine, general wood-worker or estate-carpenter, wood-wool machinery for working up waste pieces, timber-lifters, &c.

Where the estate work only consists in cutting up timber into gate-posts, fence-rails, &c., travelling engines and saw-benches may in some districts be hired at about 30s. a day, exclusive of fuel, water, and labour other than that of the sawyer and driver in charge.

The Cost of Conversion must of course vary considerably according to circumstances, as it depends on the combination of such various factors as the cost of timber-haulage, quantity, size, and quality of timber, price and quality of labour, capacity and quality of machinery, &c. Except the mill-manager, who should receive a regular salary *plus* a bonus on the net profit of working, all the mill-hands should be on piecework at so much per sleeper or per 1000 superficial feet for each different width and thickness of boards, planks, &c., the contract rate being fixed according to the known size and quality of the timber and the easily ascertained capacity of the machinery, so as to provide a good pay for a good day's work.[1]

There can, therefore, be no absolute rule laid down to guide one; but the following are some of the usual contract prices. If we assume that the saw-mill is situated at an average distance, not more than 1½ mile, from the timber to be manufactured, the cost of carting should be ¾d. per cubic foot, including bark. For felling and cross-cutting into lengths, no length to be under 6 ft., Scots Fir and Larch ½d., Spruce ¾d. to 1d. per cubic foot; for hardwoods, 1d. to 2d. per cubic foot. The cost of sawing and stacking to season (exclusive of motive-power), from 1¼d. to 1½d. per cubic foot—say, 4s. per 1000 superficial feet of ⅜-inch thick, to 7s. 6d. per 1000 superficial feet of 1-inch boarding (Mackenzie, *op. cit.*, p. 144).

In his article, which should be studied by all those engaged, or about to be engaged, in converting timber for estate purposes, Mr. Mackenzie gives a list of the contract prices he pays for different kinds of standard sizes of felloes, spokes, naves, shafts, sides, bottoming, &c., for cartwright, van, lorry, coach, barrow and waggon wood, and also for timber for general purposes, such as wedges, railway keys and waggon sprags, railway-sleepers, pit-sleepers and pillar wood, fencing-wood, mill rollers, barrel staves and ends, &c. Hardwood scantlings and planks of different thickness are paid at 2d. per cubic foot, and railway keys at 7s. 6d. per 1000; Scots Pine boarding per 1000 superficial feet of ½ in. 4s. 6d., ⅝ in. 5s. 6d., ¾ in. 6s. 6d., and 1 in. 7s. 6d.; Scots Pine and Spruce pit-sleepers (3½ or 3¾ ft. × 5 in. × 2 in.) 2s. per 100; Larch and Pine railway-sleepers from 5s. 6d. per 100 (for 7 ft. × 7 in. × 3½ in.) up to 8s. 4d. to 10s. (for 9 ft. × 9 in. × 4½, or 9 ft. × 10 in. × 5 in. with 5 in. square slab on back); Larch stobs up to 4s. 8d. per 100 (for 6 ft. × 6 in. × 3 in.), and rails 7s. 6d. per 1000 lineal feet (3 in. × 1 or 1¼ in.); Sycamore spinning-mill rollers 3s. 6d. per gross (7 to 9 in. × 1¾ in.); hardwood shuttle-blocks 1s. 9d. per 100 (22 in. × 2½ in. × 2¼ in.).

Besides the ordinary standard sizes of wood in general use which are most likely to find a ready sale from an estate mill, there are, as Mr. Mackenzie remarks (*op. cit.*, p. 147), other uses to which the various classes of timber can be put:—"For example, the smaller sizes of Beech and Oak are sent direct from the woods to the chemical works to be made into vinegar and charcoal. Small Ash is used for tool-handles if clean grown. Bent timber of Oak or Elm is used in boat-building and boat repairs. The smaller sizes of clean Oak are cut up for telegraph-arms. Beech is used for butchers' tables, wheel-cogs, and plumbers' tools; while large well-grown Willow and Poplar are used for saddlers' and shoemakers' cutting benches, as also for railway carriage-brake blocks. Plane or Sycamore trees under 6 in. diameter, whether branches or stems, are used by turners for making fancy boxes of small sizes; those from 6 to 10 in. diameter are cut into spinning-mill pressing-rollers 7 to 9 in. long, and 1¾ in. thick; from 10 to 19 in. in diameter are used by cabinetmakers—to order—and for bakers' troughs and tables, rollers for washing, wringing, and mangling machines. All large cleanly grown cuts are sent direct to the calico-works for printing-blocks, but nothing less than 20 in. diameter is of use. The inferior cuts, both of the main stem and branches, are cut into barrel staves and ends. . . .

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[1] **Handsawing** costs per 100 super. ft., for *boards*, from 2s. 6d.-3s. (softwoods) to 3s. 6d.-4s. 6d. (hardwoods); and for *planks*, 3s. 6d.-5s. (softwoods) to 5s.-7s. (hardwoods).

"The fact is, that in a properly managed establishment there is very little waste, and if a distilling apparatus and wood-pulper be added there need be none at all, not even of the sawdust. It is found that the charring of the latter in a common gas-retort renders it a most excellent disinfectant for stables, byres, piggeries, and poultry-houses, and after becoming saturated with the manurial ingredients, it forms, as might be expected, a very good manure."

Where log-ends have on any large scale to be broken up into **firewood**, this can be very quickly done by placing the flat section on a framework consisting of 2, 3, or 4 axe-edged blades set diametrically to cut into 4, 6, or 8 billets, and cleaving it with the blow of a heavy mallet, when the split pieces fall down below. **Kick-stamp** machinery has been invented for this purpose, and consists of a heavy iron hammer raised by a hand-lever and allowed to fall on the log-section to be split.

II. **The Preparation of Wood-pulp and Cellulose.**—Next to the conversion of timber in saw-mills, the consumption of wood in making pulp and cellulose for paper-mills and many other industries ranks next in importance. Until about fifty years ago (see vol. i. p. 84) paper was made almost entirely from rags, but during the last thirty years especially the use of wood as a raw material for paper-making, and for many other miscellaneous purposes, has created vast new industries throughout all the woodland parts of Europe and North America.[1]

When the woody-fibrous substance is prepared purely by mechanical means the product is called **Wood-pulp**, and when the cell-substance of the pulp is also extracted chemically, the product is **Cellulose**. The present value in Britain of the former is about £4, 10s. a ton, and of the latter £7 a ton.

Owing to the insufficiency of our woodlands there are but few wood-pulp or cellulose factories in Britain. The latter have mainly to use imported wood as their raw material, while the preparation of the coarser wood-pulp is too heavily handicapped to compete with that ground in Scandinavia and Canada by water-power in forests where the wood is obtainable close at hand.

British imports of wood-pulp (see vol. i. p. 94) now amount annually to close on 600,000 tons, valued at about £2,500,000, which is just about one-tenth of the value of our annual wood imports. The great disadvantage under which British pulp-mills work may be judged of by the fact that at the Kellner-Partington Pulp Company's mills at Glossop, in Derbyshire, where a special acid process patented by Mr. Partington is in use with Poplar and Spruce chiefly, imported from Norway and the Baltic, the wood (poles 6 in. in diameter and cut to 6 ft. lengths) costs about 60s. per cubic fathom at the nearest seaport, and 90s. by the time it reaches the mill; and the average yield per cubic fathom is 1 ton of dry cellulose, 1 ton of water, and 1 ton of extractive, for which there is as yet no profitable use (Anderson, in *Jour. Roy. Agric. Socy.*, 1903).—As a cubic fathom of such wood will contain about 3 tons, or 150 cub. ft., of solid contents ($216 \times 0{\cdot}7 = 151{\cdot}2$), this means that the wood to be pulped costs about 7d. a cubic foot delivered at the mill.

For a cellulose mill to be worked at a profit it is calculated that about 80 cubic fathoms (240 tons = 12,000 cub. ft.) of wood are needed weekly, or over 4000 fathoms (12,000 tons = 600,000 cub. ft.) per annum, which is equivalent to the yield from

[1] That paper could be made from wood has been known for at least 150 years. In the forestry museum of Munich University there is an interesting specimen of coarse dirty-brown paper made about 1750 by a country clergyman, who took his idea from the paper-like composition of a wasp's nest.

about 120 to 150 acres of 40-year-old Spruce (according to quality of soil and crop), and would therefore need from 4800 to 6000 acres of regular and well-managed Spruce-woods to provide a continuous supply of pulp-wood. The preparation of wood-pulp mechanically, however, can be carried on profitably on a very much smaller scale, and thinnings can thus be utilised, though even then there are comparatively few places in the United Kingdom where Spruce and other suitable softwoods are obtainable in sufficient quantity to keep a wood-pulp mill at work.

The out-turn from wood-pulp and cellulose factories has increased enormously throughout Northern and Central Europe during the last thirty years. In 1900 there were in Germany above 601 wood-pulp mills, of which 300 were in Saxony, which annually ground down about 35,000,000 cub. ft., or 700,000 tons, of wood, yielding about 200,000 tons weight of pulp; and there were 71 cellulose factories using about 29,750,000 cub. ft., or 595,000 tons, of wood, and producing about 170,000 tons of dry cellulose. In the mountain districts of Central and Southern Germany, where water-power is abundant, there is a very large number of small pulp-mills which grind up the wood in a simple manner; and it then pays to work on a very small scale. But the work is often done under conditions so primitive, that they would in Britain be an infringement of the Factories Act.

When the supply of rags began to be found insufficient to provide for the increased demand for paper, wood-pulp was first of all prepared mechanically and mixed with rags. But owing to the shortness of its fibre, its stiffness, and the difficulty of bleaching it and rendering it felty, it was in some respects an unsatisfactory addition, and only a makeshift as a substitute. Subsequently, however, by steaming the wood a longer-fibred substance was obtained, which could be made (without any admixture of rags) into the lower grades of paper, such as is used for newspapers, bills and posters, packing-paper, &c. The second and greater discovery was the use of chemicals to free the pulp from incrusting substances and enable the cellulose to be obtained in nearly a pure condition. This refined product proved so good a substitute for rags, that it has almost entirely taken their place in the manufacture of paper.

Pure Cellulose ($C_6H_{10}O_5$), not yet found in any plant, is white, silky, translucent, hygroscopic, and without taste or smell (see p. 427); and when prepared, it retains the form of the portion of the tree from which it has been obtained. From thoroughly lignified tissues, like the heartwood of Oak, Elm, and Larch, cellulose can either only be partially obtained, or else not at all. It is not completely soluble in any solvent yet discovered. In ammoniated oxide of copper it swells so rapidly that it seems to dissolve; but on acids or salts, or even a considerable quantity of water being added, it is deposited as a structureless, cloudy, or thread-like mass. Chloride of zinc also acts in the same way as ammoniated oxide of copper, but it is a much less effective solvent. The dissolution takes place easier and quicker if the cellulose is first treated with concentrated cold sodium lye. Cellulose turns yellow to brown under the action of iodine. If saturated with a solution of iodine, it turns blue on concentrated sulphuric acid being added; and this forms a test of its presence. And if either wood or cellulose be boiled in dilute sulphuric acid, sugar is produced; but as yet it has not been found practicable to utilise this property commercially in making spirits from wood.

If the wood of broad-leaved trees be first purified with ammonia and then treated with alkali lye, *xylan* or *wood-gum* ($C_6H_{10}O_5$) is produced, and when heated with dilute sulphuric acid this becomes *xylose* or *wood-sugar* ($C_5H_{10}O_5$), a non-fermenting kind of sugar. The wood of coniferous trees, however, gives no *xylan*.

Concentrated acids are used for transforming cellulose for various industrial purposes. If unsized cellulose paper be plunged for 5 to 20 seconds into strong sulphuric acid and then thoroughly washed in water, the cellulose undergoes a colloidal modification and becomes *amyloid* or *hydro-cellulose*. It then resembles animal parchment, and becomes translucent, stiff, difficult to tear, and pliable in water without dissolving like common paper; and it is known by the trade-name of *vegetable parchment*.

If treated with concentrated nitric acid, or still better with a mixture of that and of concentrated sulphuric acid (which has a strong affinity for and absorbs water), the cellulose of purified cotton or of wood becomes transformed into a nitro-product, different combinations being formed according to the temperature and the length of time the acid is allowed to operate. Thus, taking the molecule of cellulose as having 12 atoms of C, the following combinations may be produced :—

(1) Cellulose—Dinitrate, $C_{12}H_{18}O_8(NO_3)_2$.
(2) ,, —Trinitrate, $C_{12}H_{17}O_7(NO_3)_3$.
(3) ,, —Tetranitrate, $C_{12}H_{16}O_6(NO_3)_4$.
(5) ,, —Pentanitrate, $C_{12}H_{15}O_5(NO_3)_5$.
(5) ,, —Hexanitrate, $C_{12}H_{14}O_4(NO_3)_6$.

A mixture of 2 and 3 forms *collodium-wool*, which is soluble in æther-alcohol, and leaves a skin on evaporating, and which is used in photography and for surgical purposes. A mixture of the more strongly nitrated combinations 3, 4, and 5 forms *gun-cotton*, the explosive.

Nitro-cellulose is now also largely made into *artificial silk* in the St. Etienne district in France by Chardonnet's process. It is dissolved in æther-alcohol (2 : 3), and filtered under pressure. The filtered product (*collodium*) is then forced, under a pressure of about 50 atmospheres, or 700 lb. per square inch, through minute capillary glass-tubes so as to form extremely fine threads ; and as this operation takes place under water, the solvent is absorbed by the water. Nine such threads spun together form a thread fit for weaving. The threads are denitrated with a solution of sulphate of lime, and are thus retransformed into almost pure cellulose. They have a silky gloss and dye well, but are far less than half as strong as natural silk.

Another product formed from gun-cotton is *celluloid*. After being slightly damped and ground down fine, gun-cotton is thoroughly mixed with an equal weight of camphor (pigments and other substances being also added), then subjected to strong hydraulic pressure at a temperature of 112° to 140° Fahr. The blocks thus formed are damped, softened by heating to 175°-190° Fahr., and then either rolled out into thin plates, or else pressed and dried in moulds, when they become a hard, homogeneous, translucent to transparent mass, from which combs, buttons, billiard-balls, cuffs and collars, imitation ivory and horn, &c., are made. Celluloid is highly inflammable, but this can be diminished by adding phosphate of ammonia or borated salts.

An amorphous form of cellulose is also sold under the trade name of *viscose*, which is of a gelatinous nature, and can be treated so as either to form threads fit for spinning, or transformed into a very hard substitute for celluloid (Schwackhöfer, *op. cit.*, pp. 289, 323).

1. **Wood-pulp** consists of the disintegrated fibres of wood separated mechanically by grinding. It has much the same colour as the wood from which it is produced ; and as it cannot be bleached, it is therefore desirable to use light-coloured wood for its production.

Spruce-wood is mostly used, then *Silver Fir*, but to a much less extent ; and they both furnish a pale yellow pulp with fairly long fibre, which afterwards turns darker and duller in colour. *Scots Pine* is difficult to grind owing to its resinousness ; but it gives a fine, though short, reddish-yellow fibre. *Larch* gives a coarse, short, reddish fibre. Among the broad-leaved trees, which all yield only a pulp of short fibre, **Lime** is the easiest to grind, and yields the largest out-turn ; it gives a fine pale pulp, which afterwards darkens greatly and turns a dirty grey. **Aspen** and **Poplar** are also easy to grind, and give a very white pulp, which retains its light colour. *Maple*, *Sycamore*, and *Hornbeam* are difficult to grind, and give only a small out-turn of fine pulp of a pale colour.

The wood to be pulped, mostly consisting of poles from 4 to 8 in. in diameter, has first of all to be (1) cleaned and barked, (2) freed from knots and unsound parts, (3) cut into convenient lengths, and (4) split if necessary, before it is ground into pulp.

The **Cleaning** and **Barking** consist in freeing the wood from earth, sand, and other impurities which collect on the ends of the logs, and in removing the bark and cambium, which is usually done by hand in small pulp-mills, otherwise by steaming, or with special machines (see below). The **branch-knots** and unsound parts are then bored out by means of a rotating auger, or punched out with a chisel in small establishments, and cross-cut into sections of 10 to 20 (usually 14 to 16) in. long, thick billets being split to make the grinding easier.

These **billets** are then ground down by being pressed, generally lengthways, against a grinding-stone made of hard, fine, and even-grained sandstone, which rotates quickly so as to loosen the fibres at a uniform rate, and resolve them into a loose, pulpy condition. The **grinding** is usually done under a continuous stream of water to facilitate the separation of the fibres, which have then to be strained, dried, and pressed in moulds.

The **grindstones** are 40 to 60 in. in diameter, and about 18 or 20 in. thick; and they may be made to rotate either vertically or horizontally. Sometimes they are made of several segments, in place of one solid block, so as to allow of hollow portions being replaced if the stone should get worn out through chance difference in grain or hardness.

About five to eight small billets of **the wood to be pulped** are put into a box and then steadily pressed under or against the quick-rotating grindstone, and kept wet with the continuous flow of a small stream of water (**wet process**). The separation of the fibres may take place either longitudinally (as is usual), or transversely; and the force required is calculated at 4 horse-power for every cwt., or 80 horse-power per ton, of dry pulp produced per diem.

The water containing the pulpy fibres is first strained to remove splinters and coarse, incompletely ground pieces, and then passed on to the sieves. These strainers are made of perforated copper, and are set at a slight angle and kept in quick, jerky, side-to-side motion by means of a crank; and there are usually two or three of such strainers placed one above the other, with holes of different sizes. The water containing the pulp in suspension is run on to the upper strainer, then percolates to those with smaller holes, and is run off by a funnel to the pulp-machine, where the pulp is pressed into sheets. The coarser fibres thrown out from the lower edge of the strainers are collected in a gutter leading to a vat, from which they are pumped up to a churn, where they are further reduced by friction, and then once more passed through the strainers. Besides such strainers, however, cylindrical and flat rotating sieves are also in use, where the sorting of the pulp takes place by centrifugal force.

In the pulp-machine the stuff coming from the strainers is run through fine-meshed sieves, the water being drained off and the fibres left behind. But such pulp still contains 80 to 90 per cent of water, and has to be reduced by pressure to at least about half its weight before it can be transported for use elsewhere; while for more thorough drying, it has also to be heated. The pulp has a dullish indefinite colour, is unbleachable, and has a short, stiff fibre, so that it can only be used for making pasteboard, cardboard, and coarse kinds of paper; and unless thus utilised at once, or else pressed into sheets in the machine, the pulp soon changes colour and gets damaged. Pulp thus prepared is known commercially as **white pulp.**

The grinding of the pulp is greatly facilitated by steaming the wood first of all under a pressure of 4 to 5 atmospheres (56 to 70 lb. per square inch), when the disintegration takes place more easily, and in longer and softer, and more flexible and felty fibres. But steaming darkens the colour of the wood, and this process is therefore confined to the preparation of **brown pulp**. Grinding is even still easier, however, if the wood is alternately steamed and then steeped in boiling water under steam-pressure.—A common method in America is the **dry process,** when little or no water is allowed to flow on to the wood during the process of grinding. A great amount of heat is thus generated by friction, but considerably less force is required, 2½ to 3 horse-power being sufficient for each cwt. of dry pulp made every 24 hours, or 50 to 60 horse-power per ton (as compared with 4 horse-power per cwt., or 80 horse-power per ton for the *wet process*).

The preparation of wood-pulp is now confined almost entirely to out-of-the-way places, where there is good water-power, and where the quantity of suitable wood is either too small, or else transport is too dear, to make it worth while to convey it to the nearest cellulose-mill.

2. **Cellulose** is made from wood which is first cut into thin slices and small chips by machinery, then ground down between grooved rollers, and afterwards macerated or disintegrated by being boiled under high pressure in a solution either (1) of soda (the **alkali process**), or (2) of calcium sulphite (the **acid process**, the usual method), or else (3) treated by an **electro-chemical process**. The raw cellulose thus obtained is washed, then bleached with chloride of lime, and finally pressed between heated rollers and dried. Many paper-mills prefer, however, to get the raw cellulose and bleach it for themselves.

Good cellulose should be free from all such impurities as woody knots, bits of bark, earth or sand, dirt from the machinery, &c. Soda-cellulose is chemically purer than sulphite-cellulose, partly because the incrusting substances are less thoroughly dissolved by the latter process, and partly because the chemicals cannot be washed out of the raw pulp so thoroughly. From neither kind of cellulose, however, can such tough, strong paper be made as from rags, although soda-cellulose is the tougher and more like cotton rags, while sulphite-cellulose is weaker and more like linen or hempen rags.

Although *Aspen*, *Poplar*, and *Lime* give the whitest cellulose, much sought after for special purposes, yet the wood of coniferous trees, taken generally as a class, yield a better kind of fibre—longer, more flexible and felty, paler in colour, and more easily bleached—than broad-leaved trees, among which the softwoods are far preferable to most hardwoods. The kinds of wood found most suitable for preparing cellulose on a large scale are **Spruce**, which is chiefly used, then **Scots Pine**, and then **Silver Fir**; and to a much less extent also *Larch*, *Aspen*, *Poplar*, and *Birch* (see footnote to p. 428).

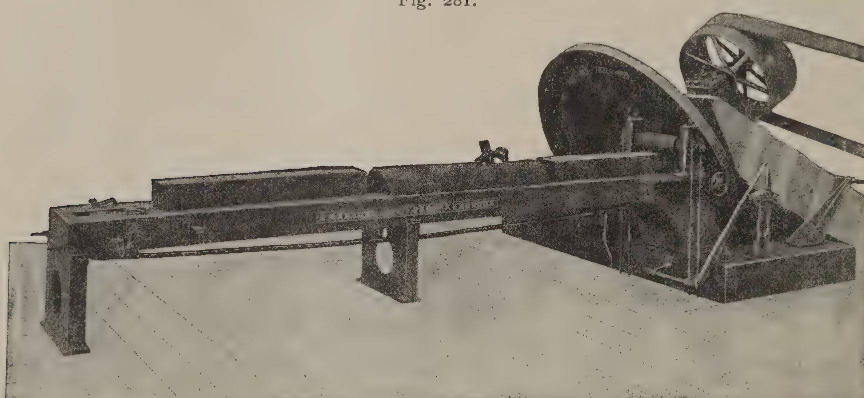
Resin hinders maceration. But if the wood-chips be treated with a mixture of alcohol and benzine, the resin is dissolved (Müller and Meyer's patent). Paper made from such de-resinised chips is said neither to turn yellow nor to become brittle. Birch yields a pinkish, and Maple and Sycamore a purplish pulp, of low grade and value. The other kinds of wood are practically unsuitable. As small poles and "lop and top" can be used, this often enables thinnings to be disposed of with advantage, unless the cost of transport to the mill is too great.

The various stages in the process of preparing the cellulose are (*a*) the cleaning and barking; (*b*) freeing from knots and unsound parts; (*c*) cutting into thin chips; (*d*) macerating in the alkali or the acid lye; and (*e*) washing, bleaching, and drying the cellulose.

The **cleaning** of the ends of the logs, the stripping of the bark and cambium, and the augering or cutting out of branch-knots and unsound places that cannot be macerated and bleached, take place in the same way as in a wood-pulp mill; but it must be done even more carefully here, as dirt of any sort cannot afterwards be removed from the cellulose. Cleaning can best be done by hand, though this is of course the dearest method, and in all large mills machinery is used to as large an extent as possible.

The wood is first cross-cut in lengths of 2 to 3 ft., and any unsound parts shown at the sawn surface are cut out. The **bark and cambium** are then removed either by being pressed against a revolving plate set with four plane-like knives, or by

Fig. 281.



Wood-Chipping Machine for Pulp-Making.

violent friction inside a revolving drum fitted with teeth-like ridges, from between which the pieces of bark are carried away by water; but as the sections of wood are seldom quite round, such barking-machines waste a good deal of the wood. It is therefore better to steam it and strip off the bark by hand, as it comes away easily and there is no loss of wood.

The **branch-knots** are bored out by pressing the wood against a rotating auger, or else they are, together with unsound pieces, cut out by hand after the wood has been cut into chips by the wood-chopping machine. There are two kinds of **chippers** or machines for cutting the billets of wood into thin chips or slicing it into small pieces. In the one the cutting chisels work vertically up and down; and in the other, the usual kind, they rotate. The chipper cuts or shaves off chips of wood at an angle of 45° to 60° to the axis of the billet; and the thinner the chips, the easier they can be acted on by the lye during the process of boiling and maceration.

Ransome's Pulp-Wood Chipping Machine consists of a large disc, on the face of which are fixed a number of steel cutters, so arranged as to act successively on the piece of wood to be cut. Holes slotted through the disc contain the chisels, placed with their bevelled edge towards the wood, so that they cut with the short side of their cutting angle in about the same plane as the direction of the cut. These chisels thus operate across the grain of the wood, and chop or break it into small pieces, which are so bruised and loosened in fibre as to be easily ground to a fine powder by the grinding machine. The disc and its spindle are tilted so as to strike the wood at an angle of 45° to 60°. The disc is fed with wood by an automatic roller worked by ratchet and pawl gearing.

Fig. 281 shows a *Wood-Chipping Machine with 7½ ft. Disc* capable of chipping either a log or a scantling (not exceeding 14 in. × 8 in.) into small pieces across the grain. It consists of a massive cast-iron disc mounted on a steel shaft, set at such an angle that the cutters strike the wood at an angle of 60°. Ten cutters are arranged in echelon on the face of one side of the disc, and project through it just sufficiently to cut chips of the desired thickness. The disc makes 240 revolutions per minute, and as the cutters are so spaced that they cut only during a period of somewhat less than half a revolution of the disc, the remainder of the revolution enables the disc to recover any momentum lost while the cutting is taking place. The chips are projected through the back of the disc, and are carried away either by a pneumatic exhaust apparatus or a conveyor.

The timber is fed up to the cutters along a horizontal table by a positive variable feed consisting of a flat-link chain running in the bed of the table, and into which suitable steel dogs can be inserted at any desired point to suit scantlings of different lengths. The dogs are so constructed that they fall out of the chain as it turns round the chain tumbler, and before the dogs come within reach of the cutters. The rate of feed can be varied to suit the hardness of the timber being cut, and the gear is controlled by levers worked by a hand-lever placed near the operator.

From the chipper the wood-chips go into a **grinding-mill**, in which they are ground down or minced between grooved rollers into small pieces about three-quarters of an inch long and one-fifth to one-third of an inch thick, and then passed on to a drum-sieve, where they are freed both from fine dust and from coarse bits of branches, unground chips, &c., and thus made ready for maceration. The loss of wood in these preliminary processes of cleaning and preparing amounts to from 5 or 6 up to 10 or 15 per cent for barked poles and stems with few branches, according to their quality; while, for wood of branching growth and with the bark on, it varies from 15 to 20 per cent for large poles, and up to 30 per cent for small poles below about 3 in. diameter.

(1) **The Alkali or Soda process** of macerating the wood is the oldest method of treating the chips; but as it is the more expensive, and produces only a smaller quantity of cellulose, it is now less generally in use than the acid process. It is still in use, however, and likely to remain so, as its product makes a good class of paper, fine, soft, and pliable, which takes ink well. There are two varieties of this method, in one of which *caustic soda* (NaHO) is used in producing maceration, while in the other (Dahl's process) this is effected by means of *sulphate of soda* (Na_2SO_4). The latter is less caustic in its action, though sufficiently so to dissolve the lignin; it therefore causes less waste of cellulose. It is also much cheaper and easier to prepare and renew the lye; but it has the great disadvantage of causing an abominable stench, both in preparing the lye and while boiling the chips, so that such factories must form a public nuisance to any residents round about where they are in operation. Only the *caustic soda* process need therefore here be considered in detail.

When **Caustic Soda** or **Hydrated Sodium** (Sodium hydroxide, NaHO) is used in a solution of 8 to 10 per cent strength (generally about 10 per cent) to boil the wood-chips at a temperature of 320°-365° Fahr. (thereby generating an extra pressure of 5-10 atmospheres, or about 70 to 140 lb. per square inch), the ligneous and other incrusting substances become entirely dissolved from the woody fibres, and a very pure cellulose remains after the lye is run off. The process is therefore effective; but its drawbacks are (1) that caustic soda is dear, (2) that it can only be partially re-obtained from the lye after use, and (3) that it eats into part of the cellulose and thus causes wastage.

The **caustic lye** is prepared by causticising a solution of soda with quicklime in iron vessels provided with a stirring apparatus and an intermittent steam blast-pipe. Carbonate of soda and quicklime are mixed in the proportion of 2 to 1·1 (although this proportion of quicklime is about 2 per cent more than is needed theoretically), and the transformation which takes place in boiling this by means of jets or blasts of steam and continuous stirring is that $Na_2CO_3 + CaO + H_2O = 2\ NaHO + CaCO_3$, and when the steam is shut off the carbonate of lime ($CaCO_3$) is allowed to settle at the bottom, and the hydrated sodium or caustic soda lye is drawn off and filtered to purify and clear it. The deposit is also washed when sufficient in bulk, to get the caustic soda contained in it.

For every cwt. of dry cellulose produced, from 150 to 160 gallons of lye are needed, or about $1\frac{2}{5}$ gallons for each lb. in weight.

The lye becomes discoloured and dark-brown from the decomposed lignin, &c., during the boiling and maceration of the wood-chips, but most of the soda remaining in it can be recovered and the lye brought up again to the proper strength by adding new soda. The operation of recovery is, however, tedious and expensive. The discoloured lye has to be heated till all the water is evaporated as steam, and the dry residuum is then calcined in a furnace, when the organic matter is consumed and carbonate of soda is left—the soda being burned as white as possible, but without quite reaching its melting-point. If fine particles of carbon then still remain in the soda they cannot afterwards be removed by filtering ; and if they subsequently get in among the cellulose during boiling, they produce a greenish-blue discolouration that cannot be removed in bleaching. The calcining occasions a loss of about 12-15 per cent of the soda, and as the soda becomes more and more impure silicates are formed, while the wear and tear of the sole-plates of the furnace make frequent repairs necessary.

The wood-chips are macerated in upright cylinders of about 350 cub. ft. capacity, made of strong sheet-iron, packed with asbestos, and cased in wood to keep in the heat as much as possible ; and all the piping and other parts coming in contact with the caustic lye must also be of iron. Horizontal boilers placed directly over a furnace were formerly used, but upright boilers are now generally preferred. Inside the boilers there are perforated sheet-iron cases, with holes large enough to allow the lye to circulate freely, but small enough to prevent the wood-chips being washed out. The wood-chips are packed into these perforated cases from an opening on the top of each boiler, and the raw cellulose is taken out from a side-hole below. The boilers are of course fitted with piping and taps for bringing in and leading off steam, and for running in fresh lye and carrying off what has been used. The boiler is filled from below with the caustic solution, so as to drive the air upwards from between the chips, and thus get rid of it before the boiler gets filled and hermetically sealed, and the boiling and maceration begin. In large pulp-works two or more boilers are sometimes connected together with piping, so that the caustic solution circulates from one to the other; this utilises the lye more thoroughly, and produces a fine quality of cellulose. The strength of the lye used, the time allowed for boiling, and the temperature at which, and consequently the atmospheric pressure under which, the chips are boiled, depend on the kind of wood being treated. The caustic lye usually varies from 8 to 12 per cent, the time of boiling from 6 to 24 hours, and the pressure from 5 to 10 atmospheres (70 to 140 lb. per square inch); but accurate details as to temperature (*i.e.*, pressure) and duration of boiling are generally trade secrets. Conifers are easier to treat than the wood of broad-leaved trees; and among Conifers, Spruce-wood is most easily pulped, while Scots Pine and Larch can both be macerated much more easily than Silver Fir.

In the above soda process, where as much as possible of the caustic soda remaining in the lye is recovered, the raw cellulose is washed for this purpose before being bleached. It is therefore moved direct from the boiler to an iron or cement cistern with a perforated bottom, which forms one of a set of four to eight similar cisterns, ranged at different levels and connected by off-flow pipes. Water is made to flow into the top cistern, and then, after percolating through the cellulose with which it is filled, drains through the perforated bottom and flows through the off-flow pipe on to the cellulose with which the next cistern is filled ; and so on, from cistern to cistern, the solution strengthening as it percolates through more and more cellulose, until at last it issues from the last cistern in about a 6 to 8 per cent solution, which can be used again when strengthened by the addition of whatever fresh caustic soda may be necessary. When the cellulose in the top cistern has been thoroughly washed its contents are removed for bleaching ; cistern No. 2 thus becomes No. 1, and the empty cistern taking its place as the last of the set is refilled with raw cellulose slid down from the boiler in a gutter-shaped shoot.

(2) **The Acid or Calcium Sulphite process** was invented by Mitscherlich about 1870, but has been much improved on since, and is now the method in general use, with special variations protected by patents. Its general principle is based on the maceration of the wood-chips by the agency of calcium bisulphite, $Ca(HSO_3)_2$, obtained by dissolving sulphate of lime ($CaSO_3$) in hydrated sulphurous acid (H_2SO_3). The active agent is here the sulphurous acid, while the use of lime is mainly subservient in enabling it to be employed in a convenient form ; and it has the advantages over caustic soda of being cheaper and of dissolving the incrusting substance without wasting much of the cellulose itself. But the cellulose is not so soft and pliable as that obtained by the soda process.

In order to prepare the lye, sulphur dioxide (SO_2) has first to be obtained—either by burning sulphur (when $S + O_2 = SO_2$), or by roasting iron pyrites (FeS_2) in specially constructed kilns (when $2FeS_2 + 11O = Fe_2O_3 + 4SO_2$)—and then hydrated (when $SO_2 + H_2O = H_2SO_3$), after which it can be made to act on limestone or carbonate of lime ($CaCO_3$) so as to produce calcium bisulphite in setting free carbonic acid and water (when $2H_2SO_3 + CACO_3 = Ca(HSO_3)_2 + CO_2 + H_2O$). This preparation generally takes place in high towers, 60 to 100 ft. high, and 5 to 6 ft. square, made of planking closed with tow, tarred, and bounded with iron bands to strengthen it. The limestone, broken into pieces from 3 or 4 up to 9 or 10 in. in diameter, rests on a strong staging of oak-beams, below which the pipe enters, bringing the gas from the burning sulphur or roasted pyrites after this has been cooled in tubing, while from a reservoir at the top of the tower a shower of water is allowed to play over the limestone. Fresh limestone can be filled in below this reservoir as required, and of course the purer the limestone, the better is the lye, and the less often is it necessary to clean out the tower thoroughly by deluging it with water. The lye obtained by the action of the sulphurous acid on the limestone collects in a masonry tank under the staging upon which the limestone rests, and is led off from there by lead piping to a wooden tank outside. It usually consists of a 5 to 7 per cent solution, the strength being rather less during summer than in winter. The average quantity of sulphurous acid (SO_2) contained is usually about 3½ per cent, of which about two-thirds are free and one-third combined with the lime.

The shower of water requires to be so regulated that only a faint smell of sulphurous acid should be noticeable at the top of the tower, but this condition can only be satisfied with very high towers. One of Kellner's improvements consisted in treating the limestone simultaneously in two towers, by leading off in an earthenware pipe the superfluous acid from the top of the first tower to the bottom of the second, and then pumping up the weak lye from the bottom of the latter to the top of the first tower, to trickle down over the limestone there and be acted on by the fresh acid coming direct from the furnace-tube. The inconvenience of these high towers has also led to various methods of preparing the lye in batteries of four or five wooden cases or cisterns arranged at different levels, and which can be closely shut. The limestone rests on a wooden framework in each, below which the water or lye collects. The sulphurous acid is pumped into the bottom of the lowest case, from the top of this it is led by a pipe to the bottom of the second case, and so on to the fourth or fifth, on reaching the top of which the whole of the active part of the acid will have been absorbed. From each of these cisterns the weak lye, after reaching a certain level, is carried away by an off-flow pipe to the next cistern below, till it reaches its maximum strength in the lowest cistern, from which it is drawn off for use.

The wood-chips are prepared and chopped in the same way as for the soda process, but the boilers in which they are macerated are of an entirely different description. While able to stand a pressure of at least 6 atmospheres, or 84 lb. per square inch, they must also be able to resist the corroding action of the sulphurous acid; and these conditions are best satisfied by cylindrical, oval, or spherical vessels of cast-iron or steel, lined with lead (Kellner's patent), or with well-burned acid-proof tiles made of porcelain or glass. The cylindrical boilers may either be horizontal, and these mostly rotating, or else upright and immovable; while the spherical boilers are always made for rotating, but are mostly used only in preparing straw-cellulose.

The boilers are of enormous size, usually having a capacity of from 2000 to 3500 cub. ft.; and some of those recently brought into use have over 7000 cub. ft. capacity, in order to profit by the advantage of reducing the proportion of their wall-surface to their contents, because the plates soon get corroded by the acid. Each boiler has its own doors for filling in the chips and taking out the raw cellulose, together with all the necessary piping for filling in and leading off the lye solution and steam, and carrying off gases evolved, taps for drawing off samples, safety-valve, pressure-gauge and thermometer, &c. The heating takes place either by bringing in hot steam, or else by means of a hard-lead pipe serpenting round the inside walls, or suspended from the apex and hanging free inside the boiler (Offenheimer's patent, with rectangular piping).

When the boiler has been packed with wood-chips up to within 15 or 16 in. of the top, these are steamed at 212° Fahr., and sometimes more, to drive out the air, so that the lye may penetrate easily into the woody substance, and to make the chips settle down firmly so that more wood can also be added for treatment. When the condensed water has been run off, the boiler is filled with lye from the top, and the temperature is gradually raised to about 260° Fahr., although this, as well as the length of time the chips are allowed to boil, depends of course on the kind of wood under treatment. The boiling generally lasts either for about 60 hours at a pressure of 3½ atmospheres (or 50 lb. per square inch), or for about 26 to 30 hours at a pressure of 4½ to 5 atmospheres (or 60 to 70 lb. per square inch). Here, however, the pressure is not regulated solely by the temperature, as the expansive power of the gas evolved from the lye also comes into play. When the boiling is ended this free sulphurous acid gas is carried off to the towers in which the lye is prepared, and is used again for acting on the limestone there. The boiler is then washed out several times with water to carry off as much as possible of the lye and of the calcium monosulphite it forms, and the raw cellulose is taken out. No attempt is here made, as in the soda process, to recover part of the lye for strengthening and using a second time.

The waste here is, however, so strongly charged with noxious chemicals as to pollute streams, and this question must be fully considered before any pulp-mill is erected. From a large boiler of the size generally in use over 2000 cub. ft., or 12,500 gallons, of used-up lye are run off, containing close on 5 tons of organic substances and 3 tons of salts of lime. By running the waste lye into cisterns and mixing it with milk of lime, monosulphite of lime is formed and deposited, and the water can then be led off to irrigate fields or meadows before discharging itself into any public watercourse.

(3) **The Electro-chemical process** was invented by Kellner, and is one of his several patents. It is based on the fact that when a strong electric current is passed through a solution of sodium chloride or common salt ($NaCl$), the chlorine and the sodium become separated at the two poles; and as water is present, the former is partly transformed into hydrogen chloride or hydrochloric acid (HCl), and the latter completely into hydrated sodium or caustic soda ($NaHO$). Kellner's method consists of an earthenware cistern encased in masonry and

divided into two parts, each of which contains one electrode; and when the wood-chips are alternately subjected to the action of soda-lye and of chlorine and hydrochloric acid, they become macerated and bleached at the same time.

As pulping by the calcium sulphite process is cheaper, however, this electro-chemical method is practically only used for bleaching purposes.

The raw cellulose taken from the washing-cistern in the soda process, or direct from the boiler in the calcium sulphite process, is a soft, crumbling, reddish-yellow mass, consisting mostly of bundles of vessels which require to be separated. This is now usually done by placing it in drums of a slightly conical shape, revolving round an axle set with wheels of spikes or finger-like processes. Through the friction thus produced when the drum revolves the bundles of vessels are separated, while any hard unmacerated pieces remain entire. The thin pulpy broken-up mass is then removed to a second drum formed by pieces of wood or vulcanite, through the narrow slits between which the water drains off and the pulp empties itself at the lower end. It is then passed down a gutter of from 30 to 60 ft. in length, in which the heavier bits of unmacerated wood and impurities of one sort and another are separated, while the fine pulp flows into a vat, from which it is raised by a bucket-wheel to have the water further drained off in fine-meshed sieves. The drying and pressing of the pulp then takes place under cast-iron cylinders heated by steam and made to rotate slowly.

Bleaching.—When the pulp has to be bleached at once, as when it is being prepared for filtering purposes, a clear watery extract of chloride of lime is almost always used, the active constituent in which is the hypochloride of lime ($CaCl_2O_2$). The pulp prepared by the acid process is easiest to bleach, and (for 100 parts of dry cellulose) about 8 per cent of chlorine (Cl_2) is sufficient; while for that made by the alkali process, from 10 to 12 per cent of chlorine is required for the sulphate-cellulose, and about 20 per cent for the soda-cellulose. Bleaching is confined merely to the necessary degree, because it diminishes the strength and elasticity of the felty fibres.

The ultimate **out-turn in cellulose** from the different kinds of wood is, weight for weight of raw material used, about the same. It is usually, however, slightly higher for Conifers than for broad-leaved trees, though the difference in the various kinds of trees is mainly due to variations as regards waste in cleaning and preparing the wood for treatment. One ton weight of seasoned wood yields on the average about 6 cwt., or 30 per cent, of cellulose by the soda process, and about 10 cwt., or 50 per cent, by the calcium sulphite process; and by the latter it has been found that every cubic foot of wood treated gives from 12 to 13 lb. of cellulose, or between 5 and 6 cwt. per ton of 50 cub. ft.

III. **Charcoal-burning** is probably, next to the conversion of timber, the most ancient of woodland industries; and it is one which was formerly of very great importance throughout Britain, before coal began to be used for iron-smelting. As early as 1558, timber-trees of Oak, Beech, and Ash were prohibited from being made into charcoal, and in 1581 and 1585 further Acts were passed to protect other trees in woods and underwoods (see vol. i., *Introduction*, pp. 18, 19). But even after the last charcoal iron-smelting furnace was shut down at Ashburnham, in Sussex, in 1809, the use of charcoal long continued to be of special importance in many industries,—such as gunpowder-factories, glassmakers, blacksmiths, locksmiths, &c. Nowadays, however, charcoal-burning plays but an unimportant part in British woodlands, being still practised on a larger scale in the Forest of Dean and in the Midlands than in any other parts of the United Kingdom. And of course with such a bulky, though light, material it is a special necessity that the place of production should be as near as possible to the place of consumption. Besides being still used by glassmakers, locksmiths, and black-smiths, it is much preferable to coal for the preparation of rolled steel and of armour-plates for warships; while for making the finer sorts of gunpowder Alder-buckthorn (*Rhamnus*) and Dogwood (*Cornus*) are still largely used when obtainable, with Alder for commoner sorts. In a glowing condition charcoal has a strong affinity for and readily absorbs gases and fluids, and also colour-ing matter and perfumes. To this property it owes its use for such purposes as extracting fusel-oil from spirits, and for clearing solutions, &c. When used for filtering water, such chemical action soon ceases, and only the purely mechanical action continues. Like other commodities, however, charcoal has felt the irresistible effects of the competition of coke from gas-works and of cheaper foreign imports both from east and west, so that now, in most parts of Great Britain and Ireland, charcoal-burning, when still carried on at all, is chiefly done to use up the lop and top and other waste wood in making small quantities for ordinary estate and household purposes.

Even in the great forests on the Continent, however, charcoal-burning has undergone quite a revolution during the last thirty years. When the author served his apprenticeship in forestry in Hanover (1873-4) a fortnight's course of charcoal-burning in the Harz mountains was considered a necessary part of one's work; but now that even within the depth of large forests wood has gradually risen in value for pulp, cellulose, &c., charcoal-burning in stacks or kilns built up in the open air with billets of wood and covered with a coating of brushwood and charcoal-dust has given place to more elaborate methods of **dry** or **destructive distillation** in retorts, which enable other products, such as acetic acid and wood-tar, to be obtained for commercial purposes, while still leaving the charcoal as a marketable residuum. Like the more primitive charcoal-burning itself, however, even these improved methods can now only prove profitable where the wood has a small value, owing to difficulty or cost of transport to timber-consuming centres.

Large quantities of wood-tar are produced in Scandinavia and Russia (see p. 603), and both these and the charcoal are exported. Even in Central Germany, at Laubach, in Hesse, it pays to use Beech for the dry distillation of acetic acid, leaving charcoal as a by-product, and the Friedrichshütte factory there consumes 280,000 cub. ft. of Beech yearly for this purpose. But of course it is only where wood is abundant and cheap that such an industry can possibly be profitable.

By the **dry distillation of wood** charcoal is produced either as (1) the chief product, or (2) merely as a by-product. In the former case, the **carbonisation** of the wood takes place under partial exclusion of air, but with direct application of fire, either in **pits** dug in the ground, or in **kilns** or **stacks** built of pieces of wood and covered with brushwood, earth, and charcoal-dust; while in the latter case it takes place in retorts, under complete exclusion of atmospheric air and without the direct application of fire. In the former processes there is, and always must be, a partial combustion of the carbon contained in the wood, simultaneously with the dry distillation; while in the latter, the more thoroughly the atmospheric oxygen is excluded, the more completely will the objects in view be effected, and the larger will be the yield both of condensible products of distillation and of the charcoal or carbonised wood forming the residuum.

When wood is heated under partial or total exclusion of air, first of all only the water it contains is driven off till the boiling-point is reached (212° Fahr.), but it is not until a temperature of about 300° Fahr. is exceeded that the decomposition of the woody substance begins. At higher temperatures than 300° Fahr., three stages of decomposition may be distinguished, viz.—(1) at from 300° to 500° Fahr., (2) at from 500° to 625°, (3) at from 625° to 800°.

During the first of these stages of great superheating (300° to 500° Fahr.) watery substances are evolved to the extent of about 60 per cent of the weight of the dry wood. These contain a small proportion of acetic acid, wood-naphtha, and similar products (combined in the form of *pyroligneous acid* or *wood-vinegar*), while tar and non-condensible gases are only emitted to a very limited extent.

During the second stage (500° to 625° Fahr.), the evolution of the watery substances decreases, and carbo-hydrates, such as marsh-gas (CH_4), acetyline (C_2H_2), aetyline (C_2H_4), &c., are given out along with carbon oxide (CO) and carbonic acid (CO_2), while the small quantity of nitrogen contained in the wood combines with the hydrogen to form ammonia (NH_3), and partly also methylamine (CH_5N). The total loss in weight now amounts to about 70 per cent.

It is during the third stage (625° to 800° Fahr.) that tar is chiefly produced, in the form of a dark-brown viscous mass, which mostly sinks down to the bottom of the watery products of distillation. Its chief constituents are paraffin, cresole, carbolic acid, benzole, toluole, &c. Almost the only gases now evolved are methan and hydrogen. By this time the original weight of the wood has been decreased by about 80 per cent, and the residuum, weighing about one-fifth of its original weight, consists of **charcoal**. If the temperature is superheated still more, the process of decomposition can be still further carried on, as an absolute elimination of all gases is impossible owing to small quantities of hydrogen and oxygen always remaining in the residuum; but for all practical purposes the **carbonisation** is fully completed at 750° to 840° Fahr. Ordinary charcoal, however, made at a temperature up to about 650° Fahr., weighs on the average about 25 per cent or only one-fourth of the weight of the wood used in forming the kiln.

In Violette's investigations into the carbonisation of the wood of the Alder-buckthorn (*Rhamnus frangula*), he obtained the following results (Schwackhöfer, *op. cit.*, pp. 325, 326, 340).

Temperature.		Every 100 parts by weight of dry wood gave		Every 100 parts by weight of the residuum contained			
Cent.	Fahr.	Distilled products.	Residuum.	Carbon.	Hydrogen.	Oxygen.	Ash.
150°	300°	...	100	47·5	6·1	0·1	46·3
260°	500°	60	40	67·9	5·0	0·6	26·5
330°	625°	68	32	73·6	4·6	0·5	21·3
432°	800°	81	19	81·6	2·0	1·2	15·2
Schwackhöfer's analyses of 18 samples of well-prepared kiln-charcoal made from soft and hard kinds of wood showed on the average the following composition (*plus* 4·6 per cent of hygrosopic water)				84·5	2·2	6·7	2·0

By whatever process it may be produced, **good charcoal** should possess the following qualities:—

(1) Its **colour** should be deep black, with a steel-blue metallic sheen, and lustrous across the transverse surface; and it should not change in appearance. The brownish or reddish colour of "foxy" charcoal is a sign of carbonisation having been incomplete;

while soft, dull-coloured charcoal which loses colour has either been made from unsound wood, or has been overburned.

(2) Its **texture** should be plainly visible ; and when broken transversely, the fracture should be shell-shaped or curved, and not straight across, and the broken pieces should show but few cracks. Charcoal made from unsound wood loses its texture, and cracks are formed if wood has been used damp or in billets of too large girth.

(3) It should be **strong** and **firm**, and should emit a clear **metallic sound** when two pieces are tied at the ends of a piece of string and struck together, or when it is being poured into sacks or baskets. Charcoal made from unsound wood, or that has been overburned, is dull both in colour and in sound, and is soft and dirty, rubbing off easily, and discolouring the hands when touched.

(4) It should burn with a short blue flame and without smoke. If not thoroughly carbonised, the flame is longer and whiter, and its heating-power is much less. Good charcoal kindles at a temperature of about 680° Fahr., and continues glowing slowly.

The specific gravity of charcoal in bulk, which partly determines its heating-power, varies from about 0·14 to 0·25, and is about 0·20 on the average. Close-grained hardwoods yield heavier charcoal than softwoods and Conifers ; large split billets give a larger out-turn than small branchwood faggots ; well-seasoned wood gives heavier charcoal than fresh, green wood ; charcoal made in kilns is generally less thoroughly carbonised, and therefore heavier, than that prepared in retorts ; and the slower the process of carbonisation, the heavier is the charcoal.

Good **kiln-burned charcoal** shrinks in length to the extent of about 10 or 12 per cent, and in girth to about 20 per cent for the wood of coniferous trees, and 25 per cent for that of broad-leaved trees. *Measured by volume*, an out-turn of about 50 per cent for soft or hard wood, and from 55 to 60 per cent for Pine and Fir wood, is a good average yield. *Measured by weight*, the out-turn varies from about 25 to 30 per cent, or about one-fourth to one-third of that of the wood with which the kiln was formed.[1]

Charcoal, if well prepared, weighs about 12 to 14 lb. a bushel when made from softwoods, and 14 to 17 lb. a bushel when made from hardwoods, or about 13 and 15½ lb. per bushel on the average respectively, and gives, as already noted, an out-turn of about one-fourth the weight of the wood used in its preparation. Thus, one ton by weight of *softwoods* will usually yield about 43 bushels of charcoal, and one ton of *hardwoods* about 36 bushels, or about 40 bushels per ton, or per small stack of cordwood, *on the general average* for different kinds of wood,—though each kiln should, if possible, be made of one kind of wood only. But of course the weight per bushel and the out-turn in bulk vary with the specific kind of wood, the size of the individual pieces of charcoal, and the way it is poured out for weighing and measurement. Its weight soon increases in the open air, as charcoal is hygro-

[1] Schwackhöfer estimates the percentage of yield in kiln-charcoal to be as follows :—

Kind of dry wood used.	On permanent hearths.		On temporary hearths.	
	By weight.	By volume.	By weight.	By volume.
Pine, Spruce, Silver Fir, Larch	20-25	60-70	18-22	50-60
Oak and Beech . . .	18-20	50-55	15-20	40-60

But on the average, *soft* woods give about 53 bushels, and *hard* woods about 37 bushels per 100 cub. ft. of stacked wood.

In France, Oak and Beech give 52-60 per cent of charcoal, Birch 65-68, Scots Pine 60-64, and Spruce 65-75 ; and a bushel of charcoal weighs 16-19 lb. (*Annuaire des Eaux et Forêts*, 1904, p. 299).

scopic, and absorbs from 5 to 12 per cent of atmospheric moisture; while if watered or exposed to rain, it can very soon absorb water to the extent of one-fourth to one-third of its own weight.

The selling price of charcoal is about 3s. a cwt., or 60s. per ton; and the actual cost of making is about 1d. a bushel, or about 7½d. to 8d. a cwt., and 13s. to 14s. a ton. Thus, if 4 tons of wood by weight, or 4 small stacks of cordwood, give an out-turn of one-fourth of their weight—*i.e.*, 1 ton or, say, 160 bushels of charcoal, then the price received for the wood (where charcoal can be made and sold at the above prices) is practically $60-14=46$s., or 11s. 6d. per ton or cord. Where charcoal-burning is still carried on as a regular bread-winning business, however, the cordwood is sold to the burners at a much lower price than this; and such kiln-men, working in pairs, can earn about 35s. to 40s. a week each, and sometimes more, during favourable weather.

The **heating-power of charcoal** is necessarily less than that of the wood used in making it, because of the loss of heat evolved during the process of carbonisation (which loss[1] generally amounts to about 40 to 50 per cent of the total heating-power of the wood); but as the carbon is purer and more concentrated in charcoal, its heating-power is greater than that of the same kind of wood bulk for bulk, and much greater weight for weight. The heating-power of charcoal for industrial purposes has been estimated (by Schwackhöfer) as follows in comparison with other kinds of fuel:—

Kind of fuel.	Heating-power in calorics or heat-units.
1. Wood, air-dried	3500-4000
2. Peat, according to age and quality . .	2500-4800
3. Lignite and brown coal, according to quality	2500-6000
4. Coal, according to quality	5000-7500
5. Charcoal, good kiln-burned . . .	6900-7600
6. Anthracite	7500-8000

Pure methylated alcohol=5310, and aethylated alcohol=7120 heat-units. Heidenstam's briquettes are said to=7800 (see p. 623).

Charcoal may be prepared in the following ways:—(1) in **pits**; (2) in **kilns**, usually *upright and dome-shaped*, or else *horizontal* and *prismoidal* in form (as sometimes on the Continent); and (3) in **furnaces** or **retorts** made of masonry and of iron, where other commercial products are chiefly to be extracted.

1. **Charcoal-pits.**—The oldest method of burning charcoal in Britain, and the most primitive and wasteful, is in **pits** dug in the ground to a depth of about 3 to 4½ ft., and with sloping walls. This is first filled with dry

[1] The loss is of course greatest in damp wood. But besides the direct loss of heating-power in eliminating the moisture, there is a further inevitable loss by the steam also combining with the glowing carbon to form carbonic acid and hydrogen ($C+2H_2O=CO_2+2H_2$); and this carbonic acid further combines with carbon to form carbonic oxide ($C+CO_2=2CO$).

brushwood and small branches, and then set fire to; and when the smoke has cleared away, the charred mass is stirred up and wood thrown in, and so on at intervals till the pit is quite full. The whole is then covered with turf and earth, and left for one or two days to cool down; then the pit is opened, and the charcoal taken out. The rough average yield is only about 30 bushels of charcoal per 128 cub. ft. of stacked wood (cord of $8 \times 4 \times 4$ ft.).

This method is still also in use on the Continent, but only where wood is of little value. And even there it is often combined with tar-boiling, the pit being dug on a hillside and lined with puddled clay or loam, and the wood raised somewhat off the ground on supports, while the progress of the burning is regulated by opening side-holes for vents, as in the case of upright kilns.

2. **Charcoal-kilns.**—An improved method of charcoal-burning in **dome-shaped kilns**, long practised in the British woodlands for ordinary estate or household purposes, was thus described by Brown (*The Forester*, here abbreviated):—

The wood being collected in billets about 15 in. long at a suitable place, the kilns or stacks are formed about 12 to 20 ft. in diameter according to the quantity required. The site selected having been levelled, a large billet of wood, pointed at one end and split crossways at the other, is fixed in the centre of the hearth, and two pieces of wood inserted at right angles through the clefts of the upper end. In these angles four billets of wood are placed, end on the ground and leaning against the central post, and large straight billets are laid radially on the ground, like the spokes of a wheel, to form a floor, the spaces between being filled with brushwood or small branches. To keep the billets in proper position as first arranged, pegs are driven into the ground round the circumference of the hearth, about a foot apart. On this floor a stage is built with billets set upon one end, but inclining slightly towards the central billet; and above these another layer of shorter billets is laid horizontally till the whole forms a cone. It is then covered with turf, and the surface faced with mixed earth and sand. To light the kiln, the central billet in the upper layer is drawn out, and pieces of dry combustible wood are substituted and set on fire. Great attention is necessary to regulate the fire properly, and to immediately close any apertures through which the flame obtrudes. The burning generally takes from four or five days, according to circumstances. When the charcoal seems ready, judging from the colour of the smoke and the absence of flame from the air-holes, all the vents are closed carefully with mixed earth and sand, to exclude the external air and prevent further burning. The fire then goes out, and the kiln is allowed to cool before the covering is removed and the charcoal taken out.

The **cubic contents of such a dome-shaped kiln** are easily known exactly if stacked cordwood has been used. Otherwise, it may be estimated from the size and shape of the kiln. The lower and the less conical its contour, the more it approximates in shape to a *paraboloid*, the cubic contents of which $= \frac{1}{2}$ (*basal area* $\times$ *height*); while the higher and the more conical it is, the more it approximates to a *cone*, the cubic contents of which $= \frac{1}{3}$ (*basal area* $\times$ *height*). In most cases, especially if the kiln be somewhat pointed, a formula of cubic contents $= \frac{4}{9}$ (*basal area* $\times$ *height*) would probably be fairly correct; but throughout Germany the general practice is to use the formula for a paraboloid and deduct about 5 per cent or more, according to shape, in order to allow for the pointing of the kiln.

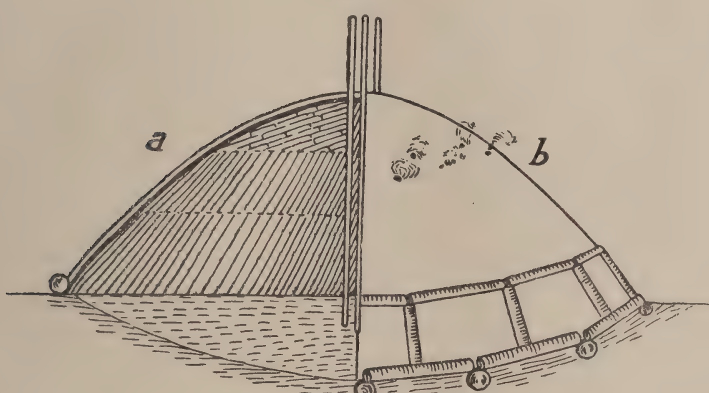
As it is easier to measure the girth than the radius of a kiln that has been built up, the above simple formula has to be modified accordingly. Thus $\frac{1}{2}$ (*basal area* $\times$ *height*)

$$= \pi r^2 \times \frac{height}{2} = \frac{\pi d^2}{4} \times \frac{height}{2} = \frac{\pi^2 d^2}{4\pi} \times \frac{height}{2} = \frac{girth^2}{4\pi} \times \frac{height}{2} = \frac{girth^2 \times height}{25 \cdot 12}.$$

The only **Continental method of charcoal-burning**, which need here be described in detail (Fig. 282), is that of preparation in **dome-shaped kilns**. This process is in many respects very similar to the above British method, although the hearth is not prepared with any staging of radiating billets. Such a radiating ground-floor staging is, however, used in the *Alpine or Italian method*, practised in the Alps (with Spruce chiefly, and to a less extent with Silver Fir and Larch, with large pieces 6 to 6½ ft. long, and only split through once if over 18 in. in diameter, built up in kilns of 5000 to 10,000 cub. ft. or more in contents). A staging of parallel poles is also used in *horizontal* or *prismoidal kilns*, shaped like a truncated wedge, and containing up to 10,000 cub. ft. of wood (the largest pieces being put near the middle), a method practised in Austria (with Austrian Pine chiefly) and also in Sweden (with Spruce and Pine).

The common method in Central Europe is to form upright paraboloidal kilns

Fig. 282.



Dome-shaped (*Paraboloid*) *Charcoal-Kiln.*

a, Central section; showing arrangement of wood in kiln (with largest billets about half-way between centre and circumference).
b, Outer view; showing smoke-vents, and lower and upper supports.

with billets of wood about 3 to 3½ ft. long, and from over 1 in. diameter at top end up to large girth. Billets over 6 in. diameter are split through once, and those of much larger size into several pieces as required; and all branches and snags are lopped to let the billets pack closely. When the hearths are merely temporary, and the charcoal-burners move from place to place, the kilns are usually of from 700 to 1200 cub. ft. contents; but on a permanent hearth they are made much larger, and contain from about 2000 to 3500 cub. ft., as of course the larger the kiln, the less covering it requires in proportion to its contents, the better is the heat utilised, and the cheaper is the cost of production. But the smaller kilns are easier to form and manipulate during the process of burning.

So far as possible, the kilns are usually made of one kind of wood, and of pieces of about much the same size (except the smaller branchwood used for filling in between the large billets), as the burning is then more regular, and the charcoal more equal in quality. Where there are differences in the kind of wood and the size of the billets, the harder, heavier, and larger wood, which is the more difficult to char, should be placed near the middle of the kiln, where the temperature soon becomes highest. The wood should be thoroughly seasoned, as damp wood takes longer to prepare, burns more irregularly, and gives only a smaller out-turn.

The charcoal-burner's work consists of the various operations of—(1) *preparing the hearth;* (2) *building, covering, and lighting the kiln;* (3) *regulating the course of the firing, filling in parts that shrink and sink, and watching the kiln till it has cooled down;* and (4) *breaking up the kiln, and assorting the charcoal according to size.*

1. **The Hearth for a Charcoal-kiln** should be level, sheltered from wind, and with plenty of water close at hand. If practicable, a large level site is best, where two or more kilns can be conveniently formed, and to which wood can be easily brought. The ground should be dry (being drained, if necessary), and the soil should be of medium consistency, neither so porous as to let air circulate comparatively freely, nor so binding as to exclude it. Too light a soil makes the kiln burn quickly, while too stiff a hearth retards the firing process, and does not readily absorb the waste products of the distillation. A loamy sand makes the best hearth, being neither too "hot" nor too "cold"; but whatever the kind of soil, it must be of the same kind and porosity all over, and should be free from cracks and large stones. An old kiln-site is preferable to, and draws better than, a new one.

Where a new hearth has to be formed, the ground should first be cleared of all surface-growth, stones, roots, &c., then levelled, and the circular outline of the kiln traced on the ground with a cord as radius attached to a peg driven in at the central point. The ground is then pared and sloped off, a regular but very slight fall being given all round from the centre to the circumference, so that the middle point is about 8 to 12 in. above the edge,—the heavier slope being of course given on a stiff, tenacious soil, to provide a freer draught and to let the distilled waste products run off better. Thus prepared, the hearth is well trodden down and left to season for some time, and preferably over a whole winter, before being repaired (if necessary) and dried superficially by kindling a fire of brushwood previous to using it for the first time. On a new hearth the first kiln always gives an out-turn of at least about 5 to 10 per cent less than what may be expected from subsequent kilns after once the hearth gets seasoned and draws well.

2. **The Building of the Kiln** commences by forming the flue for lighting it and for acting as a central vent. This is made by firmly inserting three or four good stout poles (about as thick as one's arm, and as long as the kiln is high) at 12 to 15 in. apart in the centre of the hearth, and binding them together firmly with withes to form a flue, which is filled with inflammable substances like resinous chips, dry bark and brushwood, pieces of half-charred wood, &c. A cone of similar combustible matter and half-charred wood is also piled closely round the base of this central shaft, to enable the fire to get a thorough hold of the middle part of the kiln.

If the kiln is to be fired from above, sorting of the billets can now be begun at once; but if it is to be lighted from below, a *lighting-vent* is formed on the leeward side by laying down a thick pole of about 6 in. in diameter from the foot of the central shaft to the edge of the kiln, like the spoke of a wheel; and this is gradually withdrawn as the lower stage of billets is laid.

In building up the kiln, the billets are all placed thick end downwards, and at as high an angle as is convenient, so that finally the sides of the kiln rise at an angle of about 60°. If steeper than that, there is always a danger of the outer covering of earth, &c., slipping or failing to hold well together. Where large split billets are used, they are ranged so that the split side also faces inwards towards the centre of the kiln. The smaller-sized billets are first ranged all round the central shaft, then come billets of larger diameter, then those of largest size, and then those of smaller size again towards the outer edge. Thus the billets of largest girth come half-way between the centre and the circumference, or just where the heat is greatest; while those of smallest girth occupy the inmost and outmost positions, where the heat is not so intense. By this means the process of carbonisation is effected much more regularly and equally than would otherwise be possible. To keep the lowest tier of billets level on the top, those placed above the lighting-vent have of course to be about 6 in. shorter than the others.

When the lower tier is laid to about half the length of the radius, the second tier is begun in similar manner, and the laying of both is then continued to completion, after which the third, or top, tier, consisting of small-sized billets, is laid more or less obliquely and horizontally, so as to round off the top of the kiln.

The closer the billets are packed together in forming the kiln, the less chance there is of too great a draught (and consequent wastage) during the firing; and hence the need of trimming away branches and snags as clean as possible. All interstices between the larger billets should, during the process of building them up, be filled with smaller pieces; and this is especially necessary near the outer surface of the kiln, to prevent dirt from the exterior covering trickling through into the burning kiln.

The Covering of the Kiln consists of two layers. The *inner layer* of turf-sods, leaves, moss, young branches of Pine or Fir, bracken, sedge, &c., forms a sort of elastic support for the earthy *outer layer* when the kiln begins to sink in places during the burning, besides preventing the earth from trickling through. But it is this upper and outer layer of "breeze," formed of a moistened mixture of humose loamy soil and charcoal-dust, which excludes the atmospheric air and enables carbonisation to proceed without the risk of total combustion. This should form a thick, plastic, pasty mass, stiff enough to enable it to be plastered over the inner layer, but yet soft enough to permit of the escape of steam and gas, and to settle down easily without fissuring and cracking as the kiln gradually shrinks during the process of burning. The thickness of the outer earthy covering depends on the kind of inner layer, on the size of the kiln and of the billets, and on the state of the weather, &c., and it may vary from about 2 or 3 up to 8 or 10 inches in thickness. The thinnest outer covering is put over an inner layer of turf-sods, while young Conifer branches need the thickest over-casing.

The outer covering rests upon and is kept in position by means of *supports*, of which there are usually two kinds, the *lower* and the *upper*. The *lower supports* can only be dispensed with in a kiln the inner layer of the covering of which is formed of Conifer branches, as this never lies so close to the wood inside as to form an air-tight casing. They consist of big stones of about 6 in. in diameter, or else stout forked or other pegs of wood driven in to that height, all round the edge of the kiln, and of billets laid horizontally to form a base upon which the lower part of the covering may rest. As these billets get more or less charred, and can generally only be used once, iron supports are sometimes employed. Made in the form of segments of a circle, and having a foot at one end, they are not only durable, but give a better contour to the kiln, as they can be laid closer to the kiln-wood than horizontal billets. A row of *upper supports*, placed 3 to 4 ft. above the lower row and resting on upright billets standing upon the latter, is only needed on kilns formed at a high angle (60° to 70°), or during dry weather, when the covering does not hold well together.

If the kiln has had to be built on a spot not naturally well sheltered, a stout wind-screen of brushwood has to be formed higher than the kiln, and about 7 to 10 ft. to windward, as a strong breeze interferes with steady firing.

The Lighting of the Kiln may take place either from above or below, as previously arranged for. In the former case, a small fire is kindled at the top of the central shaft filled with inflammable material, and this gradually burns its way down to the conical mass of combustible stuff piled round the base of the flue. If lighted from below, a torch is made by splitting and splintering the end of a long pole and priming this with resinous chips, which are set fire to and carefully pushed along the lighting-vent to the foot of the central flue, so as to ignite the combustible material in it, and around its base. Whether the kiln be lighted from above or below, however, draught-holes must at first be left open between the lower supports; and it is always lighted before daybreak on some wind-still morning.

3. It is in **regulating the Course of the Firing** that the main art of charcoal-burning lies. Whether lighted from above or below, the fire first consumes the combustible matter within and around the base of the central shaft or flue, and from here it ascends to the top of the kiln and spreads over the dome. When this becomes thoroughly heated, steam and thick cloudy white smoke, highly charged with gases, issue through the covering of the kiln, thus showing that the fire has caught on properly. As soon as the temperature inside the kiln rises sufficiently high, the moisture in the wood is converted into steam, which at first condenses through contact with the cold earthy outer layer of the covering, and the whole of its dome then begins to smoke and "sweat." This is a critical time for the kiln, because if the earthy outer layer of the covering be not sufficiently porous to let the steam and gases escape, or if the hearth be so porous as to create too strong a draught all over the sole, or if the fire burn very quickly and steam be generated too rapidly (as is most likely to happen with thoroughly seasoned wood), or if there be a large proportion of combustible gases (and especially of carbon oxide and carbo-hydrates) emitted along with the steam, there is always more or less of danger that the pent-up steam and gases may cause an explosion, which would blow off the covering, disarrange the kiln, and necessitate at any rate partial rebuilding. At this preliminary stage it is chiefly the explosive power of the steam that is to be feared; while the danger of the kiln being blown up by a gas-explosion is subsequently greater.

When the risk of such a mishap has passed, within an hour or two the smoke becomes very pungent and acrid, showing that the process of carbonisation has begun, and that the decomposed substances are being emitted. The glowing mass of fire at a very high temperature then begins to assume the outline of an inverted cone, the point of which gradually extends downwards to the foot of the kiln, while the sides spread more horizontally all round towards the circumference, until finally the process of carbonisation extends even to the lowest and outermost edge, when flames issue from the base, and the firing is completed.

The actual progress of carbonisation is, however, nothing like so regular and simple as above described, as a great deal of attention is required to regulate the rate of the fire in its downward progress. On the leeward side vents or smoke-holes have to be opened by shoving a good thick stick or broom-handle right through the covering in order to stimulate the progress of the fire, while all round the kiln the covering has to be packed firm to make it less porous, and to prevent the fire from pushing downwards unevenly or too quickly—the aim always being to keep the outer level or base of the inverted cone of fire as nearly horizontal as may be possible. Until about 24 hours after lighting the kiln, when the "sweating" is ended, and about 8 to 12 hours after the first and main filling-up of shrunken parts has taken place (see below), no smoke-vents are opened. But before opening any side-vents, the open spaces near the lower supports at the foot of the kiln are closed; and they are not re-opened unless an increased draught is wanted. The first vent-holes are pierced on the sheltered leeward side of the kiln, and at about the height where the second and the third tier of billets meet; and sometimes one, sometimes two rows of holes are made, according to the way the firing seems to be progressing. The manipulation of the vents is mainly regulated by the colour of the smoke issuing from them. This is at first very thick and full of steam; but as the line of fire gradually descends towards the level of the vents and the zone of complete carbonisation approaches nearer and nearer, the smoke also gradually changes, its colour becoming yellowish-brown, and its odour pungent and acrid from the pyroligneous acid and the different gases emitted as the decomposing work of dry distillation progresses. A more advanced stage is reached when the smoke becomes clearer and pale-blue in colour, and less pungent in odour; and finally (unless the vents are now closed) a blue flame (due to carbon oxide, CO) comes from the smoke-hole, thus showing that the zone of greatest heat has descended that length, that carbonisation is so far completed, and that to keep the vent open longer could only mean a wastage of carbon and combustion of the charcoal. But the charcoal-burner does not await this latter stage. As soon as the smoke turns white in colour, the whole row of vents on that level is closed with the same material as the outer covering is made of and firmed down by the back of a spade, while a fresh row of smoke-holes is opened lower down. And so on, until complete carbonisation extends right down to the base of the kiln—the progress of the fire being here stimulated by opening vent-holes, and there retarded by closing them up again, or even, wherever necessary, by watering or adding to the thickness of the outer layer of the kiln-covering.

The course of affairs never runs quite smooth in the burning of a large kiln. Despite the wind-screen, the exterior air-currents usually cause the fire to proceed too quickly on one side, and this can only be regulated by skilful opening and closing of the vent-holes; and there are always smaller or larger explosions of gases, which must never be allowed to accumulate in such quantity as to blow off any large part of the covering and disarrange the wood being charred. Any little damage done by small explosions must therefore be promptly repaired so as to keep out the atmospheric oxygen as much as possible and prevent wastage. Then, too, there are always places in a big kiln where the wood sags and shrinks, and these places have to be opened, filled up with half-charred wood, and closed and firmed again as quickly as possible. The lighting of the kiln causes the first hollow, when the inflammable matter in the central shaft is burned, and as the individual billets of wood shrink during carbonisation by from 30 to 40 per cent of their original volume (or even 45 to 50 per cent if still somewhat green and unseasoned), the total shrinkage of the kiln-covering is great, and is very seldom indeed anything like so regular and equally distributed as to be accomplished without producing great hollows here and there, which have to be filled in to prevent the cover from breaking or fissuring deeply. The drier and better seasoned the wood, the closer the billets are packed in forming the kiln; while the more gradually and regularly the firing proceeds, the less sudden is the shrinkage in different parts, and the fewer the number of hollows that require to be opened and filled.

The first or main **filling-in of shrunken hollows** in the covering takes place about 12 to 16 hours after the kindling of the kiln, when the shrinkage, due mainly to the conversion of the wood-moisture into steam, causes large depressions in the covering. Unless filled, such hollows would cause a draught and lead to considerable wastage by combustion. At such places the covering is removed to the necessary extent, the inside wood pressed down, and the vacant space filled by packing in quickly as much new wood as possible, then replacing new inner and outer layers of the covering, and firming the place by beating with a broad wooden mallet. Such work of filling has usually to be repeated on a smaller scale on the second, third, fourth, and sometimes also the fifth days after kindling, the shrunken hollow places being opened, the charring wood inside rammed well in, and the vacant space closely packed with half-charred billets from a previous kiln and small pieces of fresh wood, and the covering restored and beaten down quickly. These smaller hollows are located by means of sounding with a small wooden mallet. Whenever such shrunken parts are to be filled, all vent-holes near them should be closed at least an hour previously, and the material for filling in should be collected at the spot where it is needed, so that the operation may proceed as quickly as possible, to prevent any bursting into flame. No smoke-vents are opened in filled-in hollows for about 12 hours after filling.

Watching the Kiln.—To keep the process of carbonisation as regular as may be practicable, the charcoal-burners have every evening to beat down the covering with the sounding-mallet as the fully carbonised zone extends, and to plaster and cover up cracks by dressing them with moist stuff of the same sort as the outer layer of the covering is formed, and at the same time to make any necessary fillings—the latter operation of course best taking place during darkness. Watering the covering with a watering-pan tends to diminish the risk of cracking in the upper part of the covering. The kiln has to be seen to from time to time every night.

As the filling of hollows always means a certain amount of wastage, it is of course desirable to obviate the necessity for doing it, so far as practicable, by having a good hearth, and by building the kiln closely and compactly with well-seasoned cordwood.

Cooling down the Kiln.—When the process of carbonisation is completed right down to the outer edge, the air-spaces at the base are closed (if this was not done previously), and moist earth, &c., are thrown all over the kiln, which is then allowed to cool down for about 24 hours. The extinction of the glowing mass can be hastened by scraping off the covering in strips and immediately replacing it with a fresh covering.

4. **The breaking up of the kiln** begins as soon as it has cooled down sufficiently. It is commenced in the evening after dark and continued throughout the night, as it is then easier to see the glow than during the daytime. The charcoal is taken out or "drawn" by means of a iron fork or hoe with long, bent prongs, and the drawing begins at the front of the kiln, and with a proper screen against wind. At first about 70 to 100 cub. ft. of charcoal are pulled out at one place, or just as much as can be drawn without causing the kiln to burst into flame; then the opening thus made is closed again, and a fresh draw is made from another part. As the charcoal is still very hot and easily fanned into a glow, it has usually to be sprinkled with water from a watering-can. And so on all round the edge of the kiln, until the whole of the marketable charcoal has been drawn. What is left of the central part formed by the main flue and the combustible cone at its base now consists only of small pieces of charcoal ashes and of the earth forming the covering, which are raked out over the hearth and left there for use in covering the next kiln.

The charcoal is then sorted according to size, kind, and quality. First of all it is hand-picked for all the larger pieces and then assorted as (1) *foundry charcoal*, for which all the largest pieces are reserved, and (2) *smithy charcoal*, consisting of pieces up to the size of a man's fist, or over. What then remains is sorted into two smaller sizes by being sifted through a wide-meshed screen. Half-charred billets and pieces are reserved for use in filling shrunken hollows in subsequent kilns.

The very small pieces and charcoal-dust can be pressed into *briquettes* along with some binding substance. Tar is the cheapest of these, but briquettes made with it have to be specially treated to get rid of objectionable gases; sawdust is therefore preferable to charcoal-dust (see p. 606).

The time taken to burn a kiln of course varies greatly with its dimensions, the size and the moistness of the billets of wood it is formed of, the state of the weather, and the way the firing proceeds. But the best quality and the largest out-turn are usually obtained when the carbonisation is effected at a fairly quick rate. Th average time is generally as follows:—

Kind of billets.	Size of kiln.	Time taken for carbonisation.
	Cub. ft.	Days.
Beech-wood, split	700-1400	4-5
Conifer-wood		6-8
Beech	2100-2800	7-8
Conifer		10-12
Beech	3500-5200	10-14
Conifer		15-20
Unsettled weather retards the process considerably.		

Charcoal made in masonry furnaces or iron retorts is a residuum or by-product of wood treated in closed vessels at a red heat, mainly for the production, on a commercial scale, of fluid products such as **pyroligneous acid** or **wood-vinegar** (the crude commercial form of acetic acid) and **wood-tar**,[1] which pass over in vapour and are condensed, and sometimes also of purely gaseous products like **wood-gas**. In Britain, the use of waste wood for such purposes has now practically ceased to be profitable as a petty industry on landed estates, owing to the cheaper Continental and American imports. This kind of industry can now only pay when undertaken on a large scale in permanent **factories** located near large woodlands, where wood is cheap;[2] and closed **retorts** of course give a larger out-turn than **furnaces**, owing to the air being more thoroughly excluded during the process of distillation and carbonisation.

(1) **Upright masonry furnaces** were usually originally employed, and still are, for the extraction of pyroligneous acid and tar on a large scale. If so built that the charcoal cannot be drawn until the whole furnace cools down sufficiently this occasions a great loss of time, as the dry distillation in a furnace of about 3000 to 4000 cub. ft. capacity is completed in 6 to 8 days, while it takes other 12 to 16 days before it has cooled down and the charcoal can be extracted. Hence three furnaces are needed, in order that one may always be in use for actual distillation. And they have the additional drawback that there is always a loss by percolation through the chinks of the stone or brick masonry.

Improvements of various kinds have been made on such primitive furnaces, which permit of more pyroligneous acid and wood-tar being obtained, though at the cost of a greater or less wastage of charcoal. One of the best now in use (Bach's patent) consists of an upright carbonising-shaft, ending in a neck below, from which the charcoal can be drawn, and having a cap at the top for warming

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[1] During the seventeenth and eighteenth centuries the Pine forests of the Scottish Highlands furnished, like the American Colonics, large supplies of tar and pitch for the British Navy (see vol. i. p. 25).

[2] **Small transportable metal retorts** of about 60 to 80 cub. ft. capacity are not found profitable, even in well-wooded districts on the Continent, and even though they can be made to yield from seasoned wood about 70 per cent of marketable products (pyroligneous acid or crude wood-vinegar, 45 per cent; tar, 6 per cent; charcoal, 20 per cent). The main reason for this is that the pyroligneous acid is, as a rule, only marketable when transformed into acetate of lime, which cannot conveniently be done except in a factory; while repairs to the retort and condensing apparatus are difficult to carry out; and it is often easier to transport the wood (on timber slides, or by floating) than the crude products of its dry distillation.

the wood before the destructive distillation begins. And when resinous Conifer-wood is being used, this is here treated with superheated steam, in order to carry off the oil of turpentine, before the wood is let down into the carbonising-shaft when thus warmed and partially dried. Distillation in the shaft is carried out by pumping in from below just sufficient air to maintain the fire. The carbonic acid (CO_2) thus formed becomes reduced to carbon oxide (CO) in passing over the incandescent mass, and distillation is effected by the upward current of de-oxygenised air. The temperature varies at different levels in the shaft, being greatest down below where the air is pumped in, and decreasing gradually at the higher levels. Low down, where the heat is greatest, the last remnants of gaseous constituents are volatilised, the carbonisation of the wood is completed, and the charcoal is drawn and cooled by being plunged in water. Above that, in the zone throughout which the temperature ranges from about 550° to 850° Fahr., tar-vapour is emitted; and in the upper portion of the shaft, the pyroligneous or crude acetic acid (from which pure acetic acid and wood-naphtha are subsequently obtained by *fractional distillation*) is mainly given off where the temperature ranges between about 300° to 550° Fahr. The tar and the pyroligneous acid can be collected in separate condensers, while the inflammable gases ascending to the top of the shaft are led off from there for heating-purposes—either throughout the factory, or to the foot of the carbonising-shaft of the furnace.

(2) Closed **Iron Retorts** give a larger yield of pyroligneous acid and tar than can be got from furnaces. The retorts may either be **horizontal** or **vertical**, and these latter may either be **cylindrical** and fixed in masonry, or somewhat **conical** and **movable**. The retorts now mostly used are **horizontal cylinders** of strong malleable iron, about 10 ft. long by 3 to 3½ ft. in diameter (or about 70 to 80 cub. ft. capacity), closing with a cast-iron door in front, and having a tube at the back for carrying off the products of distillation. They are built into, or rest upon, masonry supports, which contain the fire-place. In place of the flames from this being allowed to come in direct contact with the retort, the hot air and the inflammable gases, generated during distillation and utilised for heating, are made to circulate around the retort before escaping from the chimney. While still hot from the last charge, the cylinder is packed as full of wood as possible; and to facilitate the drawing of the hot charcoal, an iron frame is fitted into the back with a long iron handle extending to the front. The process of distillation takes from about 12 to 16 hours, and the charcoal is then drawn quickly into sheet-iron cooling-cases mounted on wheels, which can contain the yield of one retort and be hermetically closed and allowed to cool down for about 36 hours.

The **vertical cylinders** are built into masonry, and are filled from above and emptied from below. The heating takes place from the side, to prevent the actual contact of the furnace-flames, and the heating-gases circulate spirally round the retort before escaping from the chimney, while the tube for leading off the pyroligneous acid and tar is at the top, just below the lid.

The somewhat **conical** and **movable retorts** are attached to their masonry supports by a strong cast-iron flange round their broad upper end. They are fired from below. The flames from the furnace do not come directly in contact with the retort, but holes in the arched brickwork allow the heating-gases to ascend and heat the walls of the retort before escaping above. When distillation is completed, the retort is raised and removed by a travelling crane, the lid at the top is opened, the whole tilted up, and the hot charcoal emptied into an iron cooling-case. The retort is then filled with wood, ready for replacing the next retort to be moved.

The different **vapours and gases** generated in any of the above kinds of retorts escape through a cooling-worm, which acts as a condenser and leads the fluid, raw acid to a collecting tank, while the inflammable gases are conveyed by pipes to the furnaces, to be used in heating the retorts. On movable retorts the condensing pipe can of course be unscrewed from each retort when removed, and attached to that taking its place.

In the collecting tanks, most of the tar sinks to the bottom, while the crude pyroligneous acid may be drawn off from above.

(*a*) **Wood-tar,** known commercially as **Stockholm** or **Archangel tar,** is of a dark-brown colour and a treacly consistence, and has a characteristic tarry smell if made from the wood of Conifers; while it is grey-brown to dark-brown in colour, tallowy or fatty to the touch, and has a strong burnt smell when made from the wood of broad-leaved trees. It is mostly used in its crude condition for coating fishing-boats and bridge-piles, fencing, &c.[1]

The **chemical composition of wood-tar** is very complicated, over twenty constituents being already known. If subjected to *fractional distillation*—by the application of slow heat gradually rising to a very high temperature, and thus allowing the different constituents to escape into condensers in a *series of fractions* on their respective distilling-points being reached—it can be reduced to form three other marketable products—namely, (1) 10-15 per cent of *light oil* (sp. gr. 0·90-0·97), "pine-oil," or *naphthas*; (2) *heavy oil* (sp. gr. 1·01-1·02) or *crude creosote;* and (3) 40-50 per cent of *pitch* as residuum—the other 15-35 per cent evaporated being water and a little acetic acid.—The **light oil,** which consists chiefly of a series of carbo-hydrogen compounds (such as Benzol (C_6H_6), Toluol (C_7H_8), Xylol and Cymol), is separated as the temperature gradually rises to 320° Fahr.; and when refined, by elimination of the acetised water mixed with it, this can be used either for illuminating purposes, or in making solutions of fats, resins, &c.—The **heavy oil** distilled off when the heat increases to about 350°-500° Fahr. consists of creosote mixed with various other substances. This crude oil is sometimes used for impregnating wood, or for making waggon-grease, &c.; but it is generally refined to obtain the pure creosote by re-distillation, the oil which sinks in water being separated and mixed and shaken with concentrated sodium-lye, thus dissolving the creosote while leaving the other constituents undissolved. When this alkaline solution is cleared and treated with sulphuric acid, the heavy, oily creosote separates from the watery fluid, and can then be collected and refined by re-distillation.—The *pure creosote* thus obtained (which is, however, not a pure chemical substance, but a very complicated mixture of phenol, creosol, paracresol, phloral, &c.) is an oily and highly refractive fluid, colourless at first, then gradually turning yellow with exposure to light; it has a smoky smell, and burns the skin if applied to it. Its specific gravity varies from 1·03 to 1·08, its reaction is neutral, and its boiling-point lies between 400° and 430° Fahr., while it retains its fluidity to close upon 0° Fahr. It dissolves easily in alkaline lyes, alcohol, and æther, but not readily in water.—The **pitch** left as residuum hardens, as it cools down, into a lustrous black substance, which breaks with a shell-like fracture. It consists chiefly of paraffin and similar carbo-hydrogen compounds, and is largely used for caulking the seams between deck-planks and other wood-work of ships and boats, wood-paving-blocks, &c.

(*b*) Crude **Pyroligneous Acid** or **Wood-vinegar,** the crude commercial form of acetic acid, contains tar, creosote, wood-naphtha, and other impurities, which can only be removed by fractional distillation, and of which only the acetic acid and wood-naphtha have then a commercial value. This acid is largely used in making the acetates employed by dyers and calico-printers; and when purified and diluted with five times its volume of water, it is used as a substitute for vinegar in pickling and for table use; while it gives a "smoked" flavour to fish cured with it. As drawn off from the collecting tank the raw acid is a dull, reddish-brown fluid, having a tarry, pungent odour, a strong acid reaction, and a specific gravity of

[1] In Russia a thin, light, volatile, oily, greyish- to blackish-blue, opalescent, fluid tar, smelling very much like petroleum, is made from **Birch-bark.** It consists mainly of Toluol (C_7H_8, to about 50 per cent), Benzol (C_6H_6), and similar substances, and is used for obtaining these and for preparing "Russia leather."

1·02-1·05. Beech, Oak, other hardwoods, and Birch give the best form of acid. The crude acid drawn off from the collecting tank is usually at once prepared for market. The more primitive way of doing this is to neutralise it with quicklime, then enclose it in a retort and distil off the spirituous substances it contains ; and the dry residuum left after evaporating the water consists of grey acetate of lime—though not in a pure form, owing to its being mixed with tarry substances.

In large factories an improved method is used, by which acetate of lime and crude wood-naphtha are obtained without vinegar being formed. These purer products are got by re-distilling the raw acid, after first neutralising it, in three stills or retorts ranged one above the other, sideways, to form a battery. The lowest and largest, which is heated by steam, contains the raw acid for distillation. The acetic acid vapour here produced is conveyed to the second retort, filled with dilute milk of lime, with which the acetic acid combines. The vapour escaping from this is conducted to the third retort, also filled with dilute milk of lime, which absorbs the rest of the acetic acid. The spirituous and watery vapour now left is led off into a cooling-vessel, where it is completely condensed and run off as crude **wood-naphtha, wood-spirit,** or **methyl alcohol,** ready for refining and rectification. The acetate of lime solutions in the second and third retorts are clarified by being pumped through a filter-press, and are then led off to be dried by first evaporating the water and then heating the residual grey powder in shallow iron vessels. This purified grey **acetate of lime** ($Ca(C_2H_3O_2)_2$) is the commercial product used as the raw material for the preparation of acetic acid, acetic salts (acetates), and acetone.

To obtain **acetic acid** ($C_2H_4O_2$) the pure acetate of lime is dissolved with just sufficient dilute hydrochloric acid as may be needed, and acetic acid is distilled off at a temperature of 212°-250° Fahr.—when $Ca(C_2H_3O_2)_2 + 2HCl = CaCl_2 + 2(C_2H_4O_2)$. Though colourless, the acid thus distilled has a faint tarry smell, which is removed by re-distillation with an addition of 2-3 per cent. of bichromate of potassium. The distilled product contains about 35-40 per cent of pure acetic acid.

Since soda became cheaper, however, acetate of soda is often used in place of acetate of lime, and it has the advantage of producing almost pure acetic acid. The pyroligneous acid or wood-vinegar is neutralised with soda ; and after the tarry substances are removed, this solution is distilled and the wood-naphthas are separated. The residual fluid is run off into a flat pan and reduced by heat to a 27 per cent solution (weighed warm), when it is still coloured red from tarry constituents. While still hot it is run into iron crystallising cases, where the acetate of soda crystallises ; and on the crystals being separated centrifugally from the parent lye, they are melted in a boiler. Here the water of crystallisation is evaporated, and the heat is gradually increased till the whole mass becomes fluid and stands the test of forming a colourless solution in water. When this point is reached, the contents of the boiler are emptied into boiling-hot water, and the solution is filtered and spread out for crystallisation. These crystals are also separated centrifugally from the parent lye and distilled along with sulphuric acid, when almost chemically pure acetic acid is given off (here $2(NaC_2H_3O_2) + H_2SO_4 = Na_2SO_4 + C_2H_4O_2$).

Pure acetic acid has an extremely sharp, pungent smell, and blisters the skin if applied to it. It mixes readily in water, alcohol, and æther, and dissolves essential oils, camphor, resins, gums, &c. It is a monobasic acid, the salts of which are called *acetates*. Many of these, formed either from acetate of lime to begin with, or from free acetic acid, are used in dyeing, calico-printing, colour-making, and for chemical and pharmaceutical purposes, the chief being the acetates of lead, copper, iron, and aluminium.

By the dry distillation of **acetate of lime** at from 570° to 750° Fahr., **acetone** (C_3H_6O) is obtained. This is a fluid having a peculiar odour, a specific gravity of 0·79, and a boiling-point of 133° Fahr. ; its vapour is combustible, and forms an explosive mixture with air. It is chiefly used for the manufacture of smokeless powder, and as a solvent for oleo-resins. The crude acetone obtained by the first distillation is mixed with water to eliminate the tar-oils, and then re-distilled with the addition of soda-lye—the first, the medium, and the final products being collected separately. The medium product gives pure acetone on being rectified with permanganate of potash ; while the impure first and final products are again re-distilled, and then treated similarly. Acetate of lime gives 24-25 per cent of crude and 20-22 per cent of pure acetone.

The crude **wood-naphtha** or raw **wood-spirit** has to be subjected to several complicated processes before soluble naphtha and methylated alcohol can be produced for commercial purposes. To render it suitable for preparing aniline colours, the acetone has first to be got rid of by boiling it in a closed vessel, into which chlorine gas is introduced. This unites with the acetone, and forms a chloride having a high boiling-point, so that the wood-spirit distils off. This is again rectified with lime, and then forms the strong-smelling commercial product known as **methylated spirits**, and used for many industrial purposes. In order to obtain the colourless, chemically pure *methylated alcohol* (CH_4O), however, this common chemical product has to be raised to the boiling-point again, and mixed with an equal quantity of oxalic acid to form crystallised oxalated-methyl-æther; and this is washed in water (in which it is insoluble) to clear away impurities, then distilled along with hydrate of potash, when the pure methylated alcohol is given off (Schwackhöfer, *op. cit.*, pp. 340-344).

The **percentage** of acetate of lime and of crude wood-naphtha obtained from dry wood by its destructive distillation in closed furnaces and retorts varies considerably. The drier the wood and the slower the distillation, the larger is the yield for each of the products; the wood of broad-leaved trees furnishes more than that of Conifers, and the wood of the trunk more than branchwood; barked wood gives more acid than unbarked, and sound wood more than unsound. It is important that the wood should be used as dry as possible, in order to carry out the distillation economically; hence the necessity for having it thoroughly air-dried and well heated artificially (under proper ventilation) before distilling it.

In Continental factories 100 parts of dry barked Beech-wood usually gives about 7-8 per cent acetate of lime ("grey lime"), 1-1½ per cent crude naphtha, 7-8 per cent tar, and 24-25 per cent charcoal, or in all about 40 per cent of marketable products; while the wood of Conifers gives about 2-3 per cent less acetate of lime, and ½ per cent less naphtha, but more tar (up to 12-16 per cent in very resinous wood). In some places there is so little market for the tar, that it is used for heating the furnaces.

IV. **Small Waste Wood.**—In large saw-mills there is necessarily a considerable quantity of *small waste wood* and of *sawdust* which cannot always be used as fuel, and which it is desirable to use profitably, if possible. This is often used in preparing acetate of lime, &c., in retorts (as above described, but on a smaller scale), or in making **Wood-wool** and **Manila Shavings**, while **sawdust**, besides being largely used for petty purposes (*e.g.*, stuffing pin-cushions and dolls, cleaning dusty floors, &c.), is utilised extensively in making *oxalic acid*, and also for pressing into *briquettes*, and in the "carbonating stage" of preparing soda ash.

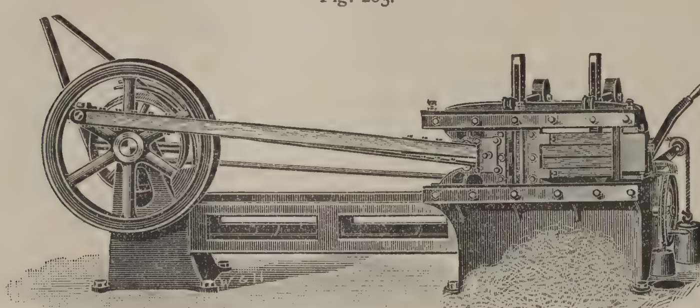
The production of the fine shavings known as **Wood-wool** and **Manila Shavings**, used for packing, for cattle litter, for rough filtering, &c., is another industry only profitable with wood of little value—*e.g.*, for utilising waste pieces in saw-mills. After being cut into lengths of about 18-20 in. long and 6 in. broad, the wood is put between two rollers and cut longways by a number of parallel knives worked with a crank, while a plane at the side shaves off these cut portions, which then fall down below. The shavings are finer or coarser according as the parallel knives are set closer or wider apart.

Another form of **wood-wool machine** is shown in Fig. 283, and may be used with profit in saw-mills where many short cross-cut ends are left, and about 25 to 30 cwts. of "wool" of various degrees of fineness can be turned out per day. The pieces of wood are placed one above the other, held down by weighted levers, and advanced to the knives by a continuous feed motion, actuated by a screw, bevel wheels, and cone pulleys. The rate of feed varies according to the wood and the fineness of wool required. The knives are fitted into a reciprocating slide and arranged to cut both ways. The feed stops automatically when as much wool is cut from the wood as is possible. The pieces of wood may be 24 × 12 × 12 in.; but they need not all be of the full length, and they may vary in thickness.

Oxalic Acid ($H_2C_2O_4 + 2H_2O$) is made by first fusing the sawdust with its own weight of a mixture of caustic alkalies (hydrates of potassium and sodium in proportion 2 : 3) in shallow iron pans, keeping the whole continually stirred at a temperature of 470° Fahr. The grey-brown powder thus obtained is dissolved in water (which leaves the sodium oxalate undissolved) and boiled with milk of lime to form oxalate of lime, which is dissolved with sulphuric acid, while the filtrate is evaporated sufficiently to allow the oxalic acid to crystallise. From 100 parts sawdust about 80 per cent of raw oxalic acid is obtainable, which can be used for dyeing, calico-printing, &c., either in this form or as oxalates (salts).

In **Briquette-making** sawdust is used, or waste wood is reduced to pieces as small as practicable. One of the best processes is Heidenstam's patent, now used

Fig. 283.



Machine for making Wood-Wool.

in Sweden. In this the sawdust and chips are passed under pressure between rollers to get rid of as much moisture as possible; then further dried in an apparatus heated by the uncondensed gases coming from the dry-distillation-cylinder; and then moulded in briquette-presses and passed into the carbonising and dry-distilling apparatus, consisting of an upright iron cylinder built into a masonry furnace and provided with a pipe at the lower end for running off the distilled products. The briquettes are kept under pressure in a press during the whole time of their dry distillation, to prevent them falling to pieces. By regulating the temperature and also the pressure that is being applied to the briquettes, the dry distillation and carbonisation proceed in such a way that all the more volatile products are distilled off, and little else but the pitchy residuum of the tar is left behind, which binds and gives good consistence to each briquette. A cylinder containing a charge of about 2 tons of such material takes 14 or 15 hours for treatment. This method is said to yield (from every 100 parts Pine- and Spruce-wood containing 18-20 per cent of water) about 5 per cent acetate of lime, 0·75 per cent wood-naphtha, 8-9 per cent tar, and 33⅓ per cent of charcoal (or one-third of the original quantity of wood) in the form of briquettes; and these are said to have a heating-power of 7800 heat-units (compare with table on p. 593).

V. **Potashes** and all other kinds of **salts of potassium** were, until about forty years ago, made entirely from the ashes of wood and from various plants ; but now they are chiefly prepared either from potassium sulphate and chloride, or from the residual ash of molasses used in making rum. But in some parts of Austria, Russia, and S.E. Europe, it is still the only way of using with profit some of the inferior kinds of wood.

Potashes are made by a simple process, in four stages—(1) *burning, to reduce the wood to ash,* (2) *extracting the lye from the ash,* (3) *evaporating the lye,* and (4) *calcining the raw potashes.*

1. **The wood is reduced to ash** by combustion. Unsound trees and those of little value where they stand are selected for potash-burning. Such are cut into so as to form a hollow, and fire is lighted there to gradually consume the heart of the tree, while the pure ash that collects at the base is collected from time to time, and a fresh fire is kindled, if necessary. This produces the purest kind of ash, and at the same time protects it from wind and rain. Or when trees are felled for this purpose, holes about 12 × 6 in. are notched here and there along the lower side of the stem, and fires are kindled there. And in either case, the outer shell remaining unburned and the branchwood are piled and fired to reduce them also to ash, which is stored in barrels and kept in wood-lined vaults to protect it against damp till it can be taken to the potash-factory.

The amount and composition of the crude **ash** thus obtained varies of course with the kind of tree, and the soil, situation, and climate. But the chief constituents are lime, potash, magnesia, and phosphoric acid, all the other components occurring in much less quantity, and there being only few mineral acids. The metal oxides are mostly in the form of organic acid salts, which form carbonates during combustion ; hence in wood-ash there is always a larger proportion of carbonic acid, which does not, however, directly form part of the wood itself. But it is precisely because wood-ash consists mostly of carbonates that it is suitable for making potashes (see also table on p. 307, vol. i.).

Mineral constituents per 100 parts by weight of	Lime (CaO).	Potash (K_2O).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Manganese dioxide (MnO_2).	Alumina (Al_2O_3).	Soda (Na_2O).	Ferrous oxide (FeO).	Silica (SiO_2).	Sulphuric anhydride (SO_3).	Carbonic acid (CO_2).
Crude ash	20-45	10-25	5-15	2-10	1-8	1-8	1-5	1-4	1-3	1-5	15-20

Crude ash contains, however, about 25 per cent of fine charcoal, carbonic acid, and earthy impurities, so that the **pure ash** gives only about three-fourths of the above quantities of each constituent.

2. **The potash-lye** is extracted from the crude ash in a series of vats, forming a battery and ranged one above another sideways, like the steps in stairs. These vats are filled to about two-thirds with crude ash and the rest with water (each vat taking about 2 to 2½ cwt. of ash and 30 to 40 gallons of water), and after three or four hours' soaking the liquor from vat 1 is run down into vat 2, that from 2 into 3, 3 into 4, and 4 into 5, the concentrated lye being drawn off from the lowest vat. But the warmer the water used, the quicker the potash is extracted. Of course, when the process is in full work, the lye is run off from 5, and its drain-pipe closed before the lye is run in from 4, and so on. When the contents of vat 1 have been drenched five times the potash has been practically thoroughly extracted, so the contents are emptied and replaced by fresh crude ash. Vat 2 then becomes number 1 in the new battery, and from the lowest vat the liquor is pumped up into the top one (now number 5 in the series), from which the concentrated liquor is drawn off. And so on in succession, vat 5 of each series becoming vat 1 of the next series

The residuum emptied from the vats forms good manure, as it consists mainly of calcium carbonate and phosphate, the latter containing when dry about 8 per cent of phosphoric acid. If intended for transport, this residual manuring product has first to be dried, as it consists of 50 to 60 per cent of water.

3. **The evaporation of the lye** takes place in shallow iron pans. It is first warmed in a pan usually fitted to the calcining furnace, and then allowed to trickle down into a shallow evaporator heated by its own furnace. The evaporation is here allowed to go on until tests show that the concentrated lye hardens on cooling. The further supply from the warming-pan is then interrupted and the furnace lowered, while the mass in the pan is kept continually stirred until, after further evaporation, the raw potashes are left as a loose, friable, blackish-brown substance, still containing about 6-10 per cent of water.

4. **The calcining** to evaporate the remaining water completely, and to burn the potashes into a white powder, takes place in a fire-proof vaulted furnace, the roof of which must be within 30 in. of the bottom in order to keep the flame from the fire low down and make it pass over the potashes. The heating may consist of one or of two fires, which are kept at great heat till the furnace is thoroughly heated, when the raw potashes are thrown in and spread over the floor with an iron crook ; and during the whole process of calcining it must be kept stirred and moved, so as to bring fresh stuff to the surface. The temperature is kept moderate at first, then gradually raised to red-heat ; the potashes must not, however, be allowed to melt, as otherwise the particles of charcoal cannot be got rid of by combustion, while the sole of the furnace gets damaged and the potashes become silicated. In two to three hours the calcination is complete, and if test-pieces be taken out and broken after being allowed to cool, they should be white inside. The potashes are then drawn out and cooled down, to be packed closely into barrels. This should be done at once, as potashes are strongly hygroscopic, soon forming clumps, and then finally melting if freely exposed to the air. The yield of calcined potash is from 80 to 90 per cent of the raw potash treated, from 10 to 20 per cent being lost in the process.

The **calcined potash** is a crumbly, caked mass, that is seldom pure white, but usually more or less discoloured from minute particles of charcoal, or else reddish from ferrous oxide, or bluish or greenish from manganate of potash. It has an alkaline taste, is strongly hygroscopic, and easily soluble in water, though not in alcohol. When fresh from the calcining furnace and free from water it consists of 80-85 per cent carbonate of potash (K_2CO_3), 6-9 per cent carbonate of soda (Na_2CO_3), 6-9 per cent sulphate of potash (K_2SO_4), ½-4 per cent chloride of potash (KCl_2), and small quantities of ferrous oxide, alumina, magnesia, silica, and combinations of manganese. In chemical factories these salts can be separated by fractional crystallisation, and the carbonate of potash obtained almost pure ; but this is not necessary for most of the uses to which potashes are put, such as the manufacture of crystal glass and of soft soap, and for many chemical preparations.

VI. **Resin-tapping** and the distillation of **oil of turpentine** and **rosin** from the crude resin have also, like the production of tar and pitch, lost all the importance they once had in the Pine tracts of Scotland early in the eighteenth century (see vol. i. p. 25) ; and there is no part of the United Kingdom where this is now carried on. On the Continent, too, resin-tapping is nothing like so general as it used to be up to about thirty or forty years ago, partly owing to wood having risen considerably in value, and partly owing to the competition of cheaper imports from North America, which now supplies about four-fifths of the world's consumption of oil of turpentine and rosin (chiefly obtained from *Pinus palustris*, *P. australis*, and *P. Tæda*, and from *Abies balsamea* for

"Canada balsam" and the finer qualities of resin: most of the turpentine imported into Britain now comes from America). It still, however, forms an important woodland industry in some parts of Austria and France, and in some of the Alpine and Mediterranean districts. The chief trees tapped, and which are at the same time those that yield most resin, are the **Maritime** or **Cluster Pine** (*P. maritima* = *P. Pinaster*), in South-Western France (and especially in the sandy wastes of Gascony known as the **Landes**), Spain, and Portugal, and on the North African coast, and the **Black Pine** (*Pinus Laricio*, embracing both the climatic varieties distinguished as Austrian and Corsican Pine in Britain), throughout Austria, Southern France, and Corsica. **Spruce** is still also tapped to some extent in parts of Bohemia, and in the Thuringian and Black Forests (Central and Southern Germany), and **Larch** in the Alpine districts; but Scots Pine and Silver Fir are now seldom tapped.

Resins are widely distributed, and are found in all plant-organs except the cambium. They either form part of the cell-wall or of the cell-contents, but are generally collected and secreted in special intercellular **resin-ducts**, which are found in the bark of all the *Abietineæ* (see vol. i. p. 193), and usually also in their wood. The resin appears to flow gradually from the upper to the lower part of the tree, so that the roots contain most, and after that the base of the stem within about 6 to 7 ft. of the ground, while the quantity gradually decreases in the branches, crown, summit, and bark; and the older the tree, the more resin it contains.

The precise method in which resin is formed physiologically, by trees in a normal condition of health, is not as yet quite satisfactorily determined, although according to recent investigations it seems to be indicated that a certain part of the cell-wall becomes transformed into a sort of mucous layer (*cell-mucus*) secreting oil or resin. But it is also formed, by a more or less pathological process, from the cellulose and from starch, either directly by degenerative changes in the substance, or indirectly by the formation of tannic acid. The production of resin is certainly often greatly increased by many pathological conditions (*e.g.*, where branches are broken, and after attacks of certain insects and fungi). As the resin-ducts never open spontaneously near the outer surface of the tree, any outflow of resin is a sure sign of some sort of pathological disturbance; and in resin-tapping the wounds are made near the base of the stem in such a manner as to cause the largest possible outflow. But as the resin-ducts are very minute capillary tubes, the pressure exerted on these by the surrounding tissue of the sapwood causes the resin to exude very slowly.

Resins are very complicated chemical compounds, but those of coniferous trees contain abietinic acid ($C_{19}H_{28}O_2$) as one of its chief constituents, which in its pure condition forms colourless crystals insoluble in water, but soluble in alcohol, æther, alkaline fluids, &c. The main substance of resin is always amorphous, but in that of Conifers there are so many crystals of abietinic acid, that the whole yellow or brownish-yellow mass often appears clouded and more or less opaque. It has a strong and pleasant aroma (especially fragrant in the Douglas Fir), and gradually darkens and becomes hard and brittle with exposure to air. Another of the main characteristics of the resin of Conifers is the large quantity of ætherial oil, and especially of *oil of turpentine*, which they contain. Such turpentinous resins may either be viscous and semi-fluid (in which case they are called *balsams*), or else partially or wholly hardened (when they are respectively called *soft* and *hard resins*). The finer *balsams* (*e.g.*, *Abies balsamea*) are of a honey-like consistency, clear, and either colourless, or from a pale yellow to a brown colour, though sometimes clouded by air-bubbles or drops of water, while commoner sorts are always more or less clouded with abietinic acid crystals, and instead of clarifying, become still more opaque when heated. The *resins* are rich in carbon, poor in oxygen, and entirely free from nitrogen. Insoluble in water, they mostly dissolve in alcohol, æther, oil of turpentine, petroleum, benzoline, &c.

The finest product of all is the aromatic, clear, colourless "Canada balsam" of *Abies balsamea*, afterwards turning bright yellow, which possesses strong refractive power, and is chiefly used for optical purposes. But among European Conifers the thick viscous resin of the **Larch**, from which "Venice turpentine" is produced, and the thinner fluid resin of the **Silver Fir**, producing "Strassburg turpentine," are the finest and most turpentinous resins. The latter tree, however, yields but little resin, and that is chiefly contained in pockets throughout the bark, which are only here and there (*e.g.*, in Alsace) cut and tapped. The **Maritime Pine** (producing "French turpentine") and the **Black Pine** give a semi-fluid resin which, on being allowed to settle quietly, precipitates crystals of abietinic acid, and leaves a yellow to reddish-brown, honey-like fluid above; and in Maritime Pine resin this clear portion predominates, whereas in the Black Pine the greater part becomes crystalline. **Spruce** resin is yellow to brown, tough and semi-hardened. The resin found caked between the bark and the wood in the roots, as well as that on wound-cicatrisations, is usually sulphury-yellow, hard and brittle.

1. The **method of tapping Resin** varies according as it is to be found chiefly in the sapwood and the bark, or in interstices within the heartwood. The stem may (1) simply be bored into near the ground (*Alpine method, for Larch*), or (2) pieces of bark may be removed, and either (*a*) the exuding fluid resin is collected in earthenware cups (*French method, for Maritime Pine*), or (*b*) the semi-hardened oxidised resin is scraped off (*German method, for Spruce*), or else (*c*) deep cup-like incisions are also made into the stem to collect the resin (*Austrian method, for Black Pine*). But it will be more convenient to describe these different methods briefly in the order of their relative importance throughout Europe, as follows:—

(1) *Maritime Pine*, (2) *Black Pine*, (3) *Spruce*, and (4) *Larch*.

(1) The **French method** of tapping the **Maritime** or **Cluster Pine** in the *Landes* or sand-barrens around Bordeaux (see vol. i. pp. 86, 208, and vol. ii. p. 195) is that known as Hugues' system. Tapping begins when the trees girth over 3½ ft., by which time they are at least 30 to 35 years old. About the end of February or early in March of the year in which tapping is to begin, the rough bark near the foot of the tree is pared with a scraping iron from a strip about 2 ft. long and 4 to 5 in. broad, only a thin, smooth, reddish skin of bark being left to cover the sapwood.

During the first half of March an incision about 4 in. broad, 1-1¼ in. high, and not quite ½ in. deep is made at the pared part, about 12 or 14 in. above the ground, and a bent piece of zinc is fixed into the stem to form a gutter and lead into glazed earthenware cups, also fixed to the stem, the viscous drops of resin trickling down from the wound thus made. The zinc gutters are broader than the groove incised, and protrude forwards about 1¼-1½ in. They are fixed in the thick bark at either side, which is first indented with a sharp curved-steel cutter of the necessary shape, while the gutter is held in place in an iron casing, and hammered home into proper position. The glazed earthenware cups contain about ¾ pint, and are nailed to the stem just below the gutter. The pot is protected against rain-water and excessive evaporation of resin by means of a zinc shade attached by its ends to the tree-bark above the cup and the gutter, so that it does not interfere with the trickling down of the drops of resin (Fig. 284).

At first the incised groove has to be refreshed once a week, then afterwards once every five days, during the rest of the resin-collecting season, by extending it upwards for 4-5 in. Only a very thin shaving is pared off each time, so that the depth of the groove may not be quite ½ in. deep. Before the tapping-season ends on 15th October the grooves will have been refreshed from 40 to 45 times, and the first year's incisions will be about 22 in. long, and during the second, third, fourth,

Fig. 284.

Maritime or Cluster Pine being tapped for Resin (Hugues' system).

Pots are here shown fixed in incised grooves on the stem to catch the fluid resin, while a resin-reservoir let into the ground is hidden by its protecting wooden cover.

and fifth years they are increased by about 30 in. a year, so that they are about 12 ft. high by the end of the fifth year. The breadth of the incision remains as before, not exceeding 4 in.

As the incision extends upwards, the zinc gutter and the collecting-pot are also moved up above the hard inspissated part, so as to prevent evaporation of oil of turpentine and get as large a proportion of fluid resin (*gemme*) as possible, while reducing to a minimum the hard incrustations that have to be picked or scraped off. Every two to three weeks the *gemme* in the collecting-pots is emptied into a basket and taken to a resin-reservoir (*barcous*), consisting of the half of a barrel let into the ground and protected by a wooden cover. Very little of the hardened resin can by this method be hand-picked (*galipot*), as most of it forms a hard incrustation (*barras*), which has to be scraped off twice a year, in June and November. In packing French resin for the wholesale market, in barrels of 235 kilo., or about 4½ cwt. each, the proportion of scraped resin must not exceed 18 per cent of the whole weight, or about 1 part *barras* to 5½ parts *gemme*.

The trees are either tapped to death (*gemmage à mort*), or else merely to a slighter extent (*gemmage à vie*). The completely exhaustive process is only applied to trees that have in any case to be felled for one reason or another (*e.g.*, thinnings, and fully mature trees); and as the object then is to obtain as much resin as possible, from 2 to 6 incisions are made simultaneously in the stem. The second and non-exhaustive process is applied to all trees which it is intended to tap for several years in succession; and in this case only one incision is made at a time. When this one groove has been worked for five years, and the incision is therefore about 12 ft. long, the tree is given a rest for several years, and a new incision is made parallel to the former one, and about 6–8 in. from it. This new groove is then tapped for five years, and a rest again allowed; and so on, till the whole bole is ribbed with the resinified and more or less parallel grooves. Under this treatment the butt of the tree becomes much swollen and hypertrophied. Trees tapped to death are mostly sawn into sleepers, the small wood being exported to Britain as pit-props.

Fig. 285.

Tapping of Austrian Pine.

The yield in woods of 30-35 years old is on the average about 240 kilo. (or a little more than 1 barrel of 235 kilo., or 4½ cwts., and containing about 50 gallons), while 40–70-year-old crops give 450 kilo. *per hectare annually*, which is equivalent to about 1·87 and 3·53 cwt. of crude resin *per acre annually*. On the average about 4 lb. (1 gallon = about 10¼ lb.) is collected from each grooved incision, though the quantity of course varies with the size of the tree; and each man employed can work about 5000 grooves, and collect about 40 barrelsful (or about 2000 gallons, weighing about 180 cwt. or 9 tons) of crude resin during the course of the season from March to October.

(2) The **Austrian method** of tapping the **Black Pine**, less economical than the above, consists in first making, about the middle of April, a deep cup-like incision into the butt of the stem about 1 ft. above the ground, in which the resin collects on trickling down. This incision (*Grandel*) generally extends about one-fourth to one-third round the stem (but sometimes more, up to a maximum of two-thirds of the girth), and to a depth of about 3 in. (Fig. 285). On each side of this a slanting cut is made above it, so that their downward ends point inwards, and form grooves directing the flow of the resin towards the cup-like hollow; and above these the bark is peeled and the sapwood of the last 2 to 4 years chipped away. It is useless to cut in

deeper, as no resin exudes from the heartwood. At first the blaze is only made a few inches high, but as it has to be freshened once a week, it gradually extends to 14-16 in. by the end of the first season; and in the following years it needs freshening every 4-5 days to prevent incrustation and stoppage of the exudation. Tapping is continued for about 8-12 years, the barked and blazed surface gradually increasing in height by about 15 in. a year, while the breadth remains the same from year to year.

The tapping season extends from spring to autumn, beginning in the second half of April and continuing till the beginning or middle of October. During the first year, while the blaze is still small, most of the resin flows (*Rinnharz*) into the cup-like incision, and comparatively little becomes incrusted on the blaze, and has to be scraped off (*Scharrharz*); but when the blaze becomes prolonged and the resin has farther to trickle down in reaching the *Grandel*, a good deal of oil of turpentine evaporates, and most of the resin incrusts, and has to be scraped off. To minimise this loss by evaporation, side-cuts are made at either side of the blaze, parallel to the two first cuts made above the cup, and chips of wood (*Leitspäne*) are inserted in them, in order to keep the flow of the resin as near the centre of the blaze as possible. Every fourteen days the resin is collected from the *Grandel* and stored in casks let into the ground, while the hard incrusted resin is scraped off with an iron in autumn.

Only one blaze is usually made on each stem, but large trees are sometimes tapped twice, the second blaze being made when the first has reached a height of 13-16 ft., so that only two narrow bands of bark then remain on the stem.

The yield of resin varies of course according to the size of the trees, the soil, situation, climate, &c., but is largest in quantity and best in quality in small trees from the fourth to sixth years of tapping, and in large trees during the seventh to ninth years; and most resin exudes about the end of June. The best out-turn is obtained when the blazes are refreshed during mild, soft weather, and when the freshly-cut surface is yellowish-red. Trees of 10-12 in. diameter yield on the average from $3\frac{3}{4}$ to $5\frac{1}{2}$ lb. of crude resin annually during the ten years' period of tapping, while those above 12 in. diameter give from $7\frac{1}{2}$ to 9 lb.; and in either case the proportion of hard resin (*Scharrharz*), worth only two-thirds of the price of the finer quality (*Rinnharz*), usually varies from about 40 to 60 per cent. The resin is rich in turpentine, 1 cwt. of crude resin distilling off 15-22 lb. weight of oil of turpentine, and leaving about 67 lb. of rosin as residuum (see p. 615). Tapping makes the wood coarser and rougher, but improves its technical qualities.

(3) The **German method** of tapping **Spruce**, now only practised to a very slight extent, differs from the above methods owing to the resin incrusting soon in place of flowing. It consists in cutting two blazes into the sapwood in May or June on opposite sides of the stem to a height of $3\frac{1}{2}$-5 ft., and a breadth of $1\frac{1}{4}$-$2\frac{1}{2}$ in., and ending in a point at the lower end, so as to prevent rain-water lodging. During the first year the blazes become incrusted with resin, which is scraped off in July of the following year; and every 2 to 3 years (or in some places every year) they are refreshed by their edges being pared at the sides during the summer, until at length only two narrow strips of bark remain on the stem. Sometimes a modification of this method obtains, where only two narrow blazes are made at first and tapped for two years; then two new blazes are opened and tapped for other two years; and so on till only narrow strips of bark are left uncut. The tapping of Spruce trees generally continues for 10 to 15 years, and the yield per tree averages about $1\frac{1}{2}$ lb. of resin annually, about two-thirds of which (*Bruchharz*) are scraped off the face of the blaze, and one-third is of coarse and poorer quality (*Pickharz*) cut from the edges.

(4) The **Alpine method** of tapping **Larch** differs from all three of the above ways, in that the resin is mainly obtained from the heartwood, and from the region

between heart- and sap-wood, where shakes in the tree get filled with resin. The tapping consists in boring in early spring an auger-hole of about 1-1¼ in. in diameter into the stem in a slightly upward slanting direction, about 1 ft. above the ground. This hole is bored right in to the centre of the tree, and is bunged up with a wooden plug. By autumn this hollow becomes filled with resin, which is then scooped out clean with a long, hollow, semi-cylindrical scoop (*Räumer*). The hole is then plugged up again, and the fresh resin collecting is removed annually for about 20 to 30 years. Sometimes, however, the bore-hole is left open for the first season and the exuding resin is collected in pots ; and after the first autumn the hole is plugged up, and cleared out and left open again once every 2 to 6 years ; but no new hole is bored into any tree already tapped. Trees are not tapped till they are at least 80 years old, and those with thick bark give most resin, although the quantity yielded depends to a great extent on whether or not any, or many, resinous clefts happen to be bored through.

The yield may therefore vary greatly, from about ¼ to 1 lb. *per tree per annum*, although large trees tapped with an open bore-hole can yield up to 6½ lb. during the course of a year.

The resin collecting in stopped-up holes is of better quality, though less in quantity, than that allowed to flow out, which is dirtier, and contains less oil of turpentine. This practice does not deform the stem like the methods used with other trees, but it exhausts the tree considerably. Though small in quantity, Larch resin is of superior quality.

2. **The crude Resin** is almost entirely used for the distillation of **oil of turpentine** and **rosin** or **colophony**, only small quantities being employed medicinally (for ointments, bandages, &c.). When the oil of turpentine is entirely distilled off, the residuum is rosin or colophony ; but when only part of the former is extracted, the viscous mass remaining is known commercially as common, crude turpentine.

Distillation may either take place primitively in small local works, or by a more careful and elaborate method at some central factory, the latter being the more thorough and economical way of working on any large scale.

In the **primitive method** the crude resin is put into a large copper kettle or boiler with a movable lid, and boiled over an open fire. When the resin melts, water is added to assist in dissolving the oil of turpentine, which is carried off along with the steam through a cooling-worm into a receiver shaped like a Florentine-flask, where the condensed vapour is collected and the oil separates and floats above the water. When the whole of the oil of turpentine obtainable in this rough fashion has been separated, the watered resin or "white pitch" remaining in the boiler still contains a considerable quantity of minute drops of water, and on cooling becomes a hard, dull, bright-yellow to syrup-brown mass, which is used for sizing paper and closing the pores of cask-staves (but not for making brewers' pitch, see p. 615). But this water must be got rid of entirely before marketable rosin or colophony is prepared, so the lid of the boiler is taken off and the contents boiled until they become transparent, when they are strained by being poured through a wire or straw sieve into boxes or casks for transport. Impurities, such as chips of wood and bits of bark, are thus easily got rid of, while heavier, earthy dirt sinks to the bottom of the boiler, and can be broken up, and re-boiled and purified when a sufficient quantity of it has been collected. As the contents of the boiler are heated very unequally, this primitive method produces only ordinary dark-brown rosin, more or less dulled and discoloured through the decomposition of part of the crude resin which sticks to the superheated parts of the boiler next the fire. And of course the yield of oil of turpentine, being only partial, is comparatively small.

The better method is to melt the crude resin and strain it through a sieve before commencing distillation. The filtering vat is double-walled for steam-heating, and contains a movable sieve; and it is connected with the distilling retort by a pipe, so that the filtered resin reaches this in a warm and fluid condition. The sheet-iron retort has both an outer casing for steam-heating, at about 180°-190° Fahr., and also a steam-pipe, so that steam can be turned directly into it; and the base is prolonged like a wine-funnel, so that the rosin can afterwards be run off easily and entirely. Distillation is best effected under diminished pressure, obtained by passing blasts of steam through the throttle of the pipe leading from the top of the retort to the condensing apparatus. The latter consists of coils of tubing, around which cold water is kept circulating; and on the oil-charged vapour being condensed and passed into the reservoir-tank, the lighter turpentine can easily be separated as it floats above the heavier water, and can be run off by an overflow pipe. And when all the oil of turpentine has been distilled off, the rosin or colophony is run off in a clear, pale yellow-brown stream by the pipe at the base of the retort, and strained through copper wire-gauze while still hot. From here it passes into a tank, from which it is run off into barrels containing about 7 cwt. each, or into moulds forming cakes of convenient size for packing in casks. By means of the partial vacuum which can thus be created as above described, the filtration of the crude resin and the filling of the retort can take place more easily and quickly, while the quantity of oil of turpentine is larger and its quality better, owing to distillation being effected at a lower temperature than is otherwise possible.

The yield of oil of turpentine and rosin varies greatly, according to the kind and quality of resin. But, on a rough average, crude resin in general gives (by weight) from 15 to 30 per cent of *oil of turpentine* and about 65 to 75 per cent of *rosin* or *colophony*, while from 5 to 10 per cent are due to impurities (bark- and wood-chips, earth, &c.) and loss in the process of distillation. Among the European Conifers habitually tapped for resin, that of Silver Fir and then that of Larch contains the largest percentage of turpentine, that of Maritime and Black Pines occupies an intermediate position, and that of Spruce contains least.

Products of Resin.—When crude resin is combined with metallic oxides, **resinates** are formed. Alkaline resinates are soluble in water, lather freely, and form **resinous soap**; and when this is made with any alkaline earth, it is much less soluble in water than ordinary fatty soaps.

Oil of turpentine consists of a mixture of hydrocarbons, and its chief component is a substance called *pinen*, having the chemical formula $C_{10}H_{16}$. It is insoluble in water, but dissolves in alcohol, æther, benzol, &c. In the crude product obtained by distillation over an open fire the turpentine also contains some of the products of the decomposition of the rosin, as well as resinous acids, &c. This can be refined and rectified, however, by mixing it with lime-water and re-distilling it by steam-heating; but even after re-distillation each kind of turpentine has its own peculiar properties. When fresh, oil of turpentine is a thin, colourless fluid with a very distinctive odour, which varies according to the kind of resin used in obtaining it, and with a sp. gr. of 0·85-0·88, and a boiling-point of 300°-330° Fahr., although it evaporates freely at any ordinary temperature. On giving off its essential oil it absorbs atmospheric oxygen, and forms a pungent *aldehyde* ($C_{10}H_{16}O_3$); and as oxidisation proceeds further, the oxygen is transformed into ozone, and the whole gradually turns into a solid, brittle, pale-yellow colophonous mass, having an acid reaction. Oxidisation takes place quickest when water is present. When oil of turpentine is combined with hydrochloric acid gas it forms a soft, kneadable mass ($C_{10}H_{16}HCl$) known as *artificial camphor*.—Oil of turpentine is a good solvent for many resins, wax, fats, caoutchouc, sulphur, and phosphorus, and it is largely employed in making varnish, in oil-painting, &c.

Rosin or **Colophony**, thus named after the ancient city of Colophonia, in Ionia, where it seems to have first formed an article of commerce, but perhaps best known as "fiddler's rosin," exhibits properties varying according to the different kinds of resins. It may be transparent, translucent, or opaque, in proportion to the degree in which the crystallised abietinic acid is transformed into its amorphous anhydride; and it may vary in colour from pale yellow, golden, amber, or reddish-yellow to a deep dark-brown or almost black. Then, too, some rosins are soft and can be indented with a finger-nail, while others are so hard that they can only be scratched with iron. Hard rosin is almost odourless and tasteless, has a glassy surface, is very brittle, and can easily be pulverised. It has a sp. gr. of 1·04-1·11 at 60° Fahr., softens at about 160°, and melts between 212°-275° Fahr.; and as regards solubility, it closely resembles resin. It is used in making sealing-wax, varnish, and resinous soaps, for sizing paper and papiér-mâché, &c.; but one of its special uses is for making *brewers' pitch* for coating the insides of beer-casks, and for distilling *resinous oils*, when the *pitch* used by shoemakers, &c., is left as residuum.

As pure resin is unsuitable, owing to its brittleness, for cleaning and lining the insides of beer-casks, about 8-10 per cent of linseed-oil, cotton-oil, resin-oil, or paraffin has to be added to give elasticity, and this compound forms **brewers' pitch**. It is made simply by melting the rosin in an open vessel and adding the oil or paraffin, while keeping the whole well stirred to mix it thoroughly, and form a golden to dark-brown pitch, which neither froths when melted, nor becomes hard and brittle when cool, and which neither taints the smell or the taste of the beer (as is ascertained by tests for 3-4 days in pitched and unpitched bottles).

Resin-oils are oily fluids obtained by the dry distillation of rosin in cylindrical iron retorts with worm-condensers. When the rosin in the retort melts at about 285° Fahr., the lid is closed and the distillation begins. Up to about 520° acetised water and **light resin-oil** (*pinolin*) is given off, and the latter is mixed with sodium-lye to neutralise the acid, then washed with water and re-distilled, when it forms the refined pinolin known commercially as "spirit or essence of resin." From about 520°-550° a **dark oil**, of a brown colour and sharp, pungent odour is given off, which is also refined by mixing with sodium-lye and washed with water, then used for making waggon-grease and lime-soap. From about 550° clear, aromatic **pale oil** distils off, which gives the largest and best product, that can either be used as a crude lubricating oil, or else refined by a somewhat elaborate process (consisting of washing, steaming, neutralising, saponifying, re-washing, and oxidising, &c.) to produce a clear, pale yellowish-green, non-resinous, and almost odourless oil used for lubricating and medical purposes, making perfumery, printers' ink, linoleum, &c. From about 600° a **blue oil** is given off, which can be refined in a similar manner. At about 650° a **green oil** is obtainable, which can be used to make waggon-grease, and a dry coke-like residuum is left. But as this is useless, even for fuel, the distillation usually ceases on the blue oil stage being completed, and the remainder forms **pitch**, which is poured out into moulds and used for ships' caulking, brush- and shoe-making, &c. The yield of these products varies from 6 to 8 per cent light resin-oil, 4 to 5 per cent dark oil, 50 to 55 per cent pale oil, 15 to 20 per cent blue oil, and 6 to 7 per cent green oil, the rest being either coke-like residuum or loss in distillation (Schwackhöfer, *op. cit.*, pp. 355-365).

The dry pitch-coke can, however, be made into **lamp-black**, by burning it under a cotton awning, like a tent or an inverted wine-filler, hung over it; and as the smoke filters through this, the fine particles of soot are left adhering, and can afterwards be scraped off.

VI.—NOTE ON GRAZING IN WOODLANDS, AND ON LEAF-FODDER.

As was remarked in the concluding portion of the *Introduction* (see vol. i. p. 102), grazing may often prove worth attention in woods and plantations. Judging from the whole tenor of many of the old forest laws, there seems to be no doubt that grazing was habitual in the natural woods, and that rights of common in pasturage were frequent throughout the tracts afforested—*e.g.*, such as the grazing-rights still extant in the New Forest. But now, from various causes, there is far less of woodland grazing than formerly, or than there might be if purely economic considerations were to obtain in place of special care being given to kinds of game requiring quiet and stillness in the woods.

Owing partly to the humidity of our island climate and the comparative mildness of the winter season, and partly to very heavy thinning being customary, there is usually a far stronger and more luxuriant growth of grass and weeds throughout our woodlands than is to be found in inland Continental countries. Here, in most coniferous woods over about twenty years old, and especially under Larch, there is usually an undergrowth of grass; and though this is rather aperient at first, and neither so solid nor so gratifying a food for cattle as good meadow-grass, yet it is of much larger bulk and greater value in feeding-capacity than the rough and scanty herbage furnished by land of similar quality forming rough pasturage outside the plantations. The pasturing of sheep and cattle does no real damage to plantations of that age; and the improvement in pasture which was found to take place in woodlands, as well as in adjoining pastures sheltered to the leeward, was one of the advantages claimed for extensive plantations of Larch by those who advocated this early in the last century (see vol. i. p. 30). And when any Conifer-crop is cleared for re-plantation, a very good class of grazing can be had for the three to four[1] years during which it is customary to leave the land fallow, in order to allow the tree-stumps to dry, and thus obviate danger to the new crop from the Pine-weevil.

The quality of the grazing in woodlands depends mainly, other things being equal, on the amount of light acting on the soil.

On the Castlerigg estate (Derwentwater, Cumberland) the largest of the Conifer plantations is a block of 200 acres (Coomb Wood), an outlying plantation formed in 1846-8, of Larch with slight admixture of Spruce in moist parts and Scots Pine in exposed places. Here the rate of growth ascertained from the stems showed that they have taken from 10 to 16 years to increase by the last inch of radius (or $6\frac{2}{7}$ inches in girth), representing a current increase of over 3 per cent on the trees now forming the crop. Methodical and carefully kept estate accounts show (1) that this plantation was made at a cost of about £2 an acre (there being then no necessity for expensive wire-netting against rabbits) on land the fee simple of which was not more than £1 an acre; and (2) that from a very

[1] That, in any case, after three or four years the grass begins to fall off in quality is probably due to a reduction in the quantity of readily available supplies of potash and phosphoric acid, because good grass gives (according to Wolff) 7·2 per cent of ash, containing 1·3 per cent potash and 0·3 per cent phosphoric acid.

early age this wood, being periodically thinned in sections, has yielded thinnings almost regularly year by year. As for some years past these thinnings have really been of the nature of partial clearances of the maturing (and nearly mature) crop, which have thus already liquidated a portion of its capital value, the stock of 53- to 55-year-old timber is not so large per acre as it otherwise would have been; *but, as the grazing (of good quality) in the now rather open wood is let along with other pasture land at about five shillings an acre, this of itself forms an improved income from what the land could possibly have yielded for pasturage in the condition it was in before planting.* The well-kept estate accounts consequently prove that this compact block of plantation of about 200 acres has been a very profitable and beneficial investment to the landowner (Nisbet, article on *Forestry*, in the *Victoria County History of Cumberland*, vol. ii., 1905).

The general fodder-value of woodland grazing is reckoned at from about one-half to two-thirds of that of good meadow-grass; hence, if 3 per cent of the living weight of each beast be required for a good, satisfying feed of meadow-grass, from 4½ to 6 lb. weight of woodland fodder will be required for each 100 lb. live weight of the beasts grazed. The number of cattle that can be grazed on every 10 acres of plantation must therefore depend on the given conditions, and no general average can be quoted.

On the Continent woodland grazing still forms an important branch of rural economy in many Alpine and other mountainous districts, although in general it has gradually sunk in national-economic importance during the last century. But even where grazing is no longer customary in the woods, the grass along green lanes, or in young plantations, or on recent falls, &c., is in many places cut once or twice each summer, and brings in a small but regular annual return. Or it is sometimes harvested by the landowner himself, for feeding red-deer during the severe time of winter.

In many parts of Southern Europe the foliage of woodland trees is stripped and used as fodder for sheep and goats, and sometimes even for cattle in dry years like 1893 and 1901. All kinds of foliage, except Pine and Larch, are thus employed; but Maple and Sycamore, Ash, Canadian Poplar, Lime, Elm, Sallow or Goat-willow, and Acacia give the best fodder. In 1893, and for some years following, experiments were made to ascertain the fodder-value of bruised and boiled sprays of Spruce, &c., and with results that were not unfavourable. The chemical composition of the foliage was found closely to resemble that of meadow-hay as regards the quantity of protein and food-stuffs; but as to the actual nutrition-value only a few empirical results are known, complete investigations regarding the digestibility of foliage-fodder not having been carried out. Proposals have been repeatedly made, however, to make extensive fodder-plantations in the poorly wooded districts of Dalmatia and Hungary.

The foliage is either stripped by hand from the shoots in coppices or copse-underwoods, or the shoots are cut off and dried with the leaves attached by being tied loosely in bundles and, if possible, brought under roof for protection against rain, which makes it black and unfit for fodder. An acre of Oak coppice gives about 4 to 8 cwt. of leaves and twigs, 40 per cent of which can be used as fodder, with a feeding-value equivalent to that of about 1½ to 3 cwt. of hay, and worth locally from 8s. to 16s. Such foliage-fodder is provided by pollarding, or by thinning out unnecessary shoots in the coppice. The leaves and twigs are richest in mineral substances, and most nutritious as fodder when cut immediately after they have flushed fully (Bühler, in Lorey's *Handbuch*, &c., 1903, vol. ii. p. 286).

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[1] This Act, dealing with damage by sparks from railway engines, was passed on 4th August 1905, but does not come into operation till January 1908; and in no single case can more than £100 be awarded as damages (see vol. i. pp. 41, 57, and vol. ii. p. 8).

THE END.

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