THE SEA.

BY

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&c. &c. &c.

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PREFACE.

The Sea is of such vast extent, many of its movements are on so grand a scale, and the change of its waters is so general and so incessant, both in the upraising of pure water by the process of evaporation, and the return of that water which has performed its office upon the land in the never-ceasing flow of the various rivers, that all which can be done in one small volume is to entice the reader to a more intimate acquaintance with it, by pointing out how worthy it is of the most zealous and careful attention. Or, if there is any thing which can be done in supplement to this, or rather in aid of it, it is to present the general principles with as much of clearness and breadth as is possible, and also to show how this same sea—which occupies full seven-tenths of the surface of our globe, and consequently enjoys the same fraction of the general influence of the atmospheric fluid—works in connection, so as to aid in the producing of all those phenomena which render the place of our earthly abode at once so lovely and so comfortable.

In order to accomplish this simple and elementary plan,—a plan which, numerous as are the books that treat of the different departments of nature, may be said to be original in the design, and will, I think, be found original in the execution,—I have endeavoured to lay hold of, and exhibit in the clearest light, those features of the sea, whether considered as existing or as acting, which seem to me to be best calculated for drawing the attention to the sea itself, and for enabling the attention, when once so drawn, to turn readily to every other department of nature; and not to do so merely for the dry conning over of the simple and insulated facts of the single departments, but for leading the mind from the one to the other, so that every part of the knowledge which is acquired may help every other, and the aggregate may become one grand compound instrument, equally applicable and equally serviceable in obtaining farther information upon all, or upon any one singly, according as the necessity or the desire of the reader may suggest. Not only this, but I have in the present volume, as in its precursors, "The Heavens," "The Earth," and "The Air," endeavoured to keep constantly in view the practical uses to which all that is treated of may be applied, and the way that they may be made to co-operate in giving that tone to the mind which irresistibly leads it from creation to the Creator, and thus makes scientific knowledge the handmaid to true religion and sincere morality, without guile, lukewarmness, or hypocrisy.

In the first place, I have endeavoured to select a few of those characters of the sea, taken simply as a subject of contemplation, which appeared to me the best suited for convincing those who are unacquainted with such subjects, that here there is an abundant harvest to be reaped, which is equally rich in instruction, in pleasure, and in practical usefulness. In the second place, I have endeavoured to estimate the quantity, and point out the composition of the sea, in such a manner as seem to me most likely to put the reader in possession of the knowledge of its capacities as an element, both in respect of its great quantity of matter and of the peculiar powers with which this matter is endowed. In the third place, I have endeavoured to give a very brief outline of the distribution of the ocean waters, and I have referred the reader to the map for the filling up of this outline; and if, along with the map, the works of the best voyagers are consulted, a course of reading will be found, and a volume of knowledge acquired, of the amount of which the acquirer will hardly be aware until measuring the extent of the acquirement with the state of information on the part of those who have not been fortunate enough to enjoy this delightful labour. In the fourth place, I have entered pretty largely into the motion and action of the ocean waters, and especially into the phenomena of the tides, both as they are primarily produced and modified by the attractive influences and the varying angular distances of the sun and the moon, and in the secondary modifications, as depending upon the distribution of sea and land, of the characters of the bed of the former, and the coasts of the latter. I believe I have gone more largely into the explanation of these phenomena of the sea than any former writer who has addressed himself professedly to the unlearned, and in popular language; and I have done so advisedly; for when we consider how much the intercourse, the civilization, and the happiness of mankind depend upon navigation, and that the peril of the ship lies chiefly within the range of the shore tide, we must admit that, of all subjects, this is one of the most general interest. I believe, however, that I am correct in saying, that it is one which, not only the public generally, but many of those whose lives are spent on the sea, understand very imperfectly. On this part of the subject it will be found that the investigation is carried a little farther than is usual, that some new explanations of the actual tides are given, and that some of their most important results, which have been hitherto overlooked, have been stated.

I could have wished that more ample space had enabled me to advert to some of those progressive phenomena of the sea, and the reciprocal action between it and the land, which appear to have had so much influence in bringing our globe into its present condition: but the limits of the volume would not permit; and I thought it better to do a few things as well as possible, than to treat a great number imperfectly.

ROBERT MUDIE.

Grove Cottage, Chelsea,
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THE SEA.

SECTION I.

PRELIMINARY REMARKS.

THE "MANY-SOUNDING SEA" (Πολυφλοισβοιο ϑαλασσης) has supplied a favourite theme for the songs of poets, ever since the Mœonian sung the wars of the Greeks and Trojans, and the wanderings of the sage king of Ithaca; and, in every age, those who have endeavoured to delineate the features of nature upon an extensive scale, and to detail, in a striking manner, the causes of natural phenomena, have found the vast expanse of the oceanic waters at once the most inviting and the most perplexing in the whole range of natural substance and natural action.

Among the wonders of creation, the sea is indeed the surpassing wonder; and no human being, learned or unlearned, perhaps ever beheld the sea for the first time, or even the fiftieth, without feelings of a more intense, though somewhat mysterious character, than any thing produced by the most rich or the most romantic landscape. The plains may be ever so lovely, the forests may be ever so fair; every shrub and every plant may be in bloom, every bird may be in song; the rivulets may be twining through the glades; and the rivers rolling along, dividing the valleys, in streams and tides of limpid crystal, between banks of emerald; and the habitations of man, placed amid all that is lovely and luxuriant in nature, may bespeak a full measure of enjoyment to every sense: but, notwithstanding the very maximum of the land's wealth, brought together with that inimitable taste of nature which man's best art must follow at a very humble distance, and notwithstanding the appearance of plenty and repose, and gratification of every appetite, which may be about it, "*Surgit amara aliquid*," there is a drop of the gall of bitterness, which "bubbles up," and dashes with the taint of mortality the most apparently sweet cup of mere sensual gratification. So also, if we take the wilds, in those regions where the barren rock, or the snow-clad peak, is upheaved to the middle air, and haply tipped with volcanic flame, and canopied with volumed smokes; where the mountain lakes have torn asunder the earth with the fury of their seasonal-inundation swell, and left in their stead those little lovely valleys, where, far removed from the turmoil of cities, and the tortures of ambition, the mountain shepherd dwells in peace; where the living streams leap lithely from rock to rock, filling the air with volumes of steam, making the cliffs rich with the perpetual fall of drops of the purest water, and shaking the wilderness with the sound of their music; where, in short, all is as expressive of natural power and grandeur as the scene to which we have just alluded is of beauty and wealth; yet even here, after the momentary wonder of the stranger has subsided, there is a feeling of ruin,—for all those grand displays of towering summits, rifted rocks, and dashing waters, speak of a former state of things, which has been whelmed in dire destruction before they could be produced.

In the case of both, too, and of all land scenes which we can contemplate, there is a mingled emotion of permanence and mutability which is painful to the thought. As we return, at short intervals, the aspect of every thing remains unchanged; and whether the general character be blooming or bleak, it soon palls upon the sense. So, in like manner, if we summer and winter there, and watch from the early bud, through the leaf, the blossom, and the fruit, until the seed shall be ripened, and the leaf flung to the earth as a useless thing, the emblems of mortality are as thick around us as those fallen leaves. Thus the ultimate impression which the natural and uneducated mind receives from such scenes is a dull succession of beginnings and endings; and the life of man, and even his final destiny, (if better information prevent not,) mingles with the feeling, and deepens the anguish of the whole. Hence it is, that they who inhabit the most lovely places in nature are generally the most dead to the feeling of natural beauties, and they who tenant the sublime parts of the earth have no perception of sublimity. Either the actual observation of mankind, or the careful study of their authenticated history, will establish the truth of these remarks, and tend to show, that, in order to bring home nature to the mind with that full effect which shall arouse and elevate it to the proper feeling of the greatness and the goodness of nature's Author, and the great bounty which He has graciously bestowed on man in his works, there must mingle with the thought some element which has less of the heaviness of the dust about it, and suggests more forcibly the idea of motion which never ceases—of life that shall never die.

Some such feeling as this necessarily arises from the contemplation both of the atmospheric air and of the heavenly bodies; but the feeling in both these cases is what we may call a secondary one, or one which is arrived at by a certain process of reasoning; and therefore, however powerful it may be, it can be had and enjoyed only by those who are capable of going through this process; whereas, it is desirable that such a feeling should immediately connect itself with the exercise of the senses, so that it may lay hold of, and lead to, improvement of the unlearned, as well as the learned.

Now, a very little reflection will show that the sea is precisely the department of nature which is, above all others, calculated to produce this effect. It is a substance palpable to observation in all states; and while, as a substance, it is in continual motion and action, it possesses in itself such a power of returning to its general and average state, that, though it is ever active, it is never fatigued—though it is ever changing, there is no stamp of age upon it, but at any hour, and every hour, it appears as young and as fresh as it could have done at the moment of its creation. Upon land, change is perpetual; and there does not appear to be in dead matter there any power of return from any situation into which external causes may bring it. The common action of the air, the pelting of the rain, and the keenness of the frost, corrode the hardest rocks, or, in cases of extreme violence of the latter, rend them in pieces, with fearful din, among the mountain tops. So, also, volcanic fires blot out all memorials of the former surface, or showers of ashes bury it to the depth of many fathoms, or the earthquake shakes the land to pieces, making hill and valley change places, opening up the secret springs of the mountains, and drinking the streams of the valleys into rents and fissures of the earth,—so that, when those inhabitants who escape destruction, during those fearful convulsions, return to seek their heritage—the place of their birth and their abode—it is blotted out from the map; and though the ruins are there, the country, to their recollection of it as a country, is gone for ever. Even in the more powerful workings of the limpid air itself, such changes may be effected on the land as shall cause it cease to be known to its former inhabitants. Nay, even the little which man can accomplish may produce a permanent change upon the solid surface of our globe, and convert a garden into a wilderness, or a wilderness into a garden, according to the degree of knowledge and industry with which the labours of man are performed.

But when we turn to the sea, we find that no permanent change can be produced there; for that, both its great volume, and its peculiar properties as a liquid, which renders itself up to the power of gravitation in every particle, without any cohesion of parts by which this can be disturbed, unless through the operation of some external cause,—give to the sea, so to express it, a universal and instantaneous power of healing every injury that can be inflicted on it, and every change to which it can be subjected, either by the operations of nature, or, upon a scale immeasurably small in comparison, by those of art.

We are acquainted with many causes, the operation of which disturbs, for a time, the equilibrium of the ocean, and the height of the waters, and the appearance of the surface at particular places. Indeed, those waters are far more obedient to every external cause of action than the solid parts of the earth; but there is, in the fact of the sea being a liquid, and in that of the water having the maximum density at a temperature considerably above freezing,—though below that of the average surface either of the land or of the waters, as estimated for the whole globe,—a means of instantaneous re-action, so that, in proportion as any cause slackens in its operation, the sea resumes its former state. We shall afterwards have occasion to notice the phenomena of those leading actions on the sea, and the effects which result from them; but in order to have some general notion of the mass of water, it is necessary at least to name one or two of them in this preliminary section. We pass over those local agitations which are communicated to the sea by the land, such as take place in earthquakes, and by the action of sub-marine volcanoes, and shall name only those which may be said to result from the permanent or regular succession of phenomena on our globe. The sun and the moon, by being situated in different positions, with regard to the surface of the sea, as days, and months, and years roll on, produce constant changes in the surface of the ocean. The point at which either of those luminaries is directly over head, is nearer to the luminary by about four thousand miles than the average of the earth's mass; and the point which is most distant from the luminary, or diametrically opposite to that at which the luminary is vertical, is about four thousand miles more distant from the luminary than the average of the earth's mass. In consequence of this, the surface of the water immediately under the luminary has its attraction toward the luminary increased, and that toward the earth diminished to the same extent, and consequently it is raised up above the surface. So also at the point directly opposite to the luminary, the earth's attraction, and that of the luminary, are in the same straight line, and the water is, by their joint action, collected towards this point, until the elevation of the water here exactly balances that at the opposite point. Those two points of elevation answer to each luminary, and are united when the sun and moon are both in the same part of the heavens, or when they are in parts diametrically opposite; but when the sun and moon are so situated as that lines drawn from them would make an angle at the earth's centre,—which angle is the true angular distance of the bodies themselves, when cleared of parallax, as explained in the HEAVENS—there are two points of elevation answering to each luminary, and which are distant from each other by the angle above alluded to, which may be expressed in degrees of an arc, or reduced to a parallel of latitude, if necessary, and expressed in time, at the rate of fifteen degrees to the hour. This is the simple theoretical view of the tidal motion of the oceanic waters, as depending on the heavenly bodies; but even as theory, it requires several modifications; and when those have been carried as far as theory can go, they still agree so imperfectly with the observed phenomena—which are often apparently in direct opposition to all theory—that before we can have even a rude general knowledge of this action on the sea, we must take many circumstances into account.

Another general motion of the sea, as brought about by the action of the sun, and the daily rotation and annual revolution of the earth, is the transfer of the oceanic waters in latitude. This also is an effect depending upon many causes, and therefore exceedingly difficult to be understood in such a manner as will apply to all the details; but the general principle, without the modifications, is easily stated. The water, which receives most immediately the action of the sun, has less specific gravity than the mean, and therefore it floats, and the heavier water presses in an under current toward the place where the sun is passing vertically, while the heated water returns along the surface in the opposite direction. The return is, however, less than the supply, because the quantity of water which is taken up in vapour by the air, at the surface, is greatest where the sun is most nearly vertical. The way in which the extremes of the alternating seasons tell upon the two hemispheres,—especially in their higher, or polar latitudes,—has no inconsiderable effect upon this transfer of the ocean waters in latitude northward or southward. It will readily be understood that, within the polar circle, where the sun does not set for several days, or for several weeks, during the summer, and does not rise for a corresponding period during the winter, the whole solar action of the year must be converted into something approaching one grand solar day during the summer, and one grand solar night during the winter, alternating with each other in the two hemispheres, and bearing some resemblance in their effects on the sea, as well as on the land, to those equal days and nights which alternate with each other in the regions of the equator. But, in understanding how this works practically, we must look well at the map, and note how sea and land are situated with regard to each other; because, if any one portion of the sea, peculiar in its latitude, is wholly, or nearly, cut off from the rest by intervening land, the action of such a portion, whatever it is, must be in a great measure confined to its own locality.

It will readily be understood that the two general causes of motion in the waters of the sea which we have named must clash with each other, because the tidal motion (which is, however, the elevation of a wave, rather than an absolute transfer of water,) of itself depends on the diurnal rotation, and, consequently, proceeds from east to west along the parallel, while the transfer in latitude, whether it is made from the north southward, or from the south northward, is in the cross direction, or at right angles to that occasioned by the tide; so that the one must so interfere with the other as that the result shall sometimes be the sum of the two in absolute disturbing effect, and sometimes the difference, or it may be any thing intermediate between these; and this, it is obvious, must render the determination of the result at any particular place a matter of great difficulty, even though there were no other source of disturbance.

But there are many such sources, of which, however, we shall in the meantime name only three :—first, the interruptions offered by the land; secondly, interruptions offered by the bed of the ocean; and, thirdly, atmospheric disturbances. The last of these is not only very varied for any given time over all the earth's surface, but is constantly varying at every point; so that no theory whatever can be rendered applicable to the details, and all that we can do is to explain, if possible, the general principles. It may be resolved into two parts, —atmospheric motions, and differences of atmospheric pressure,—the first of which acts directly by the friction of the air taking hold of the surface of the water, and curling it into those irregularities which we call waves, and which may be propagated through the water in swells to distant places which the wind does not reach; and the differences of atmospheric pressure act upon the surface without the production of anything that can be considered a wave, or swell, by merely pressing it down where the atmosphere is heavier, and causing it to ascend up where the atmosphere is lighter. These are the chief general actions upon the sea, so far as the motion of its waters are concerned; but if we understood them as well as, in the present state of our knowledge, we do the opposite, their full amount would form but a small part of the introduction of the natural history of the sea, and the uncomprehended wonders of that mighty element would be as inviting to our inquiry as ever,—more so, indeed, for the little that we then knew would stimulate the desire of knowing more.

Besides the results of the compound action of those agencies, considered as mere phenomena of the sea, in enabling us to understand the economy of that element, considered in itself, and the practical uses to which we may be enabled to turn its various tides, currents, and other movements, for the purposes of navigation upon its surface, there are other effects of the same agents which are not less deserving of our attention. These may be expressed generally under the name of the action of the sea upon the land; and the more simple view of this action is that which regards it as wasting away the land in some places, and casting it up into new formations in others, by the eddyings of the waters, or spreading it over the "oozy bottom of the deep" by simple depositation. The full investigation of this portion of the subject would, in all probability, comprehend much of the progressive history of our planet, and lead us at least to conjecture by what means places which at one period must, from the peculiar character of the shells and other marine remains contained in them, have been at one time at the bottom of the deep, though they now are found at elevations some thousands of feet above its level. But farther, on this part of the subject, it is not easy to separate the action of the sea itself from the action of those great rivers which are its feeders, or supply the water which is wasted from its surface by evaporation, or rather, which is taken up there by the atmosphere, and distributed through that fluid in order to be again precipitated on the earth for the preservation of land plants and of land animals. But this is another branch of the subject, in which we must be in a great measure guided by the observation of details, and we dare not venture far upon any theoretical principle,—at the same time that it is one upon which every person who has the least desire of knowing what has been, and imagining what shall be, must feel the deepest interest; and perhaps there is not one who lives and thinks who does not experience strong desires on this most interesting subject.

But, in addition to the gradual destruction of the land at one place, and its gradual production at another, of which we can observe the slow progress in any country having shores, and especially in a country like Britain, around which the waters play with so many tides and currents, there are more instantaneous productions of land, and also more singular modes of aggregating and bringing to the surface lands which do not seem to be immediately formed out of the ruins of those which had a previous existence. In different parts of the world, and at different times, some of them recent and within the experience of those yet alive, there have been islands reared up in brief space from great, if not fathomless, depths of the sea, evidently by the violence of volcanic action, which, from the pressure of water over it, and the mass of materials upheaved, must have been energetic beyond any thing which we witness on the surface of the land; and, indeed, any species of action which can take place under the simple resistance of the atmosphere must be trifling as compared with that which can disturb the bottom of the sea at the depth of only a single mile. The pressure upon every inch of the bottom at that depth, arising from the superincumbent weight of water alone, considerably exceeds a ton on every square inch; but, for the sake of round numbers and easy recollection, let us say that it is only a ton—and this pressure is equal, upwards, downwards, and in every direction; so that, if the palm of a man's hand, exclusive of the fingers, were there applied to the surface of the bottom, or of any rock, without any intervening particle of water, a team of ten of the strongest horses would not suffice to drag it from its place;—what, then, shall we say of the power of that volcanic action, at probably double this depth, which can force upward an extent of several square miles, and which, if it could act upon them, would of course scatter, more lightly than chaff on the whirlwind, all the navies whose keels ever divided the ocean waves?

But if we have something very wonderful in this rapid production of new lands by the great powers of nature under the bed of the ocean, we have displays equally wonderful of the formation of other new lands by powers which, taken in the individual instance, are just as insignificant and minute as the others are gigantic, but which, by the countless millions of their numbers, compensate for the feebleness of each individually, thereby showing us a most singular instance of the influence of number as a compensation for the inferiority of magnitude, and thereby tending to establish the grand truth, that the action of matter, like matter itself, is divisible down to the primary atom; but that, as in the one so in the other, if this primary, and to our senses incomprehensible atom, is but sufficiently multiplied, the effect which it is capable of producing may exceed the most extensive range of our arithmetic.

We need hardly mention that here we allude to the coral formations, which are found only in the tropical or warm seas, and of which—though the little architects are so minute as to be barely, if at all, visible—the progress, taken in the mass, is in some instances exceedingly rapid. The islands and reefs which these minute creatures form are often very singular in their construction; and they differ in many very remarkable particulars from the islands of volcanic origin which are found in the same seas.

The sea is not, however, more wonderful, or more worthy of attention, in the motions of its waters and their causes, than it is considered as the abode of growth and of life. The plants and plant-like productions, (for there are many animals in the sea, the stalks or habitations of the colonies of which very much resemble plants,) are all of very different characters from those that are found upon land. Supported in a liquid of greater specific gravity than themselves, the sea plants do not require that assemblage of woody fibres which is necessary for all land plants excepting such as are procumbent on the soil or support themselves by climbing; and, as they do not draw their subsistence from the soil by means of roots, but from the water, which bathes every part of their structure, they stand in need of no vascular system for the conveying of nourishment from one part to another. Nor is there any distinction of parts in them, such as stem, leaf, and flower, or wood and bark. The whole plant, whatever may be its shape, is a simple *fronde*, or vegetable expansion, whether it consists of a peduncle and blade, or a divided expansion,

—a bunch of fibres, or any thing else; and whether the germs of the plants are gems, or little buds, at the adhesions to the rock or stone, or sporules contained in the fronde, they are as simple in their parts as the plants which they are fitted for producing. In the warmer seas, especially in the broad eddies, or revolving waters, produced in the loops of those currents which circulate in the great oceans, they are often wholly dependant on the water, and float on it, covering vast extents of surface, without any connection with the ground.

Those vegetable productions of the sea have their uses in the economy of nature as well as in the arts of life. They soften the currents of the rolling waters, and lessen the violence with which those would otherwise assail the shores of the land; they serve as food for some of the fishes, but only of a limited number, and those almost exclusively inhabitants of the warmer seas. They also serve as food for many of the larger aquatic reptiles, as, for instance, the green turtle, the flesh of which is used so abundantly in many warm countries, and which, from the slow rate at which its circulation, and indeed all the functions of life in it, are carried on, can be transported alive, though out of its proper element, to the distance of thousands of miles, affording, perhaps, the most remarkable instance of animal endurance with which we are familiar.

The same marine vegetation affords shelter to countless myriads of the smaller living creatures which inhabit the sea, and, in all probability, food to many of them. Then, if we consider the myriads upon myriads of the eggs of fishes, and other animals, which are secure in this tangled mass of plants, and of little fishes which remain securely there till they have acquired that strength which enables them to commit themselves safely and freely to the waters, we shall find that the vegetable kingdom in the sea is no barren spot in the garden of Nature, but that, in usefulness and in abundance, it does not hold an inferior rank to even the most favoured spots which we meet with upon the land.

It is in its animal productions, however, that we receive the most lively impression of the vast, the almost boundless fertility of the sea,—a fertility compared with which the whole of the land, and all its inhabitants, numerous and varied as they are, sink into absolute insignificance. We might arrive at some such conclusion as this before-hand, by reflecting on the peculiar structure of the sea, and on the vast extent of the earth's surface which it occupies; and when we come to consider this great question of the productiveness of the waters, we must include the lakes and the rivers, and every body of water which contains a living inhabitant, whether that water is salt or fresh, or whether it is stagnant or in motion. This is not the place for enumerating, far less describing, the animals of the deep, and of its tributary waters; for the bare list, leaving description almost entirely out of the question, would consume almost the whole extent to which our volume must be confined. But it is impossible to overlook one or two of the leading facts, or to have any thing like a correct notion of the inducements which we have to the study of the sea, without taking them, however briefly, into consideration.

In the first place, excepting in a certain limited space around each pole, and probably there only for a limited depth below the surface, the sea knows no winter which can be considered as a provisionless season, to some part at least, of its living inhabitants; and as we descend in latitude, its action throughout the year becomes more and more uniform, until there is, in the tropical sea, a much more perennial abundance than there is in those favoured isles of the east, which are rendered at once so fertile and so salubrious by the continual play of the sea winds over their surfaces.

In the second place, and independently altogether of its greater extent in breadth, there is a depth of inhabitableness and production in the sea to which, in the nature of things, there can be nothing corresponding upon the land. Say that, over the whole extent, the average depth to which the sea can be inhabited is only thirty fathoms. Fishes have been taken at, at least, double this depth; but as the case needs no overstraining, we shall take it thus much within the limit, in order to make allowance for the banks and shallows. The whole of this depth throughout every inch is equally inhabitable by fishes, and as their specific gravity is beautifully adapted to that of the water, they can breathe with perfect ease, or without any effort, at every inch throughout this depth. If nearer the surface, they are, no doubt, subjected to a smaller pressure, and if deeper to a greater; but the pressure, so long as the whole body of the fish is covered with water, is very nearly the same on every part of it; and we know, from our own experience, that we feel much more energetic under an increase of atmospheric pressure, and languid as that pressure is removed, unless there is a bracing influence of cold which shall make up the difference. When we ascend to a mountain top, we have the advantage of this cold, though even there the small vessels in the lips, nostrils, and other places which are kept warm by the act of breathing, are apt to burst, and bleed, in consequence of the removal of pressure. And if we remain at the same elevation, and at the same temperature, or a higher one, the diminished atmospheric pressure produces languor; and we fell heavy because the atmosphere around us is light. Thus, there is a far more extensive range for the inhabitants of the sea than there is for those of the land.

It may, however, appear to such as have not reflected on the subject, that there may be a want of subsistence; for we are so much accustomed, from what we observe around us, to connect subsistence with the mere surface of the earth, or that which immediately grows out of this surface or is attached to it, that we may not be able very readily to bring ourselves to understand how there can be countless millions of living creatures, faring sumptuously every day, over those unfathomable depths of the ocean, where probably not one of them ever approaches within several miles of the bottom. This difficulty instantly vanishes, however, when we consider —Thirdly, the extraordinary productive powers of the inhabitants of the sea, and especially of many of the fishes,—indeed, of all of them as compared with any animals upon land, except such as are of diminutive size, and remarkable for the short period of their lives. The produce of one codfish in a single season is nearer four millions than three; and though we have no evidence of the fact, and such analogies as we are able to draw from land animals are rather against it, it is not improbable that this immense production may be repeated every year. The year is the general cycle of production among most of the tribes of nature; and among the mammalia on land, though we know many instances in which it is much shorter than this, we believe that the elephant is the only well authenticated one in which it is longer. This productiveness is not confined to the fishes, but extends to the smaller inhabitants of the sea; and, during the proper season, a pin's point can hardly be put down on the rocks, favourable to production, without touching some little shell or other living creature in a rudimental state; every bit of sea-weed, too, whether fixed or floating, has its numerous colonies, all in progress towards maturity; and even the water, when it presents nothing to the naked eye, and is merely a little turbid to the microscope, if the power of that instrument is not all the greater, is full of life of some sort or other; and if we boil it, it gives out that peculiar odour, which is common to almost every animal of the sea when in a recent state, and which cannot be mistaken for any other.

Now, if we take the case of the cod, above alluded to, as an extreme one, and say that the total multiplication of living creatures within the volume of the oceanic waters is at the rate of a thousand-fold every year, there is abundance to stock the whole expanse, and to feed the one race upon the other; or, as fishes are understood not to be very scrupulous in the matter of cannibalism, to supply any one race on the surplus of its own numbers.

It is this last consideration which places the fertility —the power of production of life—in the sea in a point of view so very striking that it may well rank foremost among the wonders of the deep. On land, if we follow the series, we find that vegetation is a necessary link; and that, though there are many races of land animals, both of the earth itself and of the air, which subsist entirely upon other animals, yet if we pursue the series downward, through feeder and food, till we come to the verge of inorganic matter, where the first operation of life of any kind contends with the physical and chemical properties of mere matter, we are always brought to the vegetable kingdom, as standing between inorganized matter and the animal, and performing the first step of the process of assimilation. In the sea, however, it is not so, for there are few inhabitants of the watery element which subsist upon those vegetables which the sea produces; and therefore, in the sea, the animal kingdom primarily, in a great measure, produces its own supply. In this we perceive the vast power which is inherent in the sea as a medium or agent of production. The fishes which bring forth their young alive are few; those which carry their eggs supported on their bodies contribute nothing to the maturity of these, farther than the mere rudimental germ, which as yet is only a few atoms of jelly in the egg. Beyond all calculation, the greater portion of embryo life in the sea may therefore be said to be cast upon the waters, without any future nourishment or protection, or any reference or recognition of parent and offspring, even for a single instant. But though thus cast upon the waters, these little germs are not thrown upon the waste, for those very waters contain in themselves, or receive from the action of the sun, every element which is necessary for bringing those germs to maturity; and here again we have a striking evidence of the little waste of the action of life which there is in the economy of those living creatures which inhabit the sea.

Nor is it in this supply of its own inhabitants in which the great productive power of the sea alone appears. Of the feathered tribes alone there are probably twice the number dependant on the sea for their constant supply of food all the year round, that are dependant on the land; and there are many races in those regions where the winter is bleak and desolate that would perish in one year, were it not that, when the land is all barrenness, a store is open for them in the abundance of the sea. Tens of thousands of those birds which rear their broods, scattered over our upland moors during the summer, throng around the margins of the sea as the winter sets in; and as the tide ebbs away from the shelving shore, it is no ungratifying sight to see them running after the retreating water, and feeding upon that bounty which it leaves behind; and though their voices are not tuned to what we can exactly call harmony, yet it is no disagreeable sound to hear them whistling, and wailing, and screaming their gratitude to that Almighty Being who has bestowed the means of life upon every living creature which his good pleasure has called into existence.

Such, in the most brief and sketchy outline, are a few of the inducements which we have to acquire a knowledge of the sea, as arising from the movements of the great body of its waters, and those productions which its agency brings to life and maturity, and supports. Even with the limited knowledge which we at present possess, the catalogue might be greatly extended; and in proportion as that scientific and searching observation which, of late years especially, has been applied to this department of nature, shall be so extended as to admit of generalizing those facts which, even yet, lie, as it were, scattered over the wide expanse as at single points, the inducements to the study, and the reward of pleasure and usefulness arising from that study, will be greatly extended. And thus, as we are, even now, dependant on the sea for very many of the necessaries and the enjoyments of life, it may, one day, and that not a distant day, become the most instructive page in the volume of Nature's book.

But besides these lessons of instruction, and hours of pleasure and profit, which have to be sought for by the careful study of the sea, there are many which it communicates at sight, or even forces upon our notice. When we are weary and worn with the fatigues of our inland professions and occupations, we repair to the margin of the sea, in order to recruit the strength of our bodies, and restore the tone of our minds; when the elasticity of the system has given way, and our hours pass heavily, we plunge into its renovating tide, and, in brief space, we become new creatures. If the appetite is gone, and the food, which should bring health and strength to our bodies, is seen with loathing, we quit the land, and have not been long on the sea till we become as hungry as ravens; and, in very many deranged states of the body, under which there is neither health nor hope upon the land, a voyage over the sea, careering fleetly before the wind, and rocking buoyantly on the healthful tide, is our last and our only resource; and, if we take it in time, it is frequently as certain as it is pleasant.

There are, in this respect, some very remarkable properties about the sea. When, in what may be called the living water—that which has full and free communication with the waters and currents of the ocean, the tide retires and leaves a portion of the beach dry, there is never any of that offensive taint of putridity which pollutes the air, offends the nostrils, and is injurious to the health, when land-floods assuage, or when stagnant waters leave their beds dry. There is a delightful, though peculiar, freshness on the beach, unpolluted by man and his accumulations, which proves that the bottom of the sea, like its waters, is always clean. It is worthy of remark, too, that the air from the uncontaminated sea is always wholesome, and never damp; that its breezes are ever healthy, and that if the land suffers under any extreme, whether of heat or of cold, there is always mitigation in the sea, if its waters are unchained by frost.

Then, even if the feeling is dull, there is nothing so well calculated for arousing it as the sight of the sea. It matters not what the state of its waters may be at the time: the air may be motionless over it, and it may, in itself, be as placid and smooth as a mirror; or all the winds of heaven may be contending upon its surface, that surface may be swelled into waves, and the short twiches of the fitful gusts may cause the crests of those waves to reek, as if each of them were a furnace: but in all states, from the one extreme to the other, there is an almost equal feeling of exultation in the contemplation of the sea.

The land, what with continent, what with island, and what with islet, is many patches, which are all severed from each other by the intervening portions of the sea, broad or narrow as may be; and the inhabitants of them are cut off from all communication with each other, unless they have learned to form it by means of the water. The sea, on the other hand, once the entire surface of the globe, is *one*. It is the free highway of all nations, the route to every continent, and every land; so that man has only to build his vessel of the proper form, strength, and size, learn how to conduct it, and to launch it upon the all-accessible, all-connecting sea, and visit, at his pleasure, any one point of any shore on the whole surface of the globe.

It is highly probable that this feeling of being in the neighbourhood of all nations, and having one connecting pathway with every quarter of the world, and every isle of the ocean, is that which renders the sight of the sea so very buoyantly expansive to the mind. The land, be it what land it may, has its boundary, and if we think of land beyond that, the chain is broken, and we compare them by contrast, as if they were things of different kinds. But the thought which the sea suggests is one of continuity and general union; and the feeling that men throughout the world form but one brotherhood is neither unnatural nor remote. On the contrary, it is one of which we cannot easily repress the spontaneous suggestion, even if we would; and why should we? for there are few better calculated either for expanding the mind, or softening the heart.

Nor are what may be called the different moods of the sea, in itself, and without reference to these lands which it so wonderfully connects by seeming to divide, unworthy of our attention, or unfruitful to our contemplation.

If we love tranquillity, where can we behold it more exquisitely complete than in the unruffled surface of the glassy sea, as it lies still and waveless within its shores? and on the evening of a fine summer day, when the sun has nearly reached the horizon in the west, and the sea-breeze has died away in the offing, and the land-breeze not begun to blow, and the whole surface is golden light, fading off into delicate tints of purplish green, which cannot be imitated, or even correctly named; and even when the orb of day has declined, and the russet and the grey are contending which shall make the landward part of the pasture the more soft, there is not the wail of a sea bird, the rustle of a wing, the murmur of a rolling pebble, or the gurgle of a ripple against the rock.

If more active scenes be preferred, then nothing can exceed the spirit-stirring aspect of the ocean waters, when a steady breeze along shore just curls the surface, so as to give it its shade of the most intense blue, with just a little fringe of snow-white foam around the point of the rock; and the distance, as seen from a height, fades off till it blends with the cloudless sky, and the heavens and the earth even linked together by the lovely bond of the sea, and the sun himself appears to have become a denizen of the terrestrial system. The ship appears—with all her sails bent, and the light full upon their ample expanse,—like a giant, in or upon the extensive waters, motionless, to all appearance, from the steadiness of the breeze and the distance at which she is seen, but in brief space gliding from a horizon of many leagues in extent, and followed by another and another, till the sea appears peopled with life; and the general intercourse of nations is brought forcibly and feelingly before the mind by its most beautiful and most appropriate emblem and instrument. Nor will it fail to give additional interest and pleasure to the contemplation, if this thought should mingle with the rest, that this same ship, too long perverted as the tool of oppression and the vehicle of slavery, has now, in addition to an equitable commerce, mutually advantageous to all parties, become the means by which inquirers after knowledge have been dispersed over every part of the globe; and assuredly, when it is borne in mind that, in addition to this, the ship has become the means of dispensing "to the people who sat in darkness," the heavenly radiance of "the Sun of righteousness;" and that, in the remotest isles of the wide-stretching Pacific, the simple native, who, in the memory of those not yet old, was bowing down to the most ridiculous of idols, and calling upon the block to deliver him, and the dumb stone to save, now calls upon the living God; and that, as morning dawns, and as evening closes, he breathes forth, in the simplicity of a devout heart, his simple song of grateful adoration to the Creator, the Redeemer, the Sanctifier—" the God of the spirits of all flesh." Even if the sea had been the means of distributing nothing but this, it would have hereby been endeared to all the well-wishers of the best interests of the human race. But this is not all that has resulted from the promulgation of the word of life. The declaration of the Founder of our holy religion stands sure: " Seek ye first the kingdom of heaven, and all things shall be added unto you;" the spirit of that same pure and heavenly faith, which has done so much in weaning the people of Europe from the cruelties of their earlier state, and the midnight superstitions of the dark ages, has already begun to shed the blessings of its temporal influence upon the tenants of those remote spots of ground; and civilization, and all its concomitant blessings, are accompanying the pure and mind-awakening spirit of the Gospel. This could not have been done but for the sea; for we, at this remote part of the world, actually know more of those who dwell at the very antipodes, and have more full and free intercourse with them, than the inhabitants of the one side of even a small patch of land have with those of the other, when they are without the means of intercourse by the sea.

When Australia was first known to Europeans, the people were not in possession of any water-craft which could carry them to any distance upon the water, and, in consequence, their geographical knowledge was limited to a very few miles; and even those lands which were the nearest to each other in locality had no intercourse, save when they met with hostile intentions; and yet, at that very time, they depended chiefly upon the sea for their support, and even the tribes more inland were, at least at certain seasons, almost wholly dependant on the waters.

But it is not only in its more placid moods, and in the wind steadily sweeping over its surface,—which associate our thoughts so readily with the ship on her voyage, and entice the train of our contemplations to the uttermost ends of the earth, and thence over the wide extent of the universe,—that the sea is an object of interest. There is a pleasure in the simple and local observation of this mighty element, which brings together objects, and awakens reflections, that are to be found nowhere else; so that when, as we have said, the invalid goes to the shore of the wide-rolling ocean to recover the tone and regain the strength of his mortal frame, it is questionable whether the grand medicinal effect is not produced upon the mind, and whether the recruiting of the body is not a simple consequence of that uplifting of the spirit which the activity and life of the scene before us never fails to produce. We stand on some lofty cliff, some wide and beetling promontory, whose front is seared by the blasts of ages, and against whose base a thousand seas have flung their billows without effect. Far in the distance, the expanse, playing in various shades as the wind awakens the surface into life, spreads in full view before us, spotted with islands, studded with rocks, and with here and there a tell-tale breaker, chafing white and angrily upon the surface, but warning the mariner, both by its yeasting and its sound, that there is danger below the surface, and thus admonishing him to keep at a distance in order to be safe. Then, in the foreground, at the base of the cliff, the surges foam and thunder, and dash their spray upwards in broken jets, till it falls again, like a heavy shower, almost on the very summit; and as if the water were not in itself a weapon of sufficient power for this assailment by the sea, the fragments which time and tide have severed from the cliff are taken up by the angry waves, and battered against it with more fury than one could imagine the sea to possess, who beholds it only when it is slumbering in tranquil weather.

On some of our more exposed, and especially our caverned shores, if the wind is at the top of its bent, and the waves at the maximum of their accumulation, swinging wave upon wave in aggregated masses, till the sum of each tells like a mountain on the sea, and the "trough" between is as though the waters were cleft in twain, and a pathway of dry land were about to be prepared, the scene is truly glorious; and if no living thing is in danger, if no creature is there but such as love the sea, and are at home in the midst of its greatest excitement, there is nothing in nature so calculated to impress us with adequate ideas of that sublime in power with which the Almighty has endowed His works, and which in this case is brought about by what to us might well seem to be the very simplest of all means—the mere motion of that gentle atmospheric fluid which is necessary to the life of a mite, and which does not injure the breathing apparatus of an animalcule, the volume of which has to be magnified ten thousand fold before the eye can discern it.

If our tempest comes from the angry north, in the severity of the winter months, when its birth-place is the regions of the "thick-ribbed ice," and it howls upon the snow-clad heights, dreary and desolate even in summer, which, in the north of Scotland, overlook the Polar Sea, then, indeed, it is an unmingled display of the united action of the air and the sea; for no wing can keep the sky, no fin can approach the surface or the shore, and even the spectator must seek some sheltering cave, and cling for security to some earth-fast rock, before he can dare to trust himself to feast his wonder and rouse his admiration with this unmingled exhibition of the acting of nature's most simple powers—more splendid, more sublime, more spirit-stirring, and far more instructive, than that of all the human actors that ever trod the stage in the theatre of exhibition, or on the grand theatre of society, where the people perish by thousands, in order that some imaginary right or wrong, of which the memory shall be blotted out in a few years, may be—turned to the one hand rather than to the other.

The different strengths of the various kinds of rocks which compose those cliffy shores often give them an extreme ruggedness of outline, both in length and elevation; and the projecting points and retiring nooks which are thus formed give much additional variety and grandeur to the ocean's display. In some such places the continued action of the sea has scooped out caves, which penetrate under the cliffs to many fathoms inland; and, in some instances, these are perforated up to "the day," at the inner part of the chamber, something after the fashion of the vent of a piece of ordnance. Where this is the case, they play like fountains in the storm, but fountains which, by comparison, turn into nothing those tame and tiny jets with which man ornaments the courts of his most sumptuous palaces in warm climates. As these upward perforations are acted upon only in violent storms, while the water enters the cave below, and consequently produces some effect on it at every tide, the upward opening necessarily bears but a small proportion to that of the cave itself, unless it happens to be made through very loose and tender strata, in which case the rubbish and debris partly choke up the channel of connection; so that, unless in very violent tempests, in which cases it may fling up the stones and rubbish, there is a mere entrance of water into the bottom of the cup, but no jet thrown up into the air. This is the case at a perforated cave, the opening of which is in the middle of a corn field, a little to the eastward of Arbroath, in Forfarshire, the coast between which and the promontory of the Red Head is very sublime, and, in a strong south-easter, well-worthy of a visit by any one who loves the majesty of the sea. In the caves on the north coast, where the strata is of firmer texture, the perforations are smaller in proportion to the caves, so that, what with the condensed air, what with the pressure of the surge, which rolls unbroken from the polar ice until it reaches this part of the coast, the jet which accompanies every thunder of the sea is highly sublime. At one of these places, and perhaps at more, a large mass of hard stone reposes upon the top of the opening, and, by resisting with its weight the upward motion of both air and water, it causes the cave below to be charged like an air gun, by the condensation of the former: but, as wave succeeds wave, and the condensation increases till the pressure is, in all probability, equal to that of many atmospheres, the stone at last gives way, and is flung many fathoms upward, amid the dashing column of spray, on the return of which it descends again to its place, with a sound like thunder; and, while the height of the tide and the violence of the storm continue, this elevation and crashing fall of the stone are repeated at short intervals,—the country people say, at the "ninth wave;" but we believe that the story of superior strength in the ninth wave is a mere superstition, though it is certain that giant waves, far higher and more powerful than the rest, roll on shore at short intervals, in a way which it is, perhaps, not very easy to explain fully on any theory of undulations.

In small and lofty islands, where there is much exposure to the full action of the sea, and where some of the strata are very soft as compared with others, these caves sometimes perforate quite through, and this not only in arches open to the bay,—as are very common on all the more picturesque parts of our coast,—but so far under water as never to be dry, even at low water of the greatest spring tides. This is the case, among others, with the island of Staffa, so famed for the magnitude of its basaltic columns, and the grandeur of some of the caves formed by their removal, and the natural docks shaped out by the natural bendings of these. The pillared caves are not those which perforate the island; for though there are some of these into which the sea beats, as well as others which are above the highest reach of the tide, they all terminate, and that at a moderate distance; and the tidal ones are shelving in the bottom, and have beaches of sand and broken shells at their extremity, pointing out that in them the sea has done its utmost, in the way of destruction, and that it is now in so far making the splendid apartment, which it has at one time scooped out, a store-house for a portion of its own lumber. The caves to which we allude are formed in a stratum of soft clay-stone, which alternates with the beds of basaltic pillars, of which there are several; and it is through this substance, which is very tender, that the perforations are made. It is said, that when there is merely a local wind, let it blow how angrily soever, and work the surface into what surges it may, the action of this sub-marine passage is not much felt upon the island—which is not inhabited now, though often visited, as the surface is a rich sheep walk, fertile at all seasons, containing one of the sweetest grassy dells, on a small scale, that can well be imagined, and a spring of fresh water, as pure and limpid as ever flowed from a mountain rock. This might be expected; for those local winds, acting upon only a few miles, probably, of one side of the Atlantic, can be supposed to produce little or no motion in the vast body of its waters. But when that long and heavy "ground-swell," which tells a tale of the weather in other parts of the world, sets in, without curling wave, or broken water at the surface, it is then that the foundations of the isles are shaken, and pillared Staffa rocks to the mighty swing of the Atlantic flood.

Even in this difference between the effect of the local wind and the ground-swell occasioned by the more general excitement of the Atlantic, there is a moral lesson, and we shall just notice it, for the purpose of showing how eloquently nature is capable of teaching us in all the operations, and all the phenomena, if we would but listen to her voice. The ground-swell of the Atlantic, when it rolls toward our shores unaccompanied by any particular break or disturbance in our weather, tells us that the wide extent of that ocean has been thrown into a state of agitation to a considerable depth; and, consequently, the power by which this great action has been excited is in proportion to the action itself. But great as it is, both in active power and in resisting effect, there is the staid grandeur of the true sublime about it; and though, as we have remarked, it shakes the foundations of the islands, it is not a jot dangerous to the lightest shallop which is launched on the surface. There is no broken water, no dashing spray, and nothing which can disturb the eye, for the long reachings are slow and graceful. On the other hand, when a squall passes over the surface, and merely disturbs the little patch over which it passes, leaving all the rest of the surface glassy and tranquil around, it is astonishing with what apparent anger it chafes and vexes; and though its influence reaches only a very few feet downward, the whole surface is worked into turbulent confusion; and small craft, if caught unexpectedly in it, before those in management have had due time for preparation, are exposed to the utmost peril. It is even so with the passions of men; the just anger of the wise, arising from a deep and powerful cause, is like the ground-swell of the Atlantic, solemn and silent in its movements, though its power is in proportion; whereas the brawling turbulence of the feeble minded, trifling in itself, and excited by trifles, is like the ripple of the summer squall, noisy and vexatious, but all on the surface, and gone as easily, and with apparently as little cause, as that by which it is excited.

Under no circumstances, and in no state of the rest of creation, indeed, can we view the sea without the most lively emotions, and feelings which reach much further than the ocean expanse, ample as that is. We, of the land, behold in the waters of the ocean a new world as it were; and the wonders of the deep teach us more than, from the simple observation of the surface, whether in calm or in storm, we should be led to expect. There is connection where we should, according to our ordinary notions, predicate separation; there is neighbourhood where we should suppose there could be nothing but distance, and there is life, and the fullest and most ample enjoyment of life, in those places which we might, at first observation, suppose to be given up to the unbroken and absolute dominion of death. In many respects the sea holds an intermediate place between the earth and the air; and it really shows us more of the wonders of nature's working, than either of these. The solidity of the earth, and the resistance offered by the cohesion of the different solids of which it is made up, bring action upon it within very narrow limits, and, generally speaking, of momentary duration. The air, on the other hand, is in itself invisible, so that very much of the action of it escapes our observation. But the sea holds an intermediate post; and while the action of it is sufficiently extended for being sublime, it is at the same time, wholly open to our observation.

It would be easy to multiply instances of the inducements which we have to study the sea, from the appearances and action of that mighty element ; and, indeed, it is difficult to refrain from going into considerable breadth of detail upon a subject so inviting. The few observations which we have made, must, however, serve by way of introduction, or of enticement, if the reader chooses so to consider it ; and therefore, we shall proceed to the few details of phenomena and explanation which our limits will admit.

SECTION II.

QUANTITY AND COMPOSITION OF THE SEA.

As the sea occupies, in round numbers, about seven-tenths of the entire surface of our globe, leaving thus only about three-tenths for the whole surface of the continents and islands, we may naturally and very justly conclude, that the functions which the sea performs in the general economy of the earth, must be in a proportion corresponding to this great extent; for throughout nature, in all its departments, we find the operation and the performer beautifully adapted. This is an adaptation to which there is no exception in any one part of the system, wherever and however we may view it; and thus we may consider this law of perfect adaptation as one of the fundamental laws of the system, entering into the original design, and acted upon in every part of the execution and working throughout all its successions. In all the natural agents of whose operation we can see the effects, there is, indeed, a supplemental power beyond that which can be brought into operation. This, also, is an arrangement of which we cannot fail to observe the consummate wisdom. We know, from what we observe in our small operations of art—and, small as those are, they are not inventions of ours, though we sometimes call them so, in the plenitude of our vanity—in all probability a harmless vanity, in so far as these matters are concerned, but still erroneous, and therefore, upon the whole, calculated to mislead. Our boasted inventions are, in fact, nothing more than very humble discoveries of how far we can imitate certain operations in nature ; and if, in these our attempted imitations, we in the least deviate from that natural process which is the proper foundation and rule of our procedure, we fail in our attempt, and our labour is utterly lost. What we upon the average observe, may be regarded as the average working of all the powers of nature, and we know not what surplus may, in any case, be left behind ; but we do know, that in all the powers of nature, and in all the agencies which nature employs, there is a surplus accumulated as a provision against the evil day ; and herein again we are as forcibly, and almost as literally admonished, as if the words "Go and do likewise" were perpetually sounding in our ears. This perfect adaptation, with its provision for contingencies, which runs through the whole system of nature, is the most striking proof which we have, or can obtain, of wisdom in the Author of nature. There is no waste of energy—no bringing to action any power which is not required ; and yet there is a complete provision against failure, in the event of the many combinations which nature presents bringing about a greater difficulty than that which occurs in the average of cases. Thus, upon the general principle, though we know not all the uses of the sea, and are not prepared to state positively why its extent should so much exceed that of the land, yet we may rest assured that the very fact of this excess is a certain proof that, in that surface action which takes place between sea and land, or either of them, and the atmospheric fluid, and the influences of the sun, there is a predominance of utility toward the whole working system in the sea commensurable to the extent by which its surface exceeds that of the land. Were this not the case, there would be in this part of creation an anomaly which is quite unknown in every portion with which we are well acquainted, and, in consequence of this, we are warranted in saying, that it can have no place in the case of the ocean, any more than in that of any thing else.

The estimate which is made of the entire surface of the sea is of course only an approximation, and as such it must necessarily be a rude one. There is difficulty and uncertainty in measuring the length of even the shortest line, and the one which is the most convenient for applying the standard of measurement; and if this be the case, where our mensuration is one and simple, much more must it be the case when we endeavour to take account of the very irregular lines which separate the land and sea, and to estimate what quantity of surface is contained within either. We do not know even the probable extent of the error in this case; for we are liable to so many errors in the complicated observations which are necessary to connect together, upon a large scale, the measurements of a continent, or a sea, some of them terrestrial, and as such linear, and some of them celestial, and as such angular, that we cannot venture to say positively that the estimate which we make comes within a hundredth part, a tenth, or even a larger fraction, of the truth; but, with the understanding that our estimates are mere approximations, and that the errors, with respect to the land and to the sea, are likely to bear nearly the same proportion to the absolute extent of each, we may use those estimates in general reasoning without much chance of error in the principles, however inapplicable they might be to the minute details, which details form, however, no part of our present subject, as they are perfectly incompatible with that brevity to which we are restricted, and that simple and general view which it is our object to present.

With this understanding—that we are relating merely rude affirmations, and not positively determined results—borne constantly in mind, in order to prevent mistakes, we may state that the entire surface of the globe may, in round numbers, be estimated at 200,000,000 (two hundred millions) of miles, of which 60,000,000 are occupied by land, and 140,000,000 by sea. Of the depth of the sea, as taken on the average of the whole, we can, in the nature of things, know little or nothing with any thing at all approaching to certainty. This must be evident when we consider that, notwithstanding the number of soundings which have been taken by navigators, either finding bottom or not finding it, they can hardly have amounted to any thing like one in a mile in the vast number of miles over which, as above stated, the sea extends; and then, when the sounding is deep, there is no knowing what flexures may be given to the line by the motions of different currents in the water; and therefore there is no determining what proportion the actual depth may bear to the quantity of line that is out. As there is this uncertainty in every means which are taken to fathom the sea at depths beyond those which are exceedingly moderate, and as even those uncertain mensurations extend to only a few points of it, our estimate of its depth must be little else than a mere conjecture. It has been stated, upon the hypothesis that the depressions of the basins in which the seas are accumulated bear nearly the same relation in descent below the mean level to the elevation of the land above the same, that the surface of those basins bears to the surface of the land; and upon this hypothesis it has been concluded that the mean depth of the sea is something approaching to four, or even to five miles. But this hypothesis is not only perfectly gratuitous, and without the slightest foundation upon any thing that can be regarded as observed fact, for it is contrary to general probability, as we judge of it from the aspect of the land itself. The elevations of the land into mountains, and its depression into valleys are not in any respect the counterparts of each other, nor have they even an assignable approximation to being so. The elevated summits in general terminate in peaks, while the descents are generally bottoms of considerable breadth; and if we take the sum of the latter, we shall find that, estimated at even a moderate elevation, it greatly exceeds the sum of the former. Hence, we are reduced to the plain fact of the matter, which simply is, that we have no correct knowledge of what may be the average depth of the sea; neither does it appear that we are ever likely to possess any means of acquiring such knowledge; and thus, to say positively that it is some one definite measure and not another, is asserting that which we have no means of proving.

From the great depths which have been actually ascertained in some places, and the great extent of sea in which no bottom has been found, we may, however, conclude that we are under the estimate when, including banks and shallows, we allow one mile in depth for the whole. Even this gives us a most enormous quantity of water—a quantity which, estimated in tons weight, which may be considered about horse-loads for draught, we have the entire quantity of sea-water, with all its saline ingredients, amounting to the enormous weight of 600,000,000,000,000,000 (six hundred thousand billions of tons!) Of this enormous quantity, between three and four per cent. consists of different saline ingredients, which we shall afterwards notice, and the rest of pure water; so that the water in the sea available for the purposes of animal and vegetable life, the supply of springs and rivers, and all other purposes for which water is needed in the economy of the land, amounts to five hundred and eighty thousand billions of tons; and the quantity of salt, at least of saline ingredients, to about twenty thousand billions of tons.

These are, to all appearance, enormous quantities; but the estimate of one mile in average depth, which we have taken as the foundation of them, is certainly under rather than over the truth. Let us, then, consider how large a mass those saline ingredients would form if they were separated from the water, and exhibited in a single piece of a cubical form, or one bounded by six equal faces, each of them a perfect square. Taking the average of those saline ingredients, in the usual state in which they are naturally found, dry or crystallized, though we must bear in mind that, even in this state, they contain a considerable portion of water, their specific gravity may be taken at the average as about 18, that of water being 10, and the cubic foot of water weighing 1,000 ounces, consequently the cubic foot of the saline matters will weigh 1,800 ounces, or very nearly 100 lbs. weight; so that the total number of cubic feet will be just 20 that of the tons, or 400,000,000,000,000,000 (four hundred thousand billions) of cubic feet; now, if we reduce this to one cube, we shall have, by a rude estimate, a cubical lump of salt contained in the sea, measuring every way about 140 miles, or as much, at all events, as would build up Europe over its whole surface, islands, seas and all, as high as the summit of Mont Blanc, its most elevated mountain. Such is the mass of salt contained in the waters of the sea, as estimated, in a rude manner no doubt, but still considerably under the truth; and we shall afterwards have to state of what different salts this mass is made up, and what proportions they bear to each other. But we can, in the meantime, see, from this immense mass of matter, existing in the state of what are called neutral salts in the sea, yet still consisting of ingredients of the most active character, that there are in the sea the elements of very powerful action to an almost immeasurable extent, ready to be called into operation as the contingencies of nature require.

Let us now consider the quantity of water in the sea, and see how far it would extend over the whole surface of the globe, supposing that the solid part should by any means be reduced nearly to the same uniform surface which a liquid spheroid of the same specific gravity, and having the same motions, would assume. Here, as the real figure of the earth does not differ greatly from that of a solid of rotation, free to assume its proper form, it may be sufficient to consider the present mean surface as that which would be the average surface, supposing the basins of the seas to be elevated and the land depressed, till the whole were brought to uniformity. As the sea occupies seven-tenths of this mean surface, and we have estimated the average depth of the sea at one mile, it follows that the water of the sea, if the solid earth were all at the mean level, would cover it every where to the depth, or the height, according as it might be estimated, of seven-tenths of a mile, or, in round numbers, 3,700 feet.

When we examine the strata of the earth as they appear in sea-side cliffs, in the chasms and fissures of mountains, and in every situation where we can get a view of any extent of them in profile, we find that they have been brought together by no gentle means in almost every case where the surface of the ground is of a broken character. We find the stratified rocks by the sides of mountains—that is, the rocks which are composed of plates or layers, the one superposed upon the other, turned up at angles, twisted in a variety of directions and often cracked and rent into deep fissures, which are filled with stoney matters of a very different character. We further find vast lumps, so to speak, or aggregates of granular matter, consisting of small crystals of different kinds, rising up, occupying the centre, and often towering above the ragged edges of the stratified rock, as if some mighty force had impelled them from beneath. We find yet further, that, in some instances, the form of this central mass or nucleus of the mountain ridge, is changed at those places where it comes in contact with, and sometimes alternates with or overlaps the stratified rocks. There is there a species of stratification in it as if one portion had been poured on the top of another, but still with sufficient action of heat, or whatever other agent may have been employed in those mighty deeds, to solder them into a union far more intimate and difficult to be broken than that which subsists between the plates of the stratified rocks.

We mention these few particulars, not with any view of entering upon an attempted solution of the impossible problem of how and by what means the earth has been brought into its present state; neither do we wish to adopt or reject one or another of the theories which ingenious but speculative men have from time to time propounded, not probably with the intention, but certainly with the effect, of putting words into the mouth upon subjects whereof the mind can have no certain and substantial knowledge. We mention these few particulars for the purpose of impressing upon the reader a very general and very useful ground of caution for every one who is tempted to speculate on such subjects, and the speculation is one which an inquisitive mind, furnished with an observant eye, and favoured with opportunities of examining those mighty monuments of deeds which have been formerly done in the solid mass of our planet, can with difficulty resist. Nor is the desire of knowledge any more blameable here than it is on any other subject whatever. Wherever we turn our foot, be it on mountain or plain, we find that there is not only a constant succession and change of plants and of animals, but that the mineral world, as laid bare to our observation, is an assemblage of results, appearing every where as the fragments of something antecedent; and when we observe this, it is impossible for us not to look forward in anticipation of some change of the present state of things, even in those parts of the earth which seem to have the greatest powers of endurance; and when we find deep sea-shells at the height of between two and three miles above that of the present level of the sea, and find them there in no scattered and solitary specimens, but in quantity sufficient to people no inconsiderable extent of the ocean, we cannot well resist gliding forward on the wings of fancy to a time when the Mediterranean may lie placid over the summits of the Alps, and the white cliffs of Albion may be covered beneath a depth of the Atlantic which no deep sea-line of the mariners of our days may be able to fathom.

But these are speculations, though tempting ones; and therefore we must not allow them to entice us from our main subject—the simple examination of the sea as we find it in our own times. It is necessary, however, to know what powers slumber in the solid earth and under the ocean, and what terrible results those powers are capable of accomplishing if they are once awakened to the fulness of their energy. This is the more necessary inasmuch as, in the hands of those who are incapable of looking upon the works of God in the breadth of their continuity, the length of their succession, and the extent of their changes, human observation, and the conclusions which it draws are sometimes supposed, or made, to clash a little with the doctrines of Holy Writ. This is more especially the case with regard to the occurrence of a general deluge covering the earth until it prevailed " fifteen cubits upward, and the mountains were covered." Now it is very true that, with the earth in its present state, we are aware of no natural means by which such a catastrophe could be brought about; but we have no right to infer from the present state of the earth, which is every where a thing of ruins, what may have been its state at any former period. As little dare we deny that there are at this very moment, though they are now quiescent, powers in the earth, and in the waters, or in the combination and conflict of the two, which could in one moment—less than the twinkling of an eye—level the proud summit of every mountain, and upheave the bed of every sea, until the solid parts of the earth were brought to the uniform surface of the solid of rotation, and then the waters would cover the whole surface of the earth to the depth of 3,700 feet, as we stated above; and this would give fifteen cubits of water over a hill or even a mountain of no mean height, if we leave the giant ridges which girdle continents, or the lofty peaks which probably this same action has shot upward from the sea, out of our estimate.

There is, therefore, no violation of the ordinary laws of nature, no need for the calling in of principles or agents which are not always found in connection with the system of the globe, in order to obtain the elements of a general deluge such as that described in the book of Genesis; and who shall tell what were the specific events and occurrences of the day there alluded to with such scrupulous minuteness, as if it had been a day to be remembered by the whole posterity of the patriarch who, because he was just and faithful amid an evil generation, escaped from the calamity. "In the six hundredth year of Noah's life, in the second month, the seventeenth day of the month, the same day were all the fountains of the deep broken up, and the windows of heaven were opened."

We are unable to say what may be implied by the metaphorical expressions of the breaking up of all the fountains of the deep, and the opening of the windows of heaven, though it is probable that, in the latter case, allusion is made to the precipitation upon the earth of the whole body of water then suspended in the sky; for it is added, that "the rain was upon the earth forty days and forty nights;" and the opening of the windows of heaven may allude to the down-pouring and continuance of rain, —nor is it easy to comprehend how the atmosphere could in any other way contribute to the bringing of a flood upon the earth, as the quantity of moisture held in vapour by the atmosphere would not, under any circumstances, amount to a very serious depth of water, although it were all precipitated at once.

The breaking up of all the fountains of the deep is, however, another and a very different matter; and, as we are acquainted with no force that can so compress water as very much to increase its specific gravity, and the specific gravity of the mass of our globe not only so much exceeds that of water, but that of the most compact and ponderous rocks which we find near the surface, or even at the greatest depths to which excavation has been carried, that it is impossible to suppose that the allusion here made to the breaking up of the fountains has any reference whatever to an outlet of water. It may, however, have been such an action of those powers in the earth—which, though generally speaking latent, yet occasionally and locally display themselves in volcanoes and earthquakes—as sufficed to reduce all the more elevated parts of the earth's surface, and uplift all the depressed ones, to such a degree, at least, as would give that altitude of the water, supposing its quantity the same as at present, which is stated to have prevailed over the summits of the most elevated points then in existence. What may have been the proximate causes which brought those powerful energies into operation it is vain for us to speculate, because there is not, within the sphere of our knowledge, any thing analogous, with which we can compare it; but it is, at least, satisfactory to know, that there exists, even now, within the volume of our planet, powers which, acting in manners which are well known, would be, if aroused throughout its extent, capable of bringing about such a catastrophe as that which is so circumstantially described in Holy Writ, and of bringing it about by those very laws which are apparently inseparable from the system, and may be said to form part of its common, or every-day economy. There are no considerations which impress us more deeply than these with a sense of the infinitude of the attributes of the creating God, and the effect of the one creative fiat, in continuing the system of things secure amid all vicissitudes, and capable of every change amid its security, until the days of the years which he has appointed for it are numbered, and the period of the world's duration has come to an end; and the matter of which it is composed, disappearing to the sense, but not in one atom lost to the understanding, shall be scattered over the immeasurable regions of space, waiting there in readiness for the formation of a new earth, when the good pleasure of His will shall command it into existence. It is a delightful thought, that in the spirit we are immortal, and that, when we cast off the flesh which trammels us to this earth, we may see the rise and the fall of planets, the destruction and the renovation of systems, and behold the power of our Maker on a scale more matchless and more mighty than the present world can disclose to our view; but in the present life the scales of mortality are upon our eyes, and how strong soever may be our faith, and how delightful soever our hope, we cannot make the one or the other matter of mere physical or material philosophy; and, therefore, leaving those matters to the immortal hope, and the assurance of well-grounded faith, we must return to the more humble consideration of the leading phenomena of the sea.

From the operations which the water whence the sea is supplied performs upon the land, and from the vast quantity of life and growth, and consequently of the waste and refuse of both, which are in the sea itself, we must necessarily conclude that every substance which is soluble in water must to some extent mingle with the mass of the ocean. When the rains fall, especially in tropical countries, where they fall with such violence as to convert the valleys into temporary lakes, the waters must not only be foul with every kind of mud and decomposed vegetable substances which these swollen tides can float, but they must also contain much of the remains of animal matter which has perished from the living world, both by the previous drought and by the drowning of the flood. Even in more tranquil states of the weather, and in more temperate and peaceable climates, where those heavy rain-falls and high-swelling floods of the rivers are unknown, the most peaceable stream, the most limpid brook which twines its gentle and glassy current through the valley, must be charged with no inconsiderable portion of vegetable and animal remains, and other impurities. In fact, we observe, every showery day, that the effect of the rain upon the growing world, and probably, we may add, upon the animal world to a great extent, is not confined to the stimulating of the powers of life and of growth,—there is a general washing,—a thorough and searching purification by the falling drops that penetrate everywhere, which, in all probability, contributes as much to the healthiness and vigour of the world as does the application of humidity to plants, and the supply of drink to animals. The water, too, percolates down into all the pores and minute fissures of the soil, and dislodges from them no inconsiderable quantity of carbonic acid gas. In the season of vigorous growth and rich bloom, in the more fertile districts, it is inconceivable how much of this gas is given out by the action of vegetables, and in an especial manner by the blossoming of plants which have papilionaceous flowers, such as the pea and the bean, and more especially when those flowers, as is greatly the case with the last-mentioned one, fill the air with a rich perfume, in all probability containing prussic acid, though in so greatly attenuated a state as that it is not injurious to the life of any creature. It is found, however, by actual observation—and by fatal experience, where it is not duly attended to, that,—in those countries which contain coal mines, and have at the same time a surface soil rich enough for the growth of bean crops, when the latter are in flower, and an evening walk in the lanes which divide the fields, when the light winds barely wave their blossoms, every petal and nectary gives its sweetness to the air's embrace, and the fragrance of the gentle wind is thus superior to every thing which human art can accomplish, the production of carbonic acid gas is so great, that its heavy tide flows into the pit openings, stagnates below, like water, and, if not expelled by the action of fire,—which, by producing a current down the pit whose aperture is the lowest with reference to the general level, and another up the pit whose aperture, estimated in the same way, is the highest,—it would remain there, and be certain death to the miners. In such situations, and especially at this season, if it shall happen that there has been a sabbath, or other day of rest, during which no one has descended into the pit, it is customary, and the custom is a prudent one, to first send down a grate of burning coals at the end of a rope, to ascertain, as they simply express it, whether there be any air in the pit. If there is air,—that is, if the atmospheric fluid is there uncontaminated by the heavy and poisonous gas,—the fire in the grate burns brightly all the way down, and after it reaches the bottom of the shaft, and rests at the lower part of the mine, where, if there were any carbonic gas, it would of course be accumulated; but if the fire is extinguished, then the necessary precautions are taken to produce such a current through the mine as shall force off the poison, nor does any human being descend until the signal of safety is given by the fire burning brightly at the bottom. We mention this as an instance of the dislodgment of this peculiar gas on a large scale, and where it interferes with human labour; and from it the reader will easily perceive that innumerable dislodgments of the same gas from the fissures of the earth, from contact with the roots of plants, and from various other places where it would not only be useless, but noxious, must be accomplished by the falling rains. But this same gas, noxious as it is to the breathing of animals, is a most important element in the working both of the vegetable and the animal system; for both animals and vegetables contain in their substance a large proportion of carbon, which it is probable they all take up by decomposing carbonic acid gas; and thus the rain-shower which enters the ground and occupies the small fissures, may be said to force out of these an element which is of the utmost necessity to every creature that grows and lives.

It is true that, in the performance of these purifications, even the fresh water decomposes and disperses them in thin gaseous products, which are in general combinations of hydrogen with sulphur, phosphorus, and other substances which are very volatile, but at the same time highly poisonous. When these are separated from the other parts upon land, they taint the air; but in the water the process is more slow, it is accompanied by the solution of many substances by the water which the action of the air would decompose, and the water acts as an exceedingly fine filter in dividing such gaseous products of putridity as are given out by it. Thus the constant circulation of the water which falls in rain not only washes the land from its impurities, but actually decomposes those impurities, and by this means disperses them through the atmosphere to those places where they may be of use in new formations, with much more safety and health to the living and growing world than could otherwise be obtained. But on the land it is only the "living waters," those which flow in streams, and post onward to the ocean, or to the inland receptacle of some lake having no outlet, which have this beneficial effect; for if the water stagnates, is shallow, and thus easily acted upon by heat, and if at the same time great quantities of animal or vegetable matter are carried into it, or produced in it, such stagnant water may, especially in warm climates, and at the warm seasons of the year, become a source of pestilence; and the maledictions which have been bestowed upon the miasmata given out by such waters, and the baneful effects of "the reek o' the rotten fens," are not more graphic than they are true. This is rather a curious subject, as shewing the connection that everywhere subsists between motion and healthful action; and in this respect the "lazy pool" preaches a homily of reproof to the lazy man, who, if he allows his days to stagnate and rot in useless indolence, becomes a pestilence in society, in the same manner as the stagnant and putrifying water does in the general economy of nature.

Of the countless number of substances which the currents of the rivers bear downward to the sea, there are many of which no trace is found in the general mass of the ocean waters, neither is our observation able to discover by what process they are taken up, or to what use they are applied. Of those substances which we call *alkalis*,—and which are probably all hydrates of peculiar metals, or combinations of those metals with hydrogen, or probably with mixtures of hydrogen and oxygen, or, in other words, water,—the most abundant in those productions of the land of which there is the greatest annual waste, and consequent casting upon the waters as refuse, is potass. This enters so largely into the composition of most land vegetables, that many of them are burned for the purpose of obtaining it as an article of commerce, as it is highly useful in many of those arts and manufactures which administer to the necessities and the comforts of life. But it is remarkable, that though this alkali is the most abundant in the productions of the land, and though its carbonate, the peculiar salt in which it is most generally obtained, mixes more readily with water than almost any other salt that is known, yet that it is not found in the water of the sea in even a traceable quantity.

This, by the way, shows that the action of the water upon the land, even though it sometimes is productive of mechanical devastations, is, in itself, and according to the general wisdom and goodness of the law of Him who ordained it, a conserving action, and not a destroying one. The other alkali, soda, which is found more abundantly in animal substances, and which, in its accumulations, is very destructive of vegetation, so much so that it is the substance principally alluded to, at least in some of its combinations, when the strong expression for irreclaimable barrenness, of being "sowed with salt," is used with reference to any place. This soda is borne onward by the waters, as also are certain salts of magnesia and lime, both of which are understood to be equally unfavourable to vegetation. But while these are carried downward by the rivers and streams from that land upon which they have already performed their offices, and to whose productions they are become injurious, the potass, which enters so largely into the composition of every land plant, though probably more soluble in water than the others, and altogether a substance more easily worked upon, is not thus carried down to the sea. By what means it is separated from the fresh waters, with which it must unite pretty largely from the decomposition of vegetable matter in them, it is beyond the range of our chemistry to explain. We know, however, that, under certain natural circumstances, great quantities of nitrate of potass, the common saltpetre of commerce, is formed by natural operations. This spontaneous formation takes place most abundantly in warm countries, as in the East Indies, in Spain, and in the kingdom of Naples, from the first of which especially it is very largely imported into this country, to be used in the manufacture of gunpowder, and in many other processes in the arts. But it can be produced artificially in any part of the world by preparing a compost containing animal matter which shall putrify with some increase of heat and a supply of humidity. The pastures of cattle which are soiled by the droppings of these animals, the walls of habitations which are not kept perfectly clean, and especially slaughter-houses, drains, cesspools, where there is much animal matter in a state of corruption, are remarkable for the production of this salt of potass. As the nitric acid, which combines with the potass in forming this salt, contains one volume or bulk of nitrogen to every two and a half oxygen, or about one of nitrogen to three of oxygen in absolute weight, it is obvious that its formation must borrow pretty largely of that ingredient in the atmosphere which does not appear to be immediately required for the growth of plants or the life of animals. Thus, though in these and in many other of the operations which are carried on in nature, the nitrogen of the atmosphere appears to be passive or inert, it is highly probable that it performs a most important function in nature, by retaining upon the land this potass, the presence of which seems so essential to terrestrial vegetation, and through that to all which the land produces.

In proportion as potass is found in land plants, soda is found in those of the sea, and of the saline plains of dry countries, and also of the salt marshes; and the plants which contain this substance, even though they grow on places more than usually dry, have, in their character and texture, and also in their taste, more resemblance to the plants which grow submerged in the ocean waters, than to those which are found in the land, and even in marshy places, provided the water of the marshes is not salt. This salsolas, and salicornias, from which the barilla or purest crude soda, obtained in great part from Spain, is manufactured, have all a sort of maritime look about them, and it will be perceived from the names that they have the property of being salt. The same may be said of some few straggling plants of the same family which are met with on some peculiar spots of the British coasts; and also of the samphire which grows on some of our cliffs, too elevated for being reached even by the spray of the sea in the most violent of its storms. What the rivers carry to the sea, and what they deliver up to the atmosphere before they unite their waters with the general receptacle, is therefore a matter in which there is much to be learnt, more so perhaps than in cases where, by greater concentration and more rapid, though not more powerful action, the subject of our investigation is placed before our eyes in a single experiment, in all its operations, and in all their phenomena. So far as we know this dividing of elements by the waters,—this giving to the sea of what is best fitted for the sea, and retaining upon the land, or giving up to the atmosphere, which comes in contact with every point of surface of the land and all upon it, has not, so far as we are aware, been so much as hinted at by any one who has treated of the subject, either in a philosophical or in a popular manner; and yet, when we reflect upon it, it can hardly fail in impressing us, more powerfully than perhaps any thing else can do, of the perfect union and application to all things of that Providence in which alone the stability and the working of the whole frame of nature consist.

The subjects to which we have alluded in the two or three paragraphs immediately preceding, though eminently worthy of the attention of every reflective mind, and the most careful investigation of every one who is embued with the proper spirit and ardour of philosophy, are yet so dim and shadowy in their nature, that we can merely guess and wonder at the astonishing results to which they beckon us onward; and though we have thus casually thrown them in the way of the reader, as we shall endeavour to do every seed coming in our way, which has the chance of growing and ripening into a thought, yet we must pass them over with this simple notice, and earnest recommendation, in order that we may proceed with our more immediate subject, the composition of the water of the sea.

Considered as water, and without reference to the other substances mixed with it, the water of the sea is the same as that which is found in the state of vapour in the air, in a falling shower, in a stagnant pool, in a gurgling rill, or a flowing river; that is, the water is an oxyde of hydrogen, containing one measure by bulk of the former of these gases, and two of the latter. They are intimately connected by chemical union, so that neither of them can be separated from the other, except by the application of some very powerful agent, of which electric action, in the humid way, or by means of the slow oxydation of metallic plates in the common galvanic apparatus, is perhaps the most easily seen. So, also, if we would see the converse operation, that of the formation of water by the union of its two constituent ingredients, we must also call in the aid of some powerful action; and here again we find that electricity, though in this case it perhaps succeeds better in the dry way, is the agent best suited to our purpose. In order to do this, we have only to take two measures of hydrogen, and one measure of oxygen, procured by any of the processes which are explained in the common works of chemistry, for obtaining those gases. Then we are to mix them together in a vessel which contains nothing but themselves, and explode the mixture by an electric spark. The result of the explosion will be the complete combustion, that is, the union of the two gases, and the product will be water in a state of purity, differing very little from that which we purify by careful distillation, but a mere trace greater in specific gravity, and thus, perhaps, implying that its substance is more completely freed from air of any kind than the water which we procure by distillation. When water is obtained in this manner, by the explosion of its constituent gases, a cubic inch of it, weighed at a temperature of 60° of the common thermometer is about two hundred and fifty-two grains and a half, the weight of hydrogen in it being a mere trace more than twenty-eight grains, and that of the oxygen a trace less than two hundred and twenty-four and a half. The bulks of the gases necessary to produce this cubic inch of water, are about thirteen hundred and twenty-five cubic inches of hydrogen; and six hundred and sixty-two cubic inches of oxygen, in all, one thousand nine hundred and eighty-seven cubic inches. So that we may say that the gases, by being reduced to liquid water, occupy jointly, in round numbers, little more than the two-thousandth part of the space which they occupy when in the state of gas. Now, as bodies are maintained in the gaseous or aërial state by an additional quantity of the action of heat above what suffices to keep them liquid, we can hence account for the great action and display of sensible heat which accompanies the conversion of those gases into water. We know not what law the proportion of heat bears to the expansion of different substances, or even of the same substance, by its action, and therefore we cannot state numerically the relative proportions of heat in the liquid water, and in its constituent gases. But as the action of heat, telling chemically upon the ultimate particles of substances, always tends to cause those particles to repel each other, and increase the volume of the substance, we may safely conclude that it requires a much more powerful action of heat to make the gases occupy nearly two thousand cubic inches of space, than it does to make the liquid water which contains every particle of those gases occupy a single cubic inch.

But though, in all our speculations concerning water, and its general agency in the operations of nature, it is very desirable that we should bear in mind the component parts of water, the proportions in which they enter into its composition, the process by which the compound may be formed, and the relative bulk which the compound has, as compared with the two component parts when they are separated from each other; yet in considering the water of the sea, as contrasted with fresh water, our chief attention must, of course, be directed to the saline ingredients with which sea water is united. These ingredients, we have said, amount to between three and four per cent. of the whole weight of the water; but they differ a little in different seas, in different latitudes, and also in the two hemispheres, though in the same latitude there appears to be but small difference between the saltness of the sea at different depths.

The differences in the ingredients are perhaps greater than those of the whole quantity in different latitudes, unless where some local cause obviously gives either greater freshness, or greater saltness; but perhaps the following proportions do not deviate far from the average of the sea water which at all times of the year surrounds the shores of the British islands:—Muriate of soda, or common salt, as used for culinary purposes, *two per cent.;* muriate of magnesia, about *a-half per cent.;* muriate of lime, about *one-fifteenth per cent.;* and sulphate of soda, or glauber salt, about *one-third per cent.;* making in all three parts and nine-tenths out of the hundred of saline matters, and leaving ninety-six and one-tenth of pure water. From the smallness of the quantities of these ingredients, and the chance that there is that the one may be converted into the other in the course of our experiments, we are unable to state them as positively correct; and though we could so state them for any one place, they would be of little avail for places differently situated. The numbers which we have stated are such, however, as to express a tolerable approximation; and this is all which we can obtain upon the subject. When the experiment of analyzing the water has been made upon a large scale, there has generally been found a slight trace of potass along with the other ingredients, in the state of a muriate, or in combination with that acid, which is most abundant in the sea; but as those experiments have chiefly been made upon water taken up near the shores, it is impossible to determine whether this barely perceptible trace of muriate of potass may not have been communicated by the decomposition of some product of the land.

Those ingredients, which sea water holds in a state of complete solution, are not united with it by any very intimate chemical combination, for they can be separated by distillation; and they are in general separated by the natural process of evaporation, although the fogs, which collect immediately over the surface of the sea, generally contain salt, and sometimes are so much impregnated with it that the damp which they leave upon the hedge-rows, and other plants, often tastes salt at the distance of two or three miles inland. When those salt fogs continue for a succession of mornings, and alternate with strong solar heat during the day, their effect upon vegetation is very severe, and trees exposed to them grow badly, and are poor and stunted in their appearance. There are various reasons for this: the direct application of salt to the leaves, and other working structures of a plant, is injurious to every plant which contains potass in its substance, and not soda. Besides, when the heat of the sun evaporates the water from the damp left by the fog, the salt remains behind as an incrustation upon the leaves, and cuts off from them that free action of the air which is necessary to their healthy condition; and this mechanical injury may be produced by any sort of dust, either on plants out of doors, or those which are kept in a dusty room, and not brushed, or cleaned with water. But when the second fog comes on, after an incrustation of salt, however slight, has been left by the first one, there is perhaps a more serious mischief that ensues, especially to the very delicate texture of leaves in the early part of the season, when those fogs are most abundant, and do the greater part of their mischief. The second fog has to melt the salt which is left by the first one, and thus the two have the same effect upon the leaf as if it were placed in a freezing mixture; for the apparent cold produced by such mixtures is brought about by the rapid melting of salts, or crystals of some kind or other. The temperature which results from this operation is not, of course, so low as even that which is effected by the mixture of common salt with snow, one part of the former of which, and two of the latter, reduces the common thermometer to—5°, that is, five degrees below 0, or thirty-seven degrees below the temperature at which water freezes; but though it may not amount to this, or nearly to it, there must be a considerable depression, and the plant must feel under every such fog as if it were removed into a much colder climate. It should seem that this action,—which does not appear to have ever been examined with the attention which it deserves,—affects the whole epidermis, or external covering of the plant, as well as the leaves, and the more immediately working structures; for wherever these fogs extend, the barks of stems, branches, and twigs, are thickly covered over with those lichens which do not appear upon trees or shrubs which are in the full vigour of health, though they very generally precede the fungi in helping sickly plants on their way.

But there is no doubt that, though injurious when out of their proper situations in nature, and unnaturally applied to substances, these saline ingredients of the sea are highly useful in that element; and that, in combination with the tides, currents, and other motions of the water, they tend to preserve that freshness, healthiness, and perfect freedom from putridity, which are so remarkable in the sea. These matters are well worthy of our attention, as showing how superior the system of nature is to our little artificial systems. When we wash or otherwise purify any thing, the refuse always remains, and, generally speaking, it is offensive; and often offensive to so great a degree that the impurities which are washed away by water from a few manufactories are sufficient to poison all the fish in a large river. But though it is the general receptacle of the washings of the land, and consequently of the whole of its impurities, yet the sea, unless when mud stirred up from the bottom, or brought down by the fresh waters, is mixed with it, is every way, and to the full extent, as clean and wholesome as the land. This must be in a great measure owing to the peculiar natures of the salts with which sea water is mixed. From what was above stated, it will be perceived that, with the exception of the sulphate of soda, or glauber salts, all the other three are muriates, or have chlorine for their salifying principle. This chlorine is not only one of the most active substances with which we are acquainted, but it is the one which more than any other contributes to the destruction of all noxious and putrescent vapours. In its pure state, chlorine is a gas about two and a half times the weight of atmospheric air. The colour is greenish yellow; its smell and taste are strong and peculiar, and very disagreeable. When even a small portion of it is taken into the lungs in breathing, it acts very painfully upon that delicate organ, and strongly also upon the nostrils; and if the quantity is even moderately large, the death of the animal follows in a very short time, preceded by violent coughing, and discharge of blood from the breathing organs. In the salts which are found in the sea, the chlorine is not combined in a state of purity, but with the addition of a certain quantity of hydrogen, in which state it forms what is called muriatic acid, or spirit of salt. But in whatever state it exists, or in almost whatever combination, it is a property of this chlorine to destroy offensive smells, although its own is far from a pleasant one, and also to discharge the colours of bodies. It is also a supporter of combustion, that is to say, when bodies immersed in it are kindled, they burn as they do in oxygen, although the appearances are a little different. Diffused as this substance is through the mass of the sea-water, we are unable to say what functions it may perform in the general economy of nature, but we must conclude from every fact to which we can have recourse, that a substance so very active in its nature cannot be inert, even diluted as it is in the sea; and that the quantity of it in sea water would not be so great, unless the uses corresponded in number, in measure, or in both jointly.

Though the saline ingredients of sea water are not combined with the water itself by any very strong chemical attraction, yet there is something chemical in the union, and not a simple mechanical mixture, as takes place when one of the pure earths is mixed in water, when the vapour of water is dispersed invisibly through the air, or when the oxygen and nitrogen of the atmospheric fluid are mingled with each other. We know this fact, from the circumstance of the brackish water in the estuary of a river always being warmer than either the fresh water in the river above, or the salt water in the sea below. In such cases, we cannot suppose that there is any different action of the sun, or of any other external cause of heat upon the brackish water, any more than there is on the salt or the fresh; but the fact of a difference of temperature, to the amount of two or three degrees, independently of all external or local action, save what may take place in the water itself, has been proved by direct observation; and therefore we must conclude that this heat which is perceptible in the brackish water above the temperature either of the salt or the fresh, is the result of the union of the fresh water with the salt, or simply of fresh water with those saline substances which the salt water of the sea retains in a state of solution. Simple and local as this circumstance may appear, it is far from being without its use in the economy of nature; and the uses which we find in those apparently trifling circumstances are of very great value to us in enabling us to form proper estimates of nature, and teaching us to beware that we do not slight or turn away from any one natural circumstance on account of its being, according to our common notions, either unimportant, or obscure in its usefulness.

We find that very many of the fishes resort to this brackish water in the estuaries, not only to preserve themselves against the severity of the winter, but to take advantage of the additional heat for promoting one of the most important operations in the whole of their physiology,—the bringing forward of their spawn. For this purpose we find the estuaries of rivers resorted to both by fishes which have their general habitation in the fresh waters, and by those which have it in the sea; and both of these appear to come to this water for exactly the same purpose, namely, for the great heat which it affords them. Of fishes of this description, we may mention as instances, the common eel and the white-bait. The common eel, as every body knows, is, during the greater part of the year, not only a fresh-water fish, but a fish which inhabits deep in the waters, lurking among the stones, and sometimes boring in the mud at the bottom, and seldom or ever careering through the free waters, as is the case with many other fishes, and more especially with those which ascend the rivers for the purpose of spawning in the brooks and streams. But eels, notwithstanding their sluggish habits, make an autumnal journey to the brackish water; and in the season of their descent, those who attend to the economy of the streams are so well aware of this fact that they place nets for them in convenient places, and catch them often in many dozens in the course of a single night. That heat is the object sought after upon these migrations, is proved by many circumstances: and that, in the case of the eel, this heat brings forward the spawn till it is ready for being deposited, in the manner in which it is done by the generality of oviparous fishes, is proved by the fact that the young eels are observed ascending the rivers in great numbers during the following season, while no young eel is at the same time found either descending the stream, or crossing the river. The case of white-bait has not been so much observed, because that fish is more local in this country, and comes to the brackish water from the sea, so that we know little of its habits, except during the time that it remains in this water. For a long time it was considered as the young of another fish, the shad, which, though belonging to the same natural family, is a totally different species, and never, in any stage of its growth, like the white-bait; and it has now been ascertained by actual observation of the facts, that white-bait is a distinct species, inhabiting the sea upon ordinary occasions, but coming into the brackish water of certain rivers to spawn, and never attaining a larger size, upon the average, than those specimens have which are taken in such numbers in the Thames, and so highly prized by the lovers of good eating; nor is it unworthy of remark, as proving how little connection there is between appetite and science, that the lovers of white-bait should have been luxuriating over it every summer, from generation to generation, through a long succession of years, without having made one discovery, or probably even inquiry, or wasted one thought or one conjecture about the natural history of the little fish which all the time held them so spell-bound in the mystic chains of sheer infarction.

Generally speaking, the saline ingredients of sea-water do not separate from the mass with the portion which is evaporated; for the vapour which is taken up by the common and invisible process from the sea consists of water as pure and limpid, and as free from any taint of salt, as that which is raised from the dew upon the grass. So also when sea water is congealed into ice, the saline ingredients do not enter into the substance of the crystals into which the frozen water is formed in the act of congelation. The act of the freezing of sea water also shows that there is some chemical union between the saline ingredients and the water; for sea water requires a lower temperature to freeze it than fresh water does: the difference is not very great, but still it is something; and there is nothing to which we can attribute the difference, but the resistance offered by the salts to that separation which takes place in the act of freezing. The ice which is formed from sea water is not purely fresh when taken in the mass, or the aggregate of crystals. The formation of ice is in no one case a general or simultaneous congelation of a mass of water. It begins at a number of points, by means which we do not very well understand, or which, at all events, we cannot explain very clearly. Around each point as a nucleus the particles arrange themselves in a definite manner, so as always to form spiculæ, or fibres, which diverge at a constant angle of 60°, or the sixth part of a circumference. But this formation does not go on regularly through a large body of the water; for new points of divergence, which act as additional centres, are formed on different parts of the spiculæ, in a manner as mysterious as the original ones; and thus the progress of the ice soon becomes so complicated, that we are unable to trace it. In passing, we may remark, that there is much information with regard to the progress of ice to be gleaned from the ice which forms on the surface of very small portions of water in the ruts of roads, shallow ditches, and other places, where the quantity of water is small, and we may suppose that it has not completely saturated the soil under it. In such cases, we find a sheet of ice on the top, and the water under it entirely gone, in all probability by evaporation through the surrounding soil upon which there is no ice; and the under side of the ice often presents curious appearances, as if a very singular action took place between it—first, at final parting with the water, and secondly, by the evaporated water being sent up against its surface, after the body of liquid water had become so low that there was no more contact between it and the ice. The first of these is shown by projecting ribs or ridges on the under side of the ice, generally in curves, and often rising an inch or more beyond the surface of the icy plate. The latter shows itself sometimes in hoar-frost on the under surface of the plate of ice, and sometimes in button-like drops which adhere to the same side, and show that the quantity of vapour under the ice has been too great for immediate congelation. This is not to be wondered at, for it must be borne in mind that ice is a very bad conductor of heat, and that as it cannot be raised to a higher temperature than 32° without being melted, so nothing that is under a tolerably thick plate of ice, especially if it has little or no transparency, can be cooled much, if at all, below this degree. Sea-ice, from the salt, or the unfrozen brine, which is in the water, lying between the crystals of pure water, is rarely, if ever, transparent; and therefore, when the surface of the sea is frozen over, the temperature of the water under it does not sink much lower, if it sinks at all; and as the ice increases in thickness downwards, the heat given out to the water in that operation, and the quantity of salt which is set free, these both tend to retard the progress of congelation; and in this way the formation of ice, especially on the sea, contains in itself the means of diminishing the rate of its own progress.

Fresh water is lighter than salt water, and, in consequence, floats upon the surface of it; and, for the same reason, ice-water, or that which is formed by the thawing even of sea ice, as containing less salt, floats along the surface of the water which has not been frozen. This is further promoted by the property of liquid water having a maximum density several degrees above the freezing point; so that, independently of the salt, the newly-thawed water, which is of course at the temperature of 32°, is lighter than water at a temperature a little higher, and, consequently, floats along the surface of it. The quantity of freezing in the early part of winter, and of thawing in the early part of summer, is very considerable in the high latitudes, both in the sea and on the land. The sea ice, from its porous nature, rises up, or floats above the mean surface of the water; many of the ice-boards are also turned up on edge by the violence of the winds during the process of freezing; and the collision of one field or mass against another often throws large masses on the surfaces of both. It also snows upon the surface of the ice after it is formed; and this snow, from the intensity of frost in the individual crystals, remains in a state of loose powder, which is also light and porous. From all these circumstances, taken together, it is easy to see that every winter must, in the polar regions, accumulate on the sea a quantity of water heaped up above the mean level by the action of the frost. In so far as this water exists in snow which has descended from the atmosphere, it is of course entirely free from salt; and even in the ice which has been formed in the sea, there is, for the reasons already explained, much less salt than in the same quantity of unfrozen water in the same latitudes. Thus each polar winter prepares a mass of water which must flow toward the equator when the season of melting arrives; and thus we shall have, in the summer of each hemisphere, an approach towards the equator of a colder and less saline portion of water at the surface than that which would naturally be found in some of the latitudes which this polar water reaches. On the other hand, when the frost is heaping up the water in the polar regions, there must be a movement from the equator toward the pole; and by this means water of a more saline character will reach the high latitudes than would naturally be found in them if there were no such current. The season is considerably advanced when that portion of the polar water which finds its way so far south reaches the British shores, and, in arriving at them it has other currents to contend with; but still it is matter of common observation that the water is more saline, or, as it is usually called, "stronger" in the early part of summer than when the summer is far advanced. But the differences which arise from this cause are so much modified by the operation of other causes, that it is impossible to state positively what shall be the general effect at any one place, or at any particular season of the year. The quantity of rain has a considerable effect along the shores, and especially in the estuaries of the rivers where the "fresh," as it is technically called, floats upon the surface, and may be taken up there with very little impregnation of salt, while the denser water at the bottom, especially if the estuary is deep, is strongly brackish, or perhaps absolutely salt. The velocity with which the fresh is projected into the estuary has a considerable effect upon the extent to which it shall be carried before it is impregnated with salt; but as the result here is different for almost every river, it cannot be generalized.

When we turn our attention to the whole water of the sea, we may estimate its mean or average specific gravity at 102,777, while that of fresh water at the same temperature is 100,000. This is rather more than two-and-a-half per cent. — indeed, than two-and-three-quarters per cent.—which the sea water is heavier than fresh water, in consequence of the saline ingredients which it contains; but this is rather less than the absolute addition which those ingredients make to the mass of the water.

The specific gravity which we have now stated is that which answers to the sea under or near the equator,—the place at which, if the two hemispheres were alike, the quantity of salt, and consequently the specific gravity would be a maximum, or the greatest possible. That this would be the case is perfectly evident from the fact that the action of the sun, and consequently the evaporation, are greatest under the equator. We have proofs of this, as well in the artificial making of salt by boiling of the water, as in the crystals of salt which are left on rocks and beaches in warm countries and in warm weather, when the tide ebbs away, or when the water is thrown up in spray, or so as to form little pools in the hollows. It is highly advantageous for man that when the water is thus driven off, the muriate of soda, or common salt, which is so necessary and so wholesome for the seasoning of food, and the want of which is so severely felt in some extensive inland countries where there are no salt mines, is the first to crystallize and separate. In artificially making salt by boiling sea water, this salt crystallizes after the water has been boiled down to a certain quantity, the pure water going off in the form of a white steam; but when the crystals of this salt are formed, the remaining salts, the sulphate of soda, and the salts of magnesia and lime, remain behind in a sort of ley, which has now lost the agreeable taste which predominates over the offensive ones in sea water, and is known by the technical name of "bittern," in consequence of the bitterness of its taste. The other salts, or their bases, may be obtained out of this bittern by chemical operations, the detail of which is foreign to our purpose; but we should not do justice to this branch of the subject did we not mention, as we have done, that the most valuable salt in sea water is the one which is first and most easily procured by art; and that, under many circumstances, it is separated from the water and the others, and prepared for man's use, by

Nature's own chemistry. This furnishes another of those instances of that provident goodness of the system of nature which forces itself upon our attention at every step we can take, let that step be taken on what ground and in what direction soever it may.

The reason why the average density and average saltness of the sea is at the equator, where we might be prepared to expect the maximum, is—the different surfaces of the two hemispheres. The polar part of the northern one is to a great extent land, at least up to very high latitudes in both hemispheres; and the Polar Sea there, in consequence of its having a very narrow connection with the Pacific through Bhering's Strait, and not a very wide one with the Atlantic, in which also its connection with lower latitudes is much interrupted by the revolving currents of that ocean, is in a great measure separated from the general mass of the sea, and restricted to its own phenomena, so that it probably contains less salt than any other. In the temperate zone, too, a great portion of the northern hemisphere, is land; and there is a considerable quantity of land in the intertropical zone of that hemisphere. But in the southern hemisphere there is no known land, at least no known land of any extent within the polar circle; and the quantity without that circle is but small, as compared with what is found in the northern hemisphere.

Now, if we are to suppose that the solar action upon both hemispheres in the course of the year is nearly the same,—and there is much less difference in the influence of the sun as a heating cause than in the effects which this cause produces,—we must suppose that the quantity of evaporation, or at all events of action tending to produce evaporation, must be nearly equal, upon the whole, of each of the two hemispheres, or upon any two equal portions, one in each, situated in the same latitude.

But the evaporation from the sea must be in proportion to the quantity of surface which the sea presents to the evaporative influence; and as the southern hemisphere presents a good deal more surface of sea than the northern one, it follows by necessary, and indeed very obvious, consequence, that there must be much more absolute evaporation from the sea south of the equator than there is from the sea north of it; and (though the point here is not so well established, or so easily cleared of doubt,) it is not improbable that the whole evaporation from the southern hemisphere is greater than that from the northern. This is rendered further probable by another circumstance: the rains of the tropical countries, though they sometimes begin at the most northerly places which they reach, are almost without exception produced out of a monsoon or other current from the south. This seems to indicate that the tropical countries are in a very great degree dependant for their fertility upon the wide expanse of the south sea. But this is a point the full investigation of which is not necessary for our purpose; for in the meantime we are concerned only with the quantity of water which is evaporated from the sea in the southern hemisphere, and not with what becomes of it after it is once fairly changed into vapour and distributed into the atmosphere. But we trust we have said enough to show that there is really more demand upon the sea for fresh water in the southern hemisphere than in the northern one. Let us inquire how the two are circumstanced with regard to supply.

There may be submarine springs in many parts of the world, indeed in any part of it where the spring has a reservoir higher than the surface of the sea; but then there can be such springs only where there is land in which such reservoirs can be formed; and granting that this not very easily ascertainable source of supply for fresh water to the sea is much greater than appearances would lead us to suppose, there still must be most of it in the northern hemisphere; because the southern lands are few, most of them have no great elevation, and many of them are quite riverless and dry for great part of the year. Thus we may put this hypothetical means of supplying fresh water aside, as not bearing against the argument that the sea in the southern hemisphere receives a much smaller supply of fresh water than the sea in the northern.

Let us therefore look at the visible sources of supply to the two, namely, the quantity of water carried down to the rivers. In the northern hemisphere, passing over all the smaller ones, we have in America, the Mackenzie river to the north sea, and the St. Lawrence, the Mississippi, the Orinoco and the Amazon, into the Atlantic; each of which rolls a copious tide. In the eastern continent again, we have rivers so innumerable that we must refer to the map for the muster roll, only we may add to the list, as one of recent discovery, the Quorra, or Niger, so long a puzzle, which empties its waters into the Bight of Benin.

Let us now see what we have in the southern hemisphere, as a set-off against this muster-roll of rivers. In the first place, let us look at Australia—there is not a river in the whole country which, taking all the year round, supplies more water to the sea than the Thames; and by the greater number of the water courses in that part of the world are seasonally dry. The islands in the South Sea are, generally speaking, too small for containing rivers of any consequence; and so we may put them out of the estimate. Next let us look at Southern Africa. There are some third-rate rivers there,—such as the Zaire at Congo; the Orange river, to the northward of the Cape territory; and the Zambezi on the east coast, opposite the island of Madagascar: but these are small in the general estimate; and the character of that country, as well as of Australia, is that of being seasonally very dry. Lastly, let us look at America, south of the equator, or rather south of Cape St. Roque, the north-easterly point, for all to the northward of this goes to the sea in the northern hemisphere, and there is little else besides La Plata, for the Biobio on the west coast of South America, and the Colorado and Negro in the north-east of Patagonia, are but small rivers. We shall not in the meantime attempt to tabulate in numbers the quantities of fresh water respectively given to the two hemispheres; but we feel convinced that we are within the truth when we say, that for every gallon of water which is discharged by rivers into the ocean of the southern hemisphere, there are a hundred gallons discharged into the ocean of the northern.

Thus two very important points are clearly established with regard to the relative economy of those two oceans. The demand of the atmosphere for fresh water—and it is a demand which must be supplied, for if there is moisture there, and the air is in a mood of evaporation, that moisture the air will have, even if it should be drawn through many fathoms of dry soil,—the demand is much greater on the southern sea than on the northern; and on the other hand, the supply of fresh water given to the southern sea by the land is much smaller than that given by the northern. But the equilibrium of the two hemispheres is kept up by the principle of gravitation, which the water must obey implicitly, from the very fact of its being liquid. Therefore, the southern ocean must receive a supply of salt water from the northern, corresponding to the waste by evaporation, great part of which, as we have said, goes to the northward of the equator in the periodical rains. Hence the specific gravity of the water in the southern ocean is to that in the northern as 102,919 to 102,757; and the quantity of salt in the southern waters must be a little greater in proportion to that in the northern, because the specific gravity does not increase quite so much as the whole quantity of salt. This difference of the oceans in the two hemispheres is a very important element in enabling us to understand rightly the general working of the sea in the economy of the globe; but it is so mixed up with other actions, celestial and atmospherical, and with local resistances in the forms and positions of lands, that we must look out for some more data before we can venture to grapple with it; and in the first place, we shall have recourse to the map, in order that we may take note how the sea lies.

Before closing this section, however, we may perhaps be permitted to call the attention of the reader to the extent, simplicity, beauty, and usefulness of the whole system of the sea, in its giving water to the land, and receiving water from the land in return, and also in the action which the waters of the one hemisphere have upon those of the other. In the southern hemisphere the breadth of land is comparatively limited, and consequently there is not so much water required for the growth of plants and the refreshment of animals as in the northern hemisphere. The seas of the south are accordingly the grand laboratory from which the great supply of pure water, in the form of rain, is obtained, especially to the tropical countries, where all the operations of life are most vigorous; and the northern hemisphere is the place whence the supply of water, which has performed its functions upon the land, and become the carrier of the impurities of the land into the cleansing alembic of the deep, finds its way to the general mass of the waters. This is a very extended and very general action; but, like all other actions which are performed by the greater principles of nature's working, it is in itself too mighty for being immediately observed. We know, from the nature of the causes, that there is a constant supply of the ocean by means of the rivers of the northern hemisphere; and we also know that those rivers have no means of getting their original supply but from the ocean itself; we know, farther, from the facts which have been stated, that the supply of those rivers must come, in great part at least, from the extensive oceans of the south; and that the water which is raised from them by the process of evaporation, must be replaced by water from the north. Thus we have a constant chain,—pure water, borne viewlessly in the air,—water, impregnated with the impurities of the land, rolling in the river currents to the sea,—and the same water remaining there until the saline matters have separated its impurities and rendered it fit for ascending the atmosphere anew, for cherishing growth and life upon the land.

SECTION III.

GEOGRAPHICAL DISTRIBUTION OF THE SEA.

In this section we shall not have space to go into any detail of minute particulars, which, indeed, is not necessary for any reader who may be able to accompany us thus far, and who is willing to entrust himself with us fairly over the sea. We shall presume that such a reader is in possession of a good and modern map of the world upon a large scale; and, in conjunction with thus presuming, we may perhaps take the liberty of mentioning, that Mr. Gardner's large map of the world, in two plane hemispheres, each, we believe, four feet in diameter, is a perfect geographical treasure in this way, and one which no person or family, desirous of possessing a competent knowledge of our planet, and a ready means of reference to the broad and general features of its surface, should be without; and we may add, that as the author of this map is an enthusiast in geographical science, and has the best access to every new discovery which is made, so he carefully transfers these, from time to time, to this map; and thus it may be said to present to its inspector a faithful embodyment of the whole mass of geographical knowledge, both as regards the land and as regards the sea, up almost to the day on which a copy of it may be purchased. We say this with perfect knowledge of the facts, and also because other maps, of more antiquated date, are copied and re-engraved, again and again, with all the blunders and imperfections of the original compilers, and with many additional errors and mistakes committed again and again, by the unscientific quarriers in copper, who transmutate, confound, and counterfeit them into various scales and forms, in which every novel presentation is a farther departure from the truth than the original, from which they are all *borrowed* (to use the gentlest expression,) and of which the copyists are neither able nor desirous to correct the blunders or supply the defects, so that they produce a something which the unsuspecting world will buy. We confess that we are somewhat angry on the score of even this most valuable map, inasmuch as it is not upon a genuine stereographic projection, to which mathematical principles can be rigidly applied, but a sort of intermediate attempt to give—what no map embodying two halves of a globe within two circular spaces can afford—the seas and lands as nearly as possible of their real shapes, and in their relative magnitudes. But it might perhaps be too much to expect perfection in the most elaborate production of human art; therefore we must take such a work as this as it is presented to us, and receive it—not without thankfulness.

In noticing the geographical distribution of the different portions of the sea, we are therefore to presume that the reader, who wishes to profit by reading, is in possession of some such work as this which we have been noticing, and also that he has a perfect understanding of the lines and circles which mark position upon it, as explained in our volume on the EARTH, or in any common work on geography in which descriptions of a map are given, though we regret to add that many of these are so imperfect, that one is sorry that the author took upon himself the burden of being a teacher before he had made any very useful progress in the more humble, but, in our opinion, (for him at least,) far more useful character of a pupil.

Supposing, then, that the reader is in possession of the map to which we have alluded, or some decent map, which is not all blunders, and does not reverse the compass poles in the head, as a fog in the moors is sometimes apt to do, (and a foggy book has really more of the elements both of desolation and derangement in it than a mountain heath in its thickest investment of mist,) we shall very briefly notice the distribution of the several portions of the sea.

But before we do this, it may be as well to consider a little the meaning of the words which are made use of in treating of the watery element. Upon the great scale we use the word "Sea" and the word "Ocean" very nearly as synonymous; but in the details we use them somewhat differently. An ocean, in this use of the term, means one of the largest expanses of water, which extends over many latitudes, or many longitudes; and a sea means a smaller portion, which is partly divided from the ocean by intervening lands. But when we use the plural number, or the word "seas," and apply it to difference in latitude, it has reference to the whole body of the oceanic waters in the latitude referred to, whether the particular part be a portion of the broad and uninterrupted expanse, or one which is in part, at least, locked in, and separated from the rest by intervening lands. Farther, in the word "ocean," we allude, chiefly to the expanse of water only, without much allusion to the land which abuts upon this expanse; but when we use the word "sea," or its plural, "seas," we always have some allusion to the bounding land. Also, when we speak of the waters which surround or border any particular land, with reference to that land we always say "seas;" as, for instance, the British Seas, the Indian Seas, the American Seas; and so in other cases, even though the seas alluded to may be all oceans, when we speak of them singly, and with reference to themselves only.

Small as these distinctions may appear, they are far from being unimportant, so far, indeed, that the want of attention to the shades of difference in the meanings of those words, which they who speak loosely are in the habit of using indifferently for each other, is the primary cause of very many of the errors and blunders which we commit. Losing our way in thought and understanding bears a very close resemblance to losing it on the ground; and if the field is wide, and no beaten path over it, we are very apt to lose our way in both cases, and to lose it the more readily the slighter that the deviation of the first step is from the true path. Our words are the steps of our thoughts, and therefore we must understand them well in order that we may keep in the right.

"Shore" and "coast" are other two words in the use of which we are sometimes apt to bewilder ourselves. "Shore" means a supporter, and is properly used when speaking of the sea, as descriptive of the land by which the edges of the water are supported, or kept from spreading. "Coast" means a rib, or defender—a bulwark against interference, as it were; and it is used when speaking of the land, as descriptive of these edges of the land, which resist the farther inroads of the sea. The proper use of the two terms are, therefore, the *shores* of the *sea*, and the *coasts* of the *land*, though neither of them relates to the length and breadth of either, but merely to the line, or rather the plane, where the land and water meet; and this plane does not extend indefinitely either above water or below, but refers merely to so much of the surface of the land as may be alternately covered and uncovered by the tide or ebb, and place of the water.

With this understanding of the terms of which we are to make use, let us turn our attention very briefly to the map, considering what there is necessary to be attended to, besides the mere extent and direction, or "trending," of the shores, that may help us in obtaining some knowledge of the action of the sea. Now it is evident that the extent of the land forming the shore, the general character and climate of that land, the form of the coast or edge of the land itself, and the proximity or distance of other lands, must all have an influence upon the character and action of the sea. There is, indeed, another consideration not unworthy of our attention, namely, the angle at which the whole, or any portion of it, meets the progress of the tidal wave, the direction of a current, or any other "set" of the waters. In order properly to understand this, however, there is another element wanting—the motions of the water, and their general causes; and therefore it must be an after consideration.

The size of a bounding country has always a considerable influence upon the character of the sea in its neighbourhood; and it has generally the greater influence the more it is what we may call open to the sea—that is, the longer that it continues on or near the sea level; for the first ridge of mountains, if of even moderate elevation, casts off the influence of the sea. We have very remarkable instances of this in the American continent, and also in the southern part of India. In the former country, as long as the Andes continue like a great wall near the coast, there is little or no reciprocal action between the land and the Pacific; though, on the other side, where the country is opened to the sea by the valleys of the great rivers, the influence of the Atlantic feels its way almost to the base of the mountains. So also on the western side of the American continent, when we reach to about 20° north latitude, and the country is more open to the sea, and the shore more in the direction of the parallel, we meet with very heavy rains at the turn of the monsoon,—so much so, indeed, that the town of San Blas, which is situated on a rock standing in the middle of a low flat, is quite deserted during the rains, and the flat around it is converted into a temporary lake. In the south of India, the Ghauts, which run close by the western shore to about the parallel of 20° north, in a great measure cut off the inland country from the influence of the south-west monsoon, though that monsoon further north, where the country is much less elevated, finds its way across a much greater breadth of land, as far as the Himalaya mountains. The eastern Ghauts, also, cut off the north-east monsoon from a considerable part of the interior; and thus a portion of Southern India, above the Ghauts, is one of the dryest countries in the world.

This part of the subject, however, branches so much into detail, that it cannot well be treated as incidental to any other branch; and therefore we must defer it until we come to consider "the reciprocating action of the sea and land,"—if our limits will permit us to devote a separate section to that. But any one who travels for a considerable distance along one of the coast roads even in this country, will very readily, and with but little trouble of observation, understand the general principle, which is all that is necessary preparatory to the study of the subject. He will find that as he passes a low shore, or crosses an opening valley, there is a regular play of wind between sea and land; and that, if the situation and the season are warm, this is turned into regular sea and land breezes, which are miniatures of those which occur on the shores of flat countries within the tropic. In passing where the shores are bluff and high, and the land cold and elevated, the action between sea and land will be perceptibly less; and, if the height is great, it will cease to be apparent, unless in great general motions of the atmosphere, the causes of which are more extended than any single district of those islands. If the coast is broken, with alternate height and ravine, the winds, or local movements of the atmosphere, will be thrown into similar confusion. In such places, if the heights are considerable, it will often be found that the air rushes down the hollows something after the manner of a flood of water; and in passing such a place, vessels are liable to be overtaken by frequent squalls, and small boats are in danger of being upset. The northern fishermen, who are very adventurous, and generally have their boats rigged with a large square sail—which is powerful in action, but by no means easily managed—are often exposed to great danger in passing those irregular outlines of shore; and notwithstanding all their watchfulness, and acquaintance with the ground, a boat is always now and then taken aback by those squalls, and all is gone before the crew can in the least help themselves.

There is one other character of those different forms of shores which is worth mentioning, because, if rightly understood, it throws considerable light upon the mode of action of the sea. With scarcely a single exception, the low shore is a growing shore, or receives additions of matter from the sea at every tide, while, on the other hand, a high shore is always a wasting shore, which the action of the tide is continually grinding away to some extent or other. The precise extent to which this may be done, in any particular case, depends of course on the power of action in the sea, and of resistance in the substance of the land; and therefore each case must be worked out by direct observation of its own circumstances.

The irregularities of mere outline in the shore, without any reference to elevation or depression, have very considerable effects in modifying the action of the sea; and the influence of a jutting point, in turning the course of a current, or a tidal wave,—especially the former,—is often much greater than one would expect from the magnitude and general appearance of the projecting point. This is also a matter of detail, which must be determined by observation with regard to every locality;

and indeed this is most essentially necessary in every statement which we venture to make respecting the action of the sea near the shores. This action is so exceedingly varied, so perfectly contrary to all conclusions to which any general theory would lead us, that it does not admit of a single word of speculation.

The line of the shore, and of that portion of the sea which lies between the land, and that which is considered as a safe "offing," or sea-room, in all weathers are the places of danger to all who navigate the waters. On the wide seas, the ship, if sea-worthy, well manned, and skilfully managed, is not only in a proper element, but really in greater safety than when she lies, sometimes grounded and sometimes afloat, in a tide harbour. Her "march is on the ocean wave, her home is on the deep;" and she visits the shore only for the benefit of landsmen. The peril is in the passage between—the transition, from her proper element to that place where she ceases to be an active ship; and therefore, there is nothing to be depended upon in this perilous place of transit, except results of the actual observations of the most skilful and experienced mariners.

There is, however, a sort of epitome of this action of sea and shore which any landsman may study, with some benefit to his health, and some additional enjoyment the while. Go to a mountain stream, after it finds its way into one of the crooked valleys, and where its current is not so violent as to have swept off every thing to the solid rock, and cut far into that, and observe what are the little obstacles, loose stones, projecting points, or any thing else, which repeatedly turn the bent of its current to the right hand or to the left, so that, independently of the general shape of its channel, which is always shifting, it twines along like a cork-screw, or rather the main current of the water tacks "starboard and larboard" alternately, like a ship working board and board upon a wind. But we shall not go farther into the particulars; for there is a different character in almost every stream: the study, if study it can be called, is the simplest imaginable; and in such places, a person who is once induced to use his eyes, will find a hundred things, besides the mere course of the water, which have got most interesting stories to tell him.

We shall now very briefly glance at the trending of the shores of the principal oceans, the interruptions by which they are broken, and the seas and larger bays and gulfs which penetrate so far into the land, and also the more remarkable passages from one sea to another. We shall begin with the mere names and positions of the oceans.

The Arctic Ocean lies round the North Pole, extending on the average to about latitude 70°, or about 1,400 miles from the pole in all directions. In many places, however, the extent is much less than this; and at Baffin's Bay, or the north-east of America, it is probable that the land extends beyond 80°, or within less than 700 miles of the pole; and the island of Spitzbergen, on the north of Europe, also lies partly beyond the parallel of 80°. This ocean is, in a great measure, shut out from navigation. It is entirely so by ice in the winter months, as far south at least as the fifty-fifth degree of latitude on the American side, and to nearly the seventieth degree on the north of Europe. Its other and narrower entrance, that by Bhering's Strait, is about longitude 170° west; it is entirely shut up during the winter; even in summer there is only a sort of bay of the ice which clears in this region, not to a very great extent either on the American or the Asiatic coast. The larger opening, by the Atlantic, clears farther to the north in the summer; but, generally speaking, there may be said to be solid ice, or floating ice in large boards,—as dangerous to navigation as the solid ice is preventive of it,—extending the whole way from about the middle longitudes of the eastern continent to the middle longitudes of the western, and having a curvature or bend northward in the middle. The portion of the earth's surface which lies within those icy boundaries, and is inaccessible at all times, is that which is, properly speaking, the Arctic Ocean; for those places which are clear at one season, and frozen over at another, may be considered as seasonal elongations of the Atlantic and the Pacific. We of course know very little, and can know very little, of what this portion of the earth's surface contains, or the kinds of action that may go on within it; and it would be useless to speculate on such a subject.

The Antarctic Ocean lies in like manner around the South Pole, but has its northern boundary entirely sea, at least down to the lowest latitude in which any part of it is frozen during the winter, which is lower than the frozen extent of the Arctic Ocean. We of course know just as little about what this portion of the surface contains as we do about the former portion. Some patches of barren land are said to have been observed between the sixtieth and seventieth degrees of latitude, and in nearly the same longitudes a passage has been found clear as far south as to 74° or 75°. This ocean has not so much interest in its boundaries, even for mere curiosity, as the polar ocean in the north; for though at some seasons it is very stormy, and would be most unsafe to navigate, yet there is ample sea-room round the whole parallel between the greatest extent of ice in this ocean and every land which is inhabited, or worth inhabiting; consequently, there is no occasion for any speculation and trial for passages round the globe here, as there has been about north-east passages by the coast of the eastern continent, and north-west passages by the coast of the western. Even these, notwithstanding all the interest which they have excited, all the enterprise which they have employed, all the expense they have cost, and all the anxiety, failure, and disappointment which has been experienced concerning them, are, in a practical point of view, subjects of curiosity, and not of use. But as those polar seas are the regions of the world upon which, mathematically speaking, the action of the winter tells most extensively, they have their importance as data for rightly understanding the working of the system of things upon the globe; and in this respect the exploring of them has been of sufficient value to the cause of general science to compensate all that they have cost. Indeed we may consider it as a general maxim, that there is no spot upon the surface of the globe, to which man can by any means obtain access, but which will, in some way or other, repay the labour of visiting it; and very generally, knowledge which has been gotten in this way, and which appears to be of no use at the time, or for long afterwards, has told very effectively when some other points necessary for connecting it with the rest of our knowledge came to be properly established and understood. This has occurred so often, that it holds out the greatest encouragement for every one, wheresoever they may be situated, to take note of all that exists or goes on around them, because, though they may find it of no use in forwarding their more immediate projects and speculations, it is always too valuable to somebody.

Perhaps the best way of considering the seas, in their positions, is along with the oceans from which they branch out. In the Antarctic Ocean there are no such branchings, because it passes into sea all round; but there are some connected with the Arctic. Of these, almost the only one of any interest in the eastern continent is the White Sea, on the north of Russia, which sea receives the waters of the Dwina, a river of considerable magnitude, near the confluence of which with the White Sea, the city of Archangel, the most northerly trading city of any size, is situated.

In the American or western continent, it is not so easy to say whether the inland seas and enlargements which are so numerous on the north-east of America are or are not immediately connected, either by channels open at any time, or by passages below the ice, with the Polar Sea. The great entrance is from the extreme north of the Atlantic, in latitude 60°, where Davis's Strait leads northward to Baffin's Bay, and Hudson's Strait westward into Hudson's Bay. Farther north, in about latitude 74° or 75° on the average, Barrow's Strait, and numerous continuations and channels among barren islands and masses of ice, have been traced as far as to about 115° west longitude; but it has hitherto been found impossible to follow any of the passages to the open water near Bhering's Strait, or to ascertain whether there is, or is not, such a passage. All those seas connected with the Arctic Ocean are so much turned away from the movements of the water in the middle latitudes, and also so seasonal in their navigations, that they are of minor importance to the general question. Those of America are the most interesting, on account of their greater number, their irregular shape, the principal opening being to the south, and high and rugged lands on the extreme north. On the cliffs of those lands, extending over at least a thousand miles in latitude, vast quantities of ice and snow are necessarily piled up during the early part of the winter. These are in part melted, and they in part tumble into the sea, when the summer comes on; and as at midsummer the sun never sets on more than half the length, the melting of snow and ice is very great, and thus a great quantity of water at the temperature of 32°, containing little salt, and therefore specifically lighter than the permanent sea water, and floating on the top of it, is poured into all those seas. This quantity is much increased by the melting of the snow upon the more level grounds, and the consequent floods, or freshes, as they are locally called, of the rivers which flow through these. Lumps of ice, the size of mountains, and mountains of no mean bulk, are also tumbled from the cliffs, in some way or other, though, so far as we know, no man has recorded an instance of having actually beheld the launch of one of those giant masses. But they do come, by some means or other, and that in no stinted numbers; and as they farther increase the flood of cold and light water, the whole surface, so far as it is clear, takes the form of an inclined plane, sloping gently no doubt, but still sufficiently to occasion a southward movement of the surface water; and accordingly icebergs and water, pell-mell, in one array, march onward for the south, displaying the most singular migration which takes place on any part of the earth's surface. Some of the southern icebergs stray into lower latitudes than these, and are probably more numerous and bulky, but as they can start from any point of the parallel in the south, they are far less numerous in any one locality than they are in Davis's Strait and the adjoining sea.

This march southward of icebergs and ice-water is of course only seasonal; for during the winter, which lasts full two-thirds of the year, and more nearly three-fourths in the places of greatest cold, the whole is held fast in the fetters of the ice. But still the general trend of the shore along which this singular array sets in its season is worth attending to, the more so that it is met by a current, and also a tidal wave from the south; and where the two meet, there is of course what is called a "point of confluence," or one where opposing waters in motion flow against each other.

On looking at this part of the map, it will be perceived that there are two long lines of coast, each about 2,000 miles taken on the stretch, that meet one another nearly at right angles at the eastern part of the island of Newfoundland,—the northern, and longer of the two, extending all the way from the bottom of Baffin's Bay, and the southern from Florida. The discharge of water from the great estuary of the St. Lawrence, which is affected by a portion of the northern current setting through the strait of Belle Isle, between Newfoundland and the coast of Labrador, throws the absolute point of confluence to the southward of the angle where the two coasts meet; but still their general positions are worth attending to, as influencing the whole motions of the water within the Atlantic.

The Atlantic is to us, who are placed upon one of its shores, or rather within its volume, the most interesting of all the oceans. It ranges freely from the one Polar Ocean to the other, and thus has no definite boundary either to the north or the south. We shall not particularize its measures, as numbers are obstacles rather than any thing else in the establishing of general principles. We may mention, however, that in the middle latitude, or between the south-west of Guinea, in Africa, and the north-east of Brazil, in America, the first on the north side of the equator, and the second on the south, it is, in round numbers, about 2,000 miles across; and that this is its least breadth. Its greatest breadth, taken from the bottom of the Gulf of Mexico to the coasts of the eastern continent, which is between 30° and 33° north latitude, is not less than 5,000 miles; or, if the continuation of the Mediterranean be taken, that makes about 2,000 more, or, in all, 7,000 miles of eastward and westward navigation nearly upon the parallel, or from

36° east to 98° west,—about 134 degrees in longitude, or more than one-third of the entire girdle of the earth in that latitude. In considering its action as an ocean, we should perhaps, however, leave out both the Gulf of Mexico and the Mediterranean, which will reduce the extreme breadth from continent to continent to about 4,000 miles. The Atlantic is thus every where sufficiently wide for allowing the utmost freedom to the play of the waters, both between the equator and each of the poles, and between the two hemispheres, both in their constant and in their alternating seasonal action. We have, in consequence, the general trade winds more regular and constant upon the Atlantic than on perhaps any other ocean, as there is no alternating sea and land, north and south, in the direction of the meridian, to cause monsoons.

When we examine the trend of the Atlantic shores, we find again, on the western or American side, two long general lines, meeting, at nearly a right angle, at Cape St. Roque, in Brazil, in about 15° south latitude. The southern line,—which is the most continuous, being without any inland sea, unless the very wide estuary of La Plata may be considered as such,—is more than 4,000 miles in length; and its general direction is between south and south-east from the point of the angle made by the two at Cape St. Roque. The northern line is a little, but not a great deal, shorter; and its general direction may be stated as being a very little to the west of north-west. For rather more than the southern half of its length this line is quite unbroken; but for the remaining part, it consists of detached islands, within which there is a basin containing the Caribbean Sea and the Gulf of Mexico, which will be more particularly noticed afterwards.

Thus the whole of the eastern coast of America, as it presents itself to the action of the tides and currents of the Atlantic, may be considered as made up of four lines, each nearly straight in its general direction, and all joining each other nearly at right angles. Of these angles there are three, two on the north side of the equator, and one on the south. The first from the north is a cubical angle, sharper than a right angle, at Newfoundland, in latitude about 47° north. The second is a re-entering angle, or in-bight of the coast, blunter than a right angle, and at Florida, in about 30° north. The last one is a salient angle, also blunter than a right angle, in about 6° south of the equator, at Cape St. Roque.

The American shore is by far the most important one in endeavouring to understand the motions of the Atlantic waters. It is the windward shore, and more completely a windward shore in its middle or intertropical latitudes, where the trade winds act, than perhaps any other shore on the globe. The trade winds blow against it, the current of the water sets against it, and the motion of the tidal wave is also against it. There is, therefore, in the tropical latitudes, a more decided motion to the west of sea water and sea influence than in any other part of the sea.

This influence, and the currents and other effects which result from it, extend to both sides of the equator; but they are more decided on the north than on the south. About half the uninterrupted line of coast which trends to the north-west is on the south side of the equator; and thus a considerable portion of the action of the southern trade wind is turned into the northern hemisphere. The Caribbean Sea and Gulf of Mexico receive the current through the openings between the islands. It much raises the latter, and is discharged, with considerable violence, between Florida on the one hand, and Cuba and the Bahamas on the other, and then takes the direction of the southern line of that angle which is cubical at Newfoundland.

Upon looking at the map it will be found, that those seas which lie between the chain of the West India islands and Florida on the one hand, and the narrow part of America on the other, are, by projecting lands and islands, partially separated into three parts—the Caribbean Sea, properly so called, ranging along the most northerly part of South America, having the Caribbean Islands on the east, the larger West India islands on the north, and the coast of the main land as far as Cape Catoche, the extreme point of the peninsula of Yutacan on the west. But this portion is partially sub-divided into a northern and a southern; for it narrows between the island of Jamaica and the Mosquito shore, widens again from the Gulf of Honduras to the western extremity of St. Domingo, and again contracts between Cuba and Yutacan, where it is not much more than a hundred and twenty miles across. These interruptions occasion great irregularity in the motions of the water in the West Indian seas; and as there is generally a pretty close connection between great agitation in the motion of the waters, and corresponding agitation in the atmosphere, the weather, upon the continental shore of this sea, and also in many of the islands, is sometimes exceedingly violent. To the northward of this there are no inland seas; but when we come to about 45° north latitude, Nova Scotia stands out like a hook, and catches the current of water in the bend of the Bay of Fundy, where the tidal wave rises to an immense height. The opposite, or European and African shore of the Atlantic, is a lee-shore, in as far as the tropical action is concerned; and it is a shore at which that action has to be begun, because great part of the centre of Africa is so dry and warm as to produce a constant ascent of the atmosphere, and thereby to cut off any motion along the surface on the parallel. The whole of Europe is too far north for being within the action of the trade wind, and, consequently, the prevailing wind on that shore is the counter wind of the trade, or that from the west of south, but becoming more irregular in the high latitudes. The current of the sea is necessarily, also, a return current, and therefore it does not circulate among the European islands, or flow into the European seas, with so much violence as the current among the West India islands.

In so far as Africa is concerned, there is no inland sea, though the Gulf of Guinea forms a considerable bend, and has some influence on the Atlantic tides. The inland seas of Europe have but very narrow connections with the Atlantic, and therefore the action of that ocean does not extend much or powerfully into them. The Mediterranean, which extends along the whole south of Europe, is by far the largest of those seas; and as its waters are said to be more impregnated with salt than the average of the ocean, it is generally supposed that it receives a constant supply from the Atlantic through the narrow passage of the Strait of Gibraltar. But the Mediterranean receives a very considerable supply of water, especially through the strait connecting it with the Black Sea and from the Southern Alps. The water which comes from the Black Sea is, generally speaking, rather cold, probably not far from the temperature at which water is heaviest; and thus it is probable that it may creep along the bottom, and contribute to the under current which sets westward through the straits. But the Mediterranean is, from its situation, so land-locked, that it has scarcely any tide, and, indeed, partakes of but few of the motions and actions of the Atlantic waters. It is more tropical in its characters, and in some of its productions, than its latitude would lead us to suppose; but whether the volcanic fires which are in action under its bed may or may not contribute to this character, is a question not easy of solution, and one which, in the meantime, at least, we are not required to enter upon.

The Baltic, which is the only other inland sea of any consequence connected with the east side of the Atlantic, has even less connection with the action of that ocean than the Mediterranean has. It is situated in a high latitude, receives more than the average supply of river water, contains but little salt in any part, and, in some parts, is almost fit for the common purposes of fresh water, especially in the northern part of the Gulf of Bothnia, and in the early part of the summer, when the snows are melting on the surrounding mountains, and a great quantity of fresh water is in consequence poured into it. The Baltic also freezes to a greater or less extent every winter, and sometimes to such an extent as that a regular communication between the eastern and western sides of the northern gulf is carried on upon the ice. The entrance to this sea is very crooked, and though of considerable width for great part of its length, it is interrupted by the Danish islands, among which there are three principal channels, the Sound, the Great Belt, and the Little Belt, the first of which is the only one which is properly available for the purposes of navigation, the other two being westward, where there is a sort of eddy in the water, and they are, in consequence, very much choked up with mud. It is understood that there is a constant current setting out of the Baltic, and it is generally said, that its bed, in many places at least, is becoming more elevated, probably in consequence of the rubbish brought down by the many streams and rivers, and also that the surface of the water has become lower, probably in consequence of the discharging current scouring out the channel of the Sound; to which effect, the water ejected by the matters deposited in the general bed of this sea must no doubt, to a certain extent, contribute.

The British seas and channels are also portions of the Atlantic; and as the length of the islands lies across the general current of the ocean waters, those waters come in part round the northern extremities and in part round the southern. Winds and seasons have a considerable effect on the proportions into which the water is thus divided on the British shores, and there is consequently much irregularity in the phenomena of the sea. Nor must we omit to notice, that the variableness of the weather in the British islands, which is greater all the year through than in most parts of the world, appears to be intimately connected with this variableness of the phenomena of the sea; and this shows that, in every part of the world, there is a very close connection between disturbances of the oceanic waters and the atmospheric air.

The Southern Ocean.—This name is given to that zone, or ring, of sea which surrounds the southern hemisphere immediately without the Antarctic Ocean, which is, properly speaking, the part subject to alternate freezing and thawing; and it extends indefinitely from about perhaps the sixty-fifth degree of south latitude to somewhere about the fortieth, or near to the parallel on which Van Diemen's Island, the Cape of Good Hope, and the northern extremity of Patagonia, are situated. But the boundary is of course indefinite, because it is merely the meeting the sea with sea, where there is no distinction of the one from the other; and therefore, the Southern Ocean, or the Great South Sea, as it is sometimes called, is considered as extending into a lower, or receding into a higher latitude, in proportion as the land extends to a shorter or a longer distance southward. Thus, in the latitude of Africa, the Southern Ocean is generally considered as coming as far down as the Cape, which is in about 35° south latitude. In the longitude of New Holland it is considered as coming no farther down than the extremity of Van Diemen's

Island, which is about latitude 44°; and in the longitude of America it is sometimes regarded as not extending farther than Cape Horn, the latitude of which is about 56°. If we were to take it on the average parallel, it would include Van Diemen's Island, South America nearly as far north as the estuary of La Plata, and a portion of New Zealand, together with some scattered islands, which are not inhabited, and which do not appear to be worth inhabiting. This ocean comprises the only zone of water which any where surrounds the globe in the direction of east and west, without any interruption from land; and although, from what we have said, there can be nothing interesting in it, as respects the reciprocal action of land and sea, yet this fact of its entirely surrounding the globe gives it a character different from that of any other portion of the oceanic waters.

As this Southern Ocean is situated in so high a latitude as to be without the range of the tropical action, properly so called, and not so high as to be within that of the polar action, it seems a sort of barrier between the two, and cuts off the polar action from all places between it and the equator. Thus there is not the same gradation of climate in the southern hemisphere as in the northern, neither is there the same difference of seasons in the highest latitudes in which land is found. We know little of Africa immediately south of the equator; and the islands on the south-east of Asia, through which the equator passes, are of moderate extent, and exposed to currents, so that we can draw no positive conclusions from them. The northern extremity of New Holland, too, has rather more than 10° of south latitude; and the average of the north coast of that country is somewhere about 15°. But those who have been engaged in surveying the north coast of that country during the dry season, have found the temperature exceedingly hot, the wind from the land like the air which issues from a heated oven, and the reflection of heat from the sea almost unbearable. In South America we have the maximum, not under the equator, but considerably to the south of it, as appears from the snow remaining unmelted all the summer, farther down the mountains, immediately under the equator, than it does farther to the south.

This fact does not of course interfere with the actual distribution of heat to the two hemispheres; for it seems undoubted that the northern is, taken as a whole, more heated by the action of the sun than the southern. But this zone of sea, which surrounds the southern hemisphere, keeps the equatorial action and the polar in so far apart from each other. The general movement of the southern atmosphere, which is charged with humidity by the evaporation of so large a surface of water, is also northward for great part of the year; and as it is heated in its progress northwards, it becomes a drying wind in the southern hemisphere, and does not break in rain till it comes in contact with the warmer air of the northern lands. The very same cause which makes the motion of the polar atmosphere a north-east wind, over the sea in the northern hemisphere, except in so far as it is affected by the land, makes the motion from the south pole a south-east wind, which, on account of the uninterrupted belt of sea, is much less broken than the former. Also, the return current, which is a south-west wind in the northern hemisphere, especially on the Atlantic, is a north-west wind in the southern hemisphere, though differently modified by the difference of surface between the two. Beyond a certain latitude south, the south-east current—that is, the current from the south-east, which appears to be less disturbed by solar action upon the regions of the pole than that in the northern hemisphere—is the prevailing current, although there are apt to be return currents and eddies near the land, as is said to be the case at Cape Horn, and through the straits which separate the island of Terra del Fuego from the southern extremity of the American Continent.

There remain other two oceans, of which we have to consider the localities, the one of them lying chiefly in the southern hemisphere, having no water connection with any land far to the north, and being therefore the great theatre of monsoons, or alternating winds, between the South Sea and the northern and lateral lands; the other being, taken altogether, the largest expanse of water which is any where found on the surface of the globe, but having its chief connection at the extremity with the south pole through the medium of the southern ocean. The first of these is what is termed the Indian Ocean, and the other the Pacific.

The Indian Ocean is in the form of a great bay, extending, at its connection with the South Sea, from the southern extremity of Africa to the south-western extremity of New Holland, in breadth of longitude about a fourth part of the parallel, or about 90° from east to west,—that is, between 5000 and 6000 miles. Its general form is that of a great bay; and the depth from the line alluded to, the northern extremity, is rather greater than the breadth of the entrance. Its western boundary is Africa and Arabia, interrupted only by the entrance of the Red Sea; its eastern boundary is New Holland, the Sunda Isles, and the eastern or Malay peninsula of Asia, with the different straits and passages which lie between these,—the greater number of which are narrow, and Torre's Strait, between New Holland and New Guinea, which is one of the widest of them, is much interrupted by coral reefs. Thus, though there is probably about 1500 miles on the straight line between the continent of Asia and the continent of New Holland, and many passages in this broken part of the line, there is not enough to admit of a perfectly free communication of action, as between ocean and ocean.

Exclusive of the passages among those eastern islands, some of which are long and intricate, the principal parts into which the Indian Ocean branches are the two great bays,—that of Bengal easterly, and the Arabian Sea to the west, with the continuation of the latter in the Persian Gulf,—with the Red Sea, which is long and narrow, and the entrance of which, the Strait of Babelmandeb, is very dangerous, on account of the current which sets in, and the violent winds which often blow in that part of the world. The Bay of Bengal is partially interrupted at its entrance by Ceylon toward the west, and Sumatra on the east. It is a monsoon sea, swept both by the south-west and the north-east; the surf runs high upon its western shores, and much rain falls on its north-eastern. It receives a large supply of water from the

Ganges and its branches, and from some considerable rivers both of India and of the eastern peninsula. The current runs with great violence in the lower part of the Ganges, and, when the fresh of the bay is retained and heaped up by the violence of the south-west monsoon, there are often destructive inundations on some of the low-lying parts of the coasts.

The Arabian Sea is more tranquil, especially toward the north-west, where it is more out of the reach of the monsoons. It receives a considerable supply of water from the Euphrates and Tigris at the head of the Persian Gulf, from the Indus near its south-eastern angle, and from the Nerbuddah and some smaller rivers of India.

There is nothing worthy of being considered a river that falls into the Red Sea; and the country on its shores, especially the western shore, is exceedingly dry. There is much volcanic action under some places of it, and coral reefs rapidly form in others. It receives a constant supply of water through the straits; it contains more than the average proportion of salt; it is remarkable for the abundance and variety of its animal and vegetable productions; and it has little or no tide, and, in fact, partakes only to a trifling extent of any of the actions of the ocean. In some respects it is an interesting sea, but it is one the navigation of which is both difficult and dangerous.

The Pacific Ocean.—Under the equator, this ocean extends, if taken from the western shores of America to the continent of Asia in the Malay peninsula, from 80° west longitude to about 105° east, on the opposite side of the globe to the meridian of London; so that, under the equator, it wants only about 5° of extending half way round the globe. Its equatorial breadth may thus be reckoned at 12,000 miles, in round numbers. About 25°, or nearly 1,750 miles, of this, however, in the part immediately to the eastward of the Malay peninsula, is broken by islands; but still there is a clear stretch of the Pacific on the equator of not less than 10,000 miles, which is the greatest longitude of intertropical ocean on any part of the globe. Farther south, on the parallel of 30° south latitude, opposite the most easterly part of New Holland, its breadth in latitude is less, being about 70° west to 153° east, or 137° on the parallel; or, because the degree of longitude on the parallel 30° is less than at the equator, the distance in miles is about 8,500, which, as in the parallel under the equator, is very little broken by islands. On the parallel of 30° north, or between the coast of California in America and that of China in Asia, the extent is from about 115° west to 120° east, or 125° on the parallel, which is about 7600 miles, and this is entirely on the open sea, without any interruption. Thus we may say that there is, in the middle latitudes of the Pacific—between 30° north and 30° south, which is more than 4000 miles in latitude—an expanse of water about 8000 miles in breadth, in which there are only a few clusters of small islands. This portion alone amounts to 32,000,000 square miles of surface; and this is only a part of the Pacific.

Northward of this, the Pacific is of a trianglar form, and reaches up to the sixty-fifth degree of latitude at

Bhering's Strait. This triangular portion, allowing for all the projections of the coasts, is at least equal to one-half of the former, so that the entire extent, taken southward to the confines of what may be considered as the Southern Ocean, is more than one-fourth of the surface of the globe, and this in one continuous expanse of water, with the exception of a few groups of islands, all of them of trifling dimensions. As we remarked before, the action of this vast extent of sea does not produce much effect on the continent of South America, because that continent is the lee shore, lies in the direction of the meridian, and has the Andes near the coast, rising high above the level of all action of the sea. Neither does it produce any great fertility upon the east coast of New Holland, because it has there a good deal of the character of the south-east monsoon at the Cape; so that, unless it is met by a wind from the interior, it does not produce rain. Farther north, however, it tells much more powerfully. In that part of America north of the equator, and northward till its influence is interrupted by the cold of the north, it causes very violent seasonal rains; and many of the trees attain an elevation quite unequalled in any other country. The little islands, too, with which this ocean is studded, are remarkable for their fertility. There is, indeed, some difference arising from formation, and those that are more to the south and east are probably not quite so fertile as the others; but as we approach the windward shores, or those on which the currents of the atmosphere and the ocean are accumulated, we find them the gardens of the world. This ocean is so extensive, has been visited at comparatively so few points, and is so peculiar in some of its phenomena, that the natural history of it is far from perfect; and, as we shall afterwards see, there are some phenomena connected with it quite contrary to what our theories would lead us to expect.

The seas which branch off from, or are connected with, the Pacific, are few in number, and small in size, as compared with the vast extent of that ocean. On the whole line of the American shore there are only a few bays, of no great depth; but the countries round these are in general fertile in proportion as they open more directly to the south. All of these, of any consequence, are on the north side of the equator; but there does not appear to be any of them which has much influence upon the general currents and movements of the sea.

The western boundary of this great ocean is different; for, along the whole extent, from the southern part of Australia to Bhering's Strait, it is more or less broken by clusters of islands, or projections of the land, and in some places by extensive coral reefs, which oppose formidable barriers to the motion of the waters, and are particularly dangerous to navigation, in consequence of the rapidity with which they are formed in places where, but a few years before, there was no indication of a reef, or indeed of any bottom to be met with within the reach of those sounding lines which are supposed to indicate that a vessel has abundant sea room. Those reefs are most extensive off the eastern coast of New Holland, and extending from thence in the direction of New Guinea. To the westward of the last-named island, there is a long and narrow sea, called the Sea of Banda in the eastern part, and the Sea of Java in the western. This sea lies between two chains of islands, the southern one extending from the island of Timor, nearly on a parallel, over about 20° of latitude, or 1400 miles, to the eastern extremity of Sumatra; the northern one, consisting of islands much more irregular in their form, and comprising the celebrated spice islands eastward, next to New Guinea, the singularly-formed island of Celebes in the middle part, and the great island of Borneo toward the west. From both extremities of this last-mentioned chain, other islands extend northward, meeting at the Philippines, terminating in the island of Formosa, on the coast of China, with its northern extremity about 25° north latitude. These islands partially divide off other two seas from the Pacific:—the Sea of Sooloo, immediately northward of Celebes, which is again divided by the Sooloo Archipelago from a second basin, the Sea of Mindanao, lying between the north end of Borneo and the Philippines. Then, to the westward of Borneo, extending all the way from Java to the Chinese coast opposite Formosa, there is a large sea, the China Sea, having the continent of Asia on its western shore, and divided into several bays. Farther to the north there is another basin,—the Eastern Sea in the southern part, and the Yellow Sea in the northern,—lying between the east coast of China on the west, and the Loo-choo Islands and the southern portion of the Japan Islands on the east, and extending northward in a bay as far as the northern confines of China, between the mainland of that country and the peninsula of Corea. This peninsula approaches within a short distance of the Japan

Islands; and then we have another sea, the Sea of Japan, extending between the Japan Islands and some others on the east, and Chinese Tartary on the west, till we come to the confines of the Russian territory in Siberia. From the northern extremity of the Japan Islands, the Kurile Islands extend, and mark out the Sea of Okhotsk, the southern part of which overlaps the northern part of the Sea of Japan, and the northern part extends between the mainland of Siberia and the long peninsula of Kamtschatka. On the outside of this peninsula there is still another sea, the Sea of Kamtschatka, enclosed between the coast of Siberia and Bhering's Strait, and the long chain of the Aleutian Islands, which stretches out in a curve, convexed to the south-east from the promontory of Alaska, on the American side. This Sea of Kamtschatka, which is a sort of oval basin, is a sort of intermediate between the Pacific and the Arctic Oceans, and partakes more of the character of the former than of that of the latter, being in many places frozen over during the winter.

The islands and seas of which we have given a list as breaking the western shore of the Pacific, occasion great irregularity in the action of the sea in those places, and some of them are, at the turns of the seasons, visited with storms of the greatest violence; but the details of them would far exceed our limits, as would also the particular description of the countless islands, great and small, which are situated in this part of the world. A careful study of the map, and a reference to any book of geographical detail, will, however, supply all the information which is absolutely necessary.

We have no wish to assume the tone of lecturing; but as we conceive that we are, in part at least, addressing ourselves to the young, and to those who have upon themselves the "light and lovely" burden of leading the young to the paths of that knowledge which is both mortal and immortal, we may mention, that there are few parts of education more valuable or essential than that of having the map of the world graven on the memory; and no youth, of either sex, should be allowed to proceed to the details of geography, history, or natural history, until able, in the absence of the map itself, to trace, with moderate accuracy, all the broader features of the line which divides the land from the sea. This "sketching from knowledge" is very useful in all cases where the subject admits of its application.

SECTION IV.

TIDES OF THE SEA, AS PRODUCED BY CELESTIAL ACTION.

The tides of the oceanic waters, and the currents or lateral motions to which the tides give rise, are among the most interesting phenomena of the sea; but they are, at the same time, among the most difficult, not only to be explained in a popular manner, but to be understood in their details, or real appearances at different parts of the globe, even by those who devote to them the most scientific and most exclusive attention. This difficulty is the more provoking on account of the theory of the tides, as depending on astronomical causes, partaking of that simplicity and perfection which are so eminently characteristic of the whole system of the universe, when viewed on the grand scale; and as arising entirely from the configurations of the land, the extents and depths of the several portions of sea, and other causes of disturbance, which are all terrestrial and local, and, as such, must be studied in their details, which details are so numerous, and so different from each other, that it is utterly impossible so to generalize them as to obtain anything which can be considered as worthy of the name of a clear or general view.

The word *tide* does not differ much in meaning from the word *time*, but the two are not synonymous; for even in colloquial language we use the words "time and tide" as distinguished from each other, though the adage predicates equally of both, that they "wait for no man." From this use of the word "tide," which is a very common one, the meaning of that word may be very readily seen. The *tide* is the *event* which shall happen at some *time*, which time is the point in the succession of events at which the particular event or tide shall take place; but the succession of the time and the succession of the tide are not necessarily the reciprocal measures of each other. It is true that we use the word "tide" as descriptive of particular times of the day,—as, for instance, we say "morning-tide," "noon-tide," and "evening-tide;" but it should seem that we apply this word "tide" to a certain state of the day only when that state is variable in the absolute time of its occurrence, either with change of latitude or change of seasons. Noon-tide is, no doubt, told by the clock; but it is told by the clock only when on the same meridian; and 15° westward in longitude makes noon-tide an hour later in absolute time, 15° eastward makes it an hour earlier, and so in proportion for other differences of longitude. In like manner, morning-tide is much earlier, and evening-tide much later, in summer than in winter; but throughout all places where the sun sets, there always is a morning-tide and an evening-tide. We farther see the meaning of the word "tide" in the word "betide," which, in old English, is one of the forms of the verb "to tide," the meaning of which is, "certainly to happen," though this word is not used in modern language.

It is of some use to have a right understanding of the general meaning of this word before we come to a particular examination of its application to the phenomena of the sea, because the word itself carries us some little way in the explanation. According to the meaning which we have attempted to explain as being general in the word "tide," the tides of the sea must mean those phenomena of the waters which have been ascertained to be quite certain and infallible in their occurrence, though not occurring twice successively at the same hour, or to the same extent. This is exactly the case with the tides at any one place,—they occur at a different time on every successive day, and they occur to differences of extent which vary monthly, (as counted by the moon,) and seasonally, or annually, (as counted by the sun,) but, at every place where tides are perceptible there is a regular succession; and when the law of this succession has been once determined by observations sufficiently numerous and accurate at any one place, the recurrence of the tides, and their general quantity, for that place, may be predicted for any length of time. There are, however, some niceties with regard to the exact moment, and the exact elevation, which must always render the prediction liable to some degree of error. The sea, like the air, is sensitive throughout its volume, though not so much so as the air is, because the sea is a liquid and many times more obedient to the law of gravitation than the air; yet any impression made upon any part of it by the motion of the air, by variation of the air's pressure, or by any other cause capable of affecting the surface to a considerable extent, must be propagated to a greater or less distance, according to its intensity; and this propagated effect may, under many circumstances, extend into regions where its cause is entirely unknown. Thus, for reasons which can be better explained afterwards, a violent west or south-west wind blowing on the Atlantic may cause an unusual rise of tide on the eastern coasts of the British islands, in cases where it is not at all felt even on the western coasts.

To any one who has been but one day by the shore of the sea, or the bank of a tidal river, it is unnecessary to describe the phenomena whose succession is called the tide. Every such person must have observed that at some time of the day the shores and banks are left dry and exposed to the air for some extent or other, but that this exposure has no sooner obtained its greatest amount, than the water again begins to rise, and continues to do so, though with varying rapidity, until it covers the maximum extent of the shores or banks; and, after it has attained its maximum, it again subsides to its minimum, —that is, till the maximum of the exposed shores or bounds again occurs. When the maximum is left bare, it is said to be *low water;* when the maximum is covered, it is said to be *high water;* the rise from low to high water, is called the *flood tide,*—and the time that it takes, the *time of flood;* and the descent from high to low water is called the *ebb tide,* and the time in which it takes place is called the *time of ebb.*

In so far as their primary or astronomical causes are concerned, those tides may be considered merely as alternate elevations and depressions of the water, without any necessary transfer from place to place; but the whole being produced by an undulating or waving motion, in which the surface of the water swings upward and downward upon certain points or curves as axes of motion, at the same time that the whole of it is always in exact equilibrium between the opposing forces of gravitation, by the action of which those changes on the surface are produced. In practice, however, that is, according to the phenomena, as actually observed at different places, there is often a positive transfer of the water from one place to another. In the case of a shelving shore, there is of course a motion of water toward the ground which the higher water covers, and from it when it is again left dry; and there are some instances in which more extensive currents are produced, so that along shores and in channels there are runs of the water produced, which, under particular circumstances may amount to very dangerous rapids, or even assume partially the appearance of water-falls. An instance of the former occurs in the Pentland Firth, between the north coast of Scotland, and the OrkneyIslands; and there are remarkable instances of the latter, upon a small scale, between the islands of the Jura group on the west of Argylshire in Scotland, and those of Loffoden on the west coast of Norway. These, however, are produced entirely by local causes, and they are so numerous and so varied, in the countless narrow seas and straits which occur on the surface of the globe, that even the mere list of them would occupy more pages than are contained in the whole of this volume. Those currents sometimes run with the apparent motion of the tidal wave, sometimes across it, and sometimes against it; and it very generally happens that, in tides upon the coasts, the set of the water is from the land during part of the rise of the tide, and to the land during part of its fall. So that, upon the coast, the time of *slack water*—that is, when there is no transfer of water to or from the land—occurs sometimes before high-water, and also sometimes after low-water; while, in tidal rivers, the current very frequently is in constant motion downwards, although it may happen that in a long estuary there are several waves of high water, with troughs or hollows of low water between them, in progress up the stream, or against the general motion of the waters.

From these circumstances, and from many others which are open to common observation upon every tide coast and every tide river, and which, to a very great extent, depend upon the peculiarities of that coast or that river, it is evident that we must take some more simple and general view, in order to be able to express anything like a popular understanding of the tides. We shall, therefore, leave all local differences between place and place, as depending on the earth itself, entirely out of the question, and consider the original or astronomical causes of the tide in the most simple form under which it is possible to view them; and when we have acquired some knowledge of them in this way, we shall be better able to understand in what manner and to what extent the real appearances are so different from those to which we should naturally be led by this simple view of the case.

The grand cause of the tides is that very same principle or phenomenon of gravitation which retains the earth in its orbit, and loose bodies in their places on the surface of the land,—the same principle, in fact, which is one of the elements of stability in every atom, and in every mass of matter, whether, according to our common modes of expression, it be in motion or at rest. This being understood, it must follow that, unless from those causes of disturbance which we are in the meantime leaving out of the question, the tides must be in perfect obedience to the principle of gravitation,—directly as the mass of matter, and inversely as the square of the distance, in the case of bodies considered at rest; and varying inversely as the cubes of the different distances in the case of a body or bodies revolving in ellipses. This last is the law of variation in the radius vector, as telling upon and exactly balancing the motion in the orbit; and, therefore, as it tells upon the whole mass of the revolving body, so also must it tell in those disturbances which are produced by changes in the length of the radius vector. Some of these are a little complicated in the case of the tides; but after we have understood the general principle, perhaps we shall be able, in so far, to see our way through them.

The only two celestial bodies which are sufficiently near, and at the same time of sufficient magnitude to disturb the equilibrium of the oceanic waters,—or, more correctly speaking, to modify that equilibrium,—are the sun and the moon: the sun, in consequence of its vast magnitude, and the moon in consequence of its short distance. The relative disturbances produced by the two may be expressed by the following elements:—the quantity of matter in each, multiplied by the cube of the distance in the other. We shall not go into any calculation on this part of the subject, but we state that, in consequence of the distance of the sun being so much greater than the moon, and the cubes of the distances being elements, each one of the disturbing force of the other, while the quantity of matter enters simply into the estimate each for itself, the product, or whole disturbing force, answering to the moon, so much exceeds that answering to the sun, as that the moon's influence upon the waters of the ocean is to that of the sun very nearly as 5 to 2, or about two and a half times as much.

The celestial or primary causes of variation in the tides of the sea, as dependant on the gravitating influence of the sun and moon, are—the motions of the earth in its elliptic and oblique orbit, the orbital motions of the moon, and the rotation of the earth upon its axis. The orbital variations affect chiefly the height of the tides, and the rotation of the earth affects the times of the day at which they occur. There is of course a tide produced by, and obedient to, the apparent motion of each of the luminaries; and each of these tides must travel round the globe in the same time that the luminary occasioning it appears to occupy in performing its apparent daily circuit.

As the apparent daily motion of the sun is simply the counterpart of the real rotation of the earth, which is understood to be perfectly uniform, the solar tides, considered in themselves simply, must always occur at the same hour of the day,—at an hour as long after the sun's apparent passage of the meridian at noon and midnight as shall answer to the maximum of the sun's tide-raising effect; for this, as is the case in all motions of matter, will be after the maximum energy of the cause, as time is an element in every such effect.

It is different, however, with the tide which is produced by the action of the moon. The moon's apparent daily motion round the earth is produced by two causes, the earth's motion in rotation, and the moon's orbital motion. The effect of the former is, of course, exactly the same as that in the case of the sun, and as the influence of the mere progressive motion of the earth in its orbit is the same in both, we have not noticed it in either. It makes about one three hundred and sixty-sixth part of the apparent daily rotation, or rather less than four minutes in time. The effect of the orbital motion of the moon is much greater than this, being at the rate of about fifty minutes each day, or an entire revolution in about twenty-nine days and a half. Thus the lunar tide falls later by about fifty minutes every day than it was on the day preceding; and at the end of the revolution it again occurs at the same hour as at the beginning.

It is thus evident that the tides of the sun and moon will sometimes occur at the same hour, and sometimes at different hours; and it is equally evident that when they occur at the same hour their effects must be united, and the tide must be their sum,—that is, if the proportional numbers be 2 for the sun, and 5 for the moon, the number answering to their union must be 7. On the other hand, when they are so far apart that the greatest ridge of each coincides with the deepest hollow of the other, the resulting effect will be their difference,—that is, the number answering to it will be 3. Those unions of solar and lunar tide are called *spring tides*, and the greatest oppositions of them are called *neap tides;* and it is evident that the spring tide, or at least the maximum operation of the joint attractions which produce the spring tide, must happen when the sun and moon are on the same meridian; and that the neap tide, or greatest opposition of solar and lunar action, must take place when the sun and moon are on meridians 90°, or twelve hours in time, distant from each other. The high-water occasioned by each luminary is double, one projection of it on the hemisphere next the luminary, and another on the hemisphere opposite to the luminary; and the low water is the circumference of a great circle of which the two points of greatest high-water are the poles. The tide on the hemisphere opposite to the luminary, or the *under* tide as it is called, is rather a puzzle to beginners in the study of this science, and some of our most popular writers, who have attempted to make it plain, have fallen into errors respecting it; therefore, we shall make it the subject of a separate paragraph; and, in order to render that paragraph as clear as possible, we shall take the very simplest case, namely, that in which the earth may be supposed perfectly smooth and uniform in the surface of its solid portion, that portion every where covered by a uniform depth of water, and only one luminary acting upon it so as to affect, by a tide, the surface of that water.

This supposition, though not in accordance with the observed phenomena, is perfectly correct, so far as it goes. The real tide which results from lunar and solar action, is the *resultant* of two such cases constantly varying in their combination; and the endless varieties of local tide are modifications of this resultant, produced by the varied surface of the earth, and the varying action of the atmosphere.

To render this elementary view as clear as possible, we shall suppose that the body that causes the tide, which may be either the sun or the moon, is directly over the equator, or at right angles to the axis of the earth's rotation; and farther, that, independently of the influence of the tide, the surface of the water has the form of the spheroid of rotation,—flattened at the poles, and bulged out at the equator,—answering to the degree of rotatory motion; and also that the depth of water is such that the friction of the bottom has no effect on the tide.

In this case, the line joining the centres of the earth and the luminary, and passing through the common centre of gravity of the two, would meet the earth at one point in the equator, pass through the centre, and meet the equator again in the opposite point. These three points may be considered in the situations of nearest, medium, and most remote, with reference to the luminary; and the direction of these three points must also always be that of the centres of gravity of both earth and luminary, and the common centre of gravity round which one or both of them revolve.

The lines joining these three points with the centre of gravity, or centre of the luminary which produces the tide, though all in the same direction, and in fact the same line, in so far as direction is concerned, are all of different lengths. That joining the nearest point of course is the shortest; that joining the medium point, or centre of the earth, is the next, and half the earth's diameter, or about 4,000 miles, longer; and that joining the most distant part is 4,000 miles longer than the second, or 8,000 miles, that is, the whole diameter of the earth, longer than the first. But gravitation varies inversely as the squares of the distances, if quantity of matter or other circumstances do not affect it; and we are here speaking of points only, into our estimate of which quantity of matter does not enter. Therefore, if we take the distance between the centre of the earth and the luminary, which is a matter determinable by observation and calculating, and if we subtract half the diameter of the earth from this in one case, add the same to it in another, and square, or multiply by itself, the smaller distance, the distance of the centres, and the larger distance, those three will give us the proportions of the luminary's gravitating influence, at the nearest point, at the centre of the earth, and at the most distant point; and it is the difference between the influence at either of those extreme points, and that at the centre, which is the cause of the tide; and here it is easy to see why a comparatively small body, at a short distance, such as the moon, should have more tidal influence than a much larger body at a greater distance, such as the sun, how much more powerful soever that large body may influence the whole mass of the earth as answering to its centre of gravity, and therefore not tending in the least to change its shape from that of the spheroid of rotation, in which every section at right angles to the axis of rotation is a circle.

On the very same principle, we can see that, if by any means the luminary is brought nearer to the earth, or, which is exactly the same in effect, the earth is brought nearer to the luminary, the difference of gravitation causing the tide, and consequently the tide itself, must be greater. On the other hand, if the distance of the earth and luminary is by any means increased, the disturbance and the tide must be proportionally lessened. But the earth's orbital motion round the sun is an ellipse; and therefore the solar tides must be greater when the earth is nearer the sun in the perihelion part of its orbit, than when it is farther from the sun in the aphelion part. The monthly motion of the moon round the earth, too, or rather the motion of both round their common centre of gravity, is performed in an elliptic orbit, and consequently the lunar tide must be greater when the moon is nearer the earth in perigee, than when it is more distant in apogee. This, however, is more complicated than the former, because of the motion of the moon's orbit during the lunar period of between eighteen and nineteen years; and this brings the other causes of disturbance, arising from the angular distance of the sun and moon, as estimated from the centre of the earth, into all parts of the lunar orbit; and thus the general resultant tide obeys several periodical movements of the influencing bodies. We shall have occasion to advert to those periodical modifications by-and-by, but it is as well to bear them in mind. Let us return to our three points.

The centre of the earth is undisturbed by any influence either of the sun or moon; so that, under all circumstances, and in every part of its orbit, it remains true to the law of the square of the periodic time, always proportional to the cube of the distance; and this holds true, not only of the centre itself, considered as a mere point, but of a plane passing through the centre, at right angles to the radius vector,—or, in the case which we have supposed of the luminary directly over the equator, in the direction of a meridional circle passing through both poles, and cutting or crossing the equator each way at 90° distance from the point at which the luminary is vertical, and also from the point opposite to this. This section,—of which the gravitation answers exactly to that of the centre,—will not, it is true, be a perfect plane, or completely flat, but a portion of a spherical surface, of which the radius vector of the luminary is the radius. This may be considered as a sort of mesial plane within the earth, separating at its boundary all that portion of the oceanic waters which has more than the gravitation of the centre from that portion which has less; and thus the circumference of this plane is the only portion of the surface of the waters which remains true to the general laws of the orbit, the difference both ways increasing from this plane, until the increase is a maximum at the point where the luminary is vertical, and the decrease is a maximum at the opposite point. Thus the parts of the water nearest the luminary have more central force, or gravitating tendency toward the luminary, than the general average of the earth's mass; and the parts most distant have less of this central force. Very little consideration, in addition to this, will show us very plainly why there must be an under-tide diametrically opposite to the upper one.

The central force,—that is, the tendency to the centre, or centripetal force,—is different at the mesial plane and the two opposing points; being greatest at the point under the luminary, less at the mesial plane, and least of all at the opposite point. But the tangential, or centrifugal, force, which, by balancing the centripetal force, maintains the earth in its orbit, is common to the whole volume of the earth, and measurable by its quantity of matter and velocity, without any reference whatever to shape; and therefore, the centre of the earth, and the mesial plane to which we have alluded, are the only parts of it at which the two orbital forces are in a state of momentary equilibrium. Upon the hemisphere next the luminary, the centripetal force increases from the circumference of the mesial plane to the point where the luminary is vertical; and consequently, throughout the whole of the upper hemisphere, or the hemisphere next the luminary, it is greater than the tangential or centrifugal, and its excess increases toward the central point of the hemisphere. In the opposite hemisphere, the centripetal force is less than the centrifugal; and the deficiency increases from the circumference of the hemisphere to the point opposite to that at which the luminary is vertical.

But a fluid like the water of the sea would not hold together if the centrifugal and centripetal forces were not exactly equal upon every particle of it; and therefore the water on the upper hemisphere must give way to the greater centripetal force, and the water on the opposite or under hemisphere must give way to the greater centrifugal force, until the surface all over each hemisphere is gradually elevated, and till the central part of the surface of each hemisphere is so far lifted up, or removed from the common centre of the earth, as shall compensate for the deficiency of centrifugal force in the upper hemisphere, and of centripetal force in the under one. Such is the cause of the double tide; and though we are not called upon to investigate its amount, as depending either on the sun or the moon,—in the case of both cf which it varies with their distances from the earth,—it is easy to see that any body so situated as to exercise different gravitating effects at the opposite extremities of that diameter of the earth, over one end of which it were vertical, would of necessity produce, in an earth wholly covered with water, two elevations of tide at the opposite extremities of the diameter alluded to, and an intermediate circle of low water, every where 90° distant from those two points, the tides of the opposite hemispheres being of exactly equal height, and the whole phenomena in exact proportion to the disturbing influence of the luminary. Nor would this disturbing force on the tides produced by it be in the least influenced by the general gravitating influence of the luminary, as told upon the general mass of the earth and estimated by the centre, for this would respect all parts alike; and thus the attendant moon disturbs the waters of the ocean to two and a half times the extent to which they are disturbed by the governing sun.

Though we do not wish to fatigue the reader by the introduction of numbers when we can avoid them, we may mention, that the usual estimate for the height of the tides is 24½ inches for the sun, and 58 for the moon,—82½ for the sum, and 33½ for the difference.

Before proceeding to consider even the astronomical modifications of the tide, as they would appear on a globe of smooth and uniform surface, covered all over with the requisite depth of water for admitting of a perfectly undisturbed effect, there is one other little consideration which we may mention. The whole of the revolving earth is exactly balanced, for the moment, between the centripetal and centrifugal forces; but the centripetal force has the advantage on the waters of the hemisphere nearest the centre of revolution, and the centrifugal force has the advantage on the waters of the opposite hemisphere. Let us suppose either of those forces instantly destroyed, and see what would be the effects. It is evident, that if the centrifugal force were destroyed, the tendency of the whole planet would be toward the centre—toward the sun in the case of the earth; and it would go there, the solid part in mass, and the water of the near hemisphere a little before that, at least at the outset, in consequence of its tendency to the centre being greater. So also, if the centrifugal force were destroyed, the general tendency would be to move off in a tangent to the orbit, the water on the outer hemisphere a little in advance of the solid matter, because of its greater tangential motion at the outset. In each case it would, however, be different with the water which had an excess of motion of the kind with the destroyed one, so that the destruction of the centrifugal force would send it off at a tangent, while the destruction of the centripetal force would tend to detach a portion of the water from the inner hemisphere, and send it directly to the sun. It seems to be upon some such principle as this, or at least a modification of it, that comets, which move in very elongated orbits, and therefore approach near the sun, and change their directions rapidly near the perihelion, lose a portion of their filmy substance in getting round that luminary; but the point is involved in considerable obscurity, and it is foreign to our present purpose.

We shall now consider the astronomical modifications, taking them in the order which appears to be that of their simplicity: first, the rotation of the earth on its axis; secondly, the revolution of the earth in its orbit; thirdly, the revolution of the moon in its orbit, and the motion of the lunar orbit itself; and fourthly, the manner in which the solar and lunar tides increase or diminish each other, or are united or separated, according to the angular distances of those bodies which are continually changing during every lunation, or revolution of the moon in its orbit.

First, then, for the effects of rotation.—Here we shall still consider that we are examining a smooth globe, uniformly covered with water; and as it is indifferent whether we take the one tide or the other for illustration, we shall take the solar tide, because it is constant to solar time; and though it has only a deviation of about two feet from the figure of the spheroid of rotation, it will answer our purpose just as well as if it were 200 miles, for we are speaking of causes, and not of quantities. This spheroid of solar tides raised two feet at each of its poles, but rising gradually from the circumference intermediate between them, has the radius vector for its elongated diameter, or at least for the maximum influence which causes the elongation; and as the earth in its rotation eastward causes an apparent motion of the radius vector westward,—which is uniform, or passes over equal measures of the equator in equal times, in the case of the sun being directly over the equator,—it follows that the two high-waters, at their greatest elevation, will in this case travel westward on the equator, half the circumference distant from each other, and with the circumference of the low-water intermediate between them. Thus, in this state of things, there would be on the equator two high-waters, and two low-waters, dividing the equator into four quadrants, and following each other at six hours' distances; so that, at the equator,—that is, at any particular point of the equator,—the tide would rise for six hours and sink for six hours, alternately. At the poles, however, there would be no high water in this state of things, because the circle of low water would be constantly on them both, and revolve on them as centres; and though the high and low waters would on all the parallels follow each other at exactly the same intervals as on the equator, yet the difference would become less as the latitude increased, till it vanished to 0 at the poles. From the circumstance which we have mentioned, of physical causes acting upon matter always taking some time to produce their maximum effect after the maximum operation of the cause, (which is, in fact, the principle upon which a planet recedes from its perihelion, and approaches from its aphelion,) the time of high-water would, even in this simple state of things, take place after the sun's apparent passage of the meridian,—that is, the one high-water would be at some time after noon, and the other some time after midnight. What the length of this time might be, we have not the means of ascertaining; and as it is not an element in any estimate of the actual tides, it is not essential,—only we must bear in mind that it exists.

Secondly, let us consider what the effect of the earth's motion in its orbit would be, still upon the supposition of the earth being uniformly covered with water. In this case, the poles of the spheroid would be just as true to the radius vector as in the former, and would deviate from actual coincidence with the point when it apparently met the earth from the same cause, and to the same extent. Therefore, in understanding the tides in this way, we have only to follow the apparent path of the radius vector upon the earth's surface during the course of a year, which will be found described, with some detail, in our volume of the EARTH, to which we must refer, and content ourselves by stating the general fact. In proportion as the sun had north declination, the radius vector would be northward of the equator, in the upper-tide, or during the day, and as far on the south side of the equator during the under-tide, or tide in the night. The angular extent both ways would be the number of degrees in declination; and the distance of high water from the equator would be the arc of that circle, answering to the degrees of declination. Of course the change of high-water, northward or southward, would vary at the same rate with that of the sun's declination. If the sun were at south declination, the high-water of the upper-tide would be in the southern hemisphere, and the high-water of the under in the northern, both equally distant from the equator, and corresponding to the sun's declination.

But amid those changes, the spheroid of tidal water would remain as true to its poles as its axis did to the radius vector, and therefore the circle of low-water would still be always 90° from both points of high water. It is therefore obvious, that in as far as the apparent movement round the globe depended on the rotation, the two tides would now lie in different hemispheres, the upper-tide revolving in the same hemisphere to which the sun had declined, and the under-tide revolving round the opposite hemisphere,—their distances from the equator being equal, and each equal to the sun's declination, and deviating from the parallel, during the daily revolution, by a quantity equal to the sun's declination during the day.

Suppose, for instance, the sun had the maximum of north declination, or to be over the northern tropic, in latitude about 23½°,—as is the case at our midsummer,—the northern high-water would revolve round this tropic, and the southern high-water round the opposite or southern tropic. The two parallels of high-water would thus be about 47° asunder, and the hemispheroid of high-water answering to each would extend 23½° across each pole, or to the polar circles. There would still be no tide at the poles themselves, but the spheroid would produce very different phenomena—the day tides, in the northern hemisphere, would be higher than the night tides; and the night tides, in the southern hemisphere, would be higher than the day tides. If the sun were over the southern tropic, the circumstances of the hemispheres would be reversed, with regard to the day tides and the night tides; but, allowing for this, the amount would be the same.

The two parallels of high water, which would be thus at their greatest distance at midsummer in either hemisphere, would approach each other as the radius vector approached the equator; and when it arrived there, at the equinoxes, the two tides would be united. As the declination changes with most rapidity when the radius vector is near the equator, the approach would be most rapid near its close, and the separation near its commencement; and as there is little change of declination, for several days, near the tropics, the midsummer and midwinter tides would remain for some time in very nearly the same latitudes.

The circumstances which we have now mentioned apply to the moon as well as to the sun, and, indeed, they are subject to a greater range of variation in the case of that luminary. The orbit of the moon makes an angle of about 5½° with that of the earth, when in the position of its longer axis; and when the moon is at either extremity of that axis it must have either 5½° more or 5½° less declination than the sun. The moon may be at any of those points, or at any point intermediate between them; and therefore the moon, and the moon's tide, may be 5½° either north or south of the sun and the sun's tide, or they may be exactly on the same parallel, or any where between that parallel and 5½°. But we shall be better able to explain the general action of those lunar variations afterwards; and therefore, in the mean time, we shall merely mention farther, that notwithstanding the disturbance which is given to the tidal waves, by local causes on the earth, those modifications which arise from the different declinations of the luminaries are felt, to a considerable extent, in all cases in which the tide can be considered as primary, or more immediately a result of celestial action.

Thirdly, let us consider the modifications of the moon's tides, as occasioned by the apparent daily and real orbital motions of that luminary. The lunar tides are as true to the radius vector of the moon,—that is, the line joining the centre of the earth and moon, and passing through the common centre of gravity of the two, as well as through that of each individually,—as the solar tides are to the same line with reference to the earth and sun; and if we make allowance for the time necessary to produce the maximum effect, we may consider the elongated axis of the spheroid of lunar tide as having its one extremity where the moon is vertical, and its other extremity at a point on the earth's surface diametrically opposite, just as is the case with the spheroid of solar tide. There is only this difference, that each pole of the lunar spheroid is about fifty-eight inches above the intermediate circle of low-water, while those of the solar tide are only about twenty-four and a-half inches above their low-water.

In tracing the progress of the lunar tides over the surface of the earth, we have, therefore, merely to follow the apparent motions of the radius vector in the same way as we followed that of the sun. But here the change of tide at any one place is the result of two motions; whereas, in the case of the sun, it is the result of one only. As is the case with the sun's tides, the rotation of the earth produces the greater part of the difference—produces twelve hours of it, as between high-water and high-water,—and the moon's motion in its orbit produces the remainder, amounting, as we have said, to about fifty minutes in each day, or the half of that time between high-water and high-water, or between low-water and low-water, and consequently, the fourth of that time, or about twelve minutes and a-half, between high and low water, in any one succession.

But the orbital motion of the moon is somewhat complicated; for though the moon is in all parts of it during every lunation,—as measured from new moon to new moon, from full moon to full moon, or from age of the moon to the same age again, comprising an entire lunation, or "moon," as we call it in common language,—yet the change or commencement of this lunation may happen at any part of the orbit; and thus the new moon may have the same declination with the sun, or any declination, greater or less, than that of the sun, within the limit of 5½° either way. In every case, however, there is always a change of the lunar declination to the extent of 11°, and the same back again, whether north or south; and at whatever age of the moon the *nodes* of the lunar orbit, or those points which coincide with the position of the earth's orbit, and consequently with the apparent declination of the sun, may be situated.

Thus, if we take the ecliptic, or plane of the earth's orbit as told on the heavens, as the central curve from which the moon declines northward and southward, we have a declination of 5½° to each side of this, and back again, in the course of about twenty-nine and a-half days; but as this orbit is an ellipse, with the common centre of gravity of the earth and moon in its upper, or perigee focus, and as a more rapid motion of the moon is necessary to compensate the increased attraction by the nearer approach of the earth in perigee, the time of the moon's revolution through the perigee half of the orbit is somewhat shorter than that through the apogee half. We shall not state the quantity, but it is necessary to advert to the fact, because these halves of the orbit apply to different periods of the lunation, and therefore affect differently the time and rate of the moon's change in declination, and consequently the position of the spheroid of lunar tide.

We can merely afford space to state that such facts take place, and have certain effects, as our limits forbid us to enter into the particulars, which would, indeed, be hardly intelligible without diagrams and numerical statements. We may, however, mention generally, that if the moon has the same declination as the sun, whatever that declination may be, whether 0 when both luminaries are on the equator, and maximum when both are on a tropic, or anything intermediate between these, the poles of the spheroids of both their tides will revolve round the same parallel or parallels, only the tide of the moon will part eastward from that of the sun, fifty minutes in time, or about 12½° in longitude, in the course of the day. If their declinations are different, but both are on the same side of the equator, and nearly on the same meridian with regard to longitude, the two upper tides will circulate round the hemisphere in which the luminaries are, and the two under tides round the opposite hemisphere. If their declinations are of different affections—that is, the one north and the other south—then their upper tides will be in opposite hemispheres, and so will their under ones; and it will depend upon the difference of their right ascensions, or angular separation, as measured on the equator, whether their upper tides and their under tides are both nearer one meridian, or the one nearer one meridian and the other nearer the opposite one. If the motions in declination be such as to part the two luminaries, whether they be both on one side of the equator or on opposite sides, the tendency will be to separate the points of high-water of both, whether they have the upper and under ones near the same meridian or near opposite meridians. On the other hand, if the change of motion in declination be such as to bring the luminaries nearer to each other, the poles of the spheroids of high-water will approach each other in declination; and both in this case and in the former, the luminary which changes its declination most rapidly will bring its high-water most rapidly toward that of the other. The times of most rapid declination,—that is, change of declination in the moon,—and those at which that luminary is nearest the nodes of its orbit, and the times of least change of declination, are those near perigee and apogee; so also, in the case of the sun, the times of most rapid declination are those when the sun is apparently near the equator, and those of slowest declination when the sun is apparently near the tropics. These two seasonal changes, from the one being periodical through all its varieties in about twenty-nine and a half days, and the other in about three hundred and sixty-five and a fourth, occasion a good deal of intricacy in the actual results, and render them not very capable of verbal description, though in principle they are all equally simple; and a careful study of the apparent progress of the moon through its entire cycle, or between eighteen or nineteen years, will enable one to form a tolerably correct notion, both of the extent and the succession of the several variations.

The several hints which we have thrown out must suffice for the separate consideration of the lunar tide, which, though more complicated in its changes, and greater in its amount than the solar tide, depends upon principles exactly similar, and in the individual case is just as easily understood. We shall therefore proceed—

Fourthly, to consider the effects which, still upon a globe uniformly covered with water, would result from the combination of the solar and the lunar tides, in consequence of those differences in the apparent motions of the luminaries, or travellings of their different radii vectores over the surface of the earth, as we have attempted to explain them—though we fear that in this we have hardly succeeded.

The combinations and oppositions of the solar and lunar tides become not a little intricate when we attempt to follow them into all the minutia, even in that simple case of uniform water over all the earth's surface which we have assumed, in order to render the explanation of the general principles more easy. We shall be able to simplify it a little, however, by resolving the approaches and separations of the luminaries into the element, or parts at right angles to each other, the one in right ascension, and the other in declination, as told on the sphere of the heavens, or the first in longitude, and the second in latitude, as told on the surface of the earth, and, consequently, in the tides.

The parting, in right ascension, is nearly uniform, at the rate of about fifty minutes of time, or $12\frac{1}{2}°$ of longitude every day; but the other, or that in declination, or in latitude as told upon the earth, is much more variable. The longitudinal separation affects the time of the resultant tide, and the variations of its height, successively, during the course of the lunation; while the separation in latitude affects chiefly the height of the individual tide, and the position of the parallel, or parallels, at which the maximum elevations and depressions take place. It will be best to glance very briefly at these separately.

At the precise moment of new moon, the sun and moon appear exactly on the same meridian, or, at all events, they are exactly on the same meridian, whether they happen to be visible or not visible to an observer at any particular place. If the moon is exactly in one of the nodes of its orbit, at this time of new moon, which is also termed the time of *conjunction* of the sun and moon, the result is a central eclipse of the sun by the interposition of the moon between the sun and the earth; and this eclipse will be total or annular, according as the moon is nearer to, or farther from, the earth,—because, when it is near, it covers a greater space at the distance of the sun than when it is farther off, in the same manner as the hand brought close over the eyes eclipses the whole field of vision, while a hand of the same breadth, held up at the distance of only a few yards, covers a very limited space. In the case of an eclipse being central,—that is, of the radii vectores of the sun and moon exactly coinciding with each other,—the poles of the spheroids of tide answering to the two will exactly coincide, and the elevation of high-water on its parallel, or its parallels, in the case of declination in both luminaries, will be a maximum wherever it is situated; and so also will the depression of the circle of low-water be a maximum; but if, at the time of this conjunction, that is, of new moon, the one luminary has different declination from the other, there can be no eclipse, at least if the difference in declination is such as to remove the whole mass of the moon out of the cone formed by straight lines drawn from the eye of the observer to all points in the circumference on the disk of the sun; and in proportion as this difference of declination approaches its maximum of 5½°, the absolute elevation of the high-water and depression of the low-water will extend over a greater range of latitude, but will be lower at any one point.

From this point of new moon, or conjunction, the parting of the moon from the sun, in longitude, will be 12½° in angular distance, or about fifty minutes in time every day, until the moon arrives at the end of the first quarter, and is a quadrant, or 90° in longitude apart from the sun to the eastward, or six hours later in the apparent revolution of the heavens. At this time, wherever may be the difference in declination, the high-water of the one luminary must fall on the low water of the other, in respect of longitude, and consequently the resultant high and low water will have the least possible difference; and if in this state of things both luminaries have exactly the same declination, on the same side of the equator, the difference between high-water and low-water will be the least possible. From this point the separation of the luminaries continues, till the half of the moon's orbit is passed over, and they are in that situation with regard to each other which we call opposition, or full moon, in which case, the upper tide of the one will be on the same meridian with the under tide of the other; and as the upper and under tides, being produced by equal causes, are the same in effect, the phenomena of the tides will be the same as at the conjunction. If at the time of the opposition the moon is in or near one of the nodes of its orbit,—that is, if both sun and moon are either on the equator and have no declination, or have equal declinations but on opposite sides of the equator,—the moon would be eclipsed by passing through the earth's shadow; and in the case of the declination being exactly the same at the moment of opposition, and the eclipse, in consequence, the greatest possible, the high-water of both tides will be brought exactly to the same point, and the difference of high and low water will be the greatest possible, in the same manner as it is when similar circumstances take place at new moon. These occurrences depend on the moon's orbit, and can be calculated; but there are so many disturbances and variations in the moon's motion, that the calculation involves a number of elements.

From the time of the full moon, or opposition, the moon still gets eastward of the sun in longitude, though, in common language, we consider the direction of east as extending only from the south to the north, or from new moon to full moon; and therefore we say that, during the second half of the lunation, the moon approaches the sun in the west; but whatever name we give it, the motion is the same, though performed in the other half of the orbit. At the end of the third quarter of the lunation, or quadrant of the lunar orbit, the high-water of the moon again falls on the low-water of the sun, and the resultant tide is a neap, or the lowest in the lunation; and when the fourth quadrant is passed over, the state of things is the same as at the commencement, the moon having now performed an entire revolution in its orbit.

Thus it is evident, that from the new moon to the first quarter the tides decrease; from the first quarter to the full moon they increase; from the full moon to the third quarter they decrease; and from the third quarter to the new moon they increase. The particular heights at those times, for any given lunation, depend so much upon the different declinations of the sun and moon at the different periods of the lunation, that they do not admit of general description, and each must be calculated on its own data from the successive positions of the luminaries themselves. The positions of new moon, or conjunction, and of full moon, or opposition, are technically called the *syzygies*, which means, that the sun and moon are under the same yoke—the yoke in this case being the meridian; and the quarters of the moon are called *quadratures;* so that the spring tides happen when the moon is in syzygy, and the neap tides when in quadrature. From what was remarked of the solar tide being highest in the middle latitudes, when the sun is on the equator,—which answers to the equinoxes,—it follows, that the resultant tide of the joint actions of the sun and moon must be greatest in the middle latitudes, when both luminaries are on the equator, at the time of conjunction or opposition. The cause of this, it will be recollected, is, that the circle of low-water remains constantly at the poles, when the disturbing luminaries are on the equator; and that thus the whole water of the accumulated tide is brought into the middle latitudes. Therefore, the highest spring tides will take place near the time of the equinoxes, and the lowest ones near the midsummer and midwinter; and we need not add that when the tide is highest above the mean level in the flood, it must sink deepest below that level in the ebb, and that conversely a small rise of flood will be attended with a similarly small depression of ebb; but these circumstances, as well as those formerly alluded to, are modified by the changes in declination.

If the declination of the sun is more than $5\frac{1}{2}°$, the sun and moon must, under any circumstances, be both on the same side of the equator at conjunction, and on opposite sides of it at opposition; and as the declination of the sun increases, the average declination of the moon must increase along with it, and may be the same, or $5\frac{1}{2}°$ greater or less, or any quantity within those limits. This has some influence upon the tides at different seasons. The upper tide of the moon happens during the day, as well as that of the sun, when the moon is in conjunction; but when in opposition, the upper tide of the moon answers to the under tide of the sun, and happens during the night.

The solar tide is so small, compared with the lunar, that it is lost in it, as a distinct tide, and operates only in modifying the various heights of tide; and there are other modifications arising from variations of distance, both of the earth from the sun, and of the moon from the earth. The moon in perigee, and the earth in perihelion, with the sun and moon apparently on the equator, are the circumstances which produce the greatest possible tides; and the moon in apogee, the earth in aphelion, the sun with the greatest declination, and the moon at the greatest difference in declination from the sun, are the circumstances which produce the least tide possible; but the variations between those limits are exceedingly numerous, and they are different in every lunation. If, however, the reader has followed the course of remarks in this section, he will, we trust, be able to understand the general causes, as dependant on celestial influence only, and be prepared to enter on a short survey of the far more complicated disturbances occasioned by the distribution of land and sea on the surface of the globe.

In this section we have considered the earth as different from what it is in reality, for we have supposed it wholly covered by a uniform stratum of deep water. This, however, does not in the least affect the correctness of the explanations which we have given. These apply to the attractions of the sun and moon only; which attractions are in no way dependant upon the character of the earth's surface, but would be the same as they are, though the earth were a mass of solid stone, or iron, or any other substance in which there could be no motion of tide at all. The astronomical view of the subject is therefore as perfect as the rest of the science of the heavens; and it is when we come to the details of the earth that we feel at a loss, and must have recourse to local observation. We shall notice this branch in another section.

The tides are phenomena of so much importance, especially in coasting trade and in coast fishing, and they are, generally speaking, so imperfectly understood by common readers, that we shall consider them more in detail than we have done any of the other phenomena of the sea. In order to give clearness to those details, we shall be under the necessity of carrying forward the explanations; and this, to those who are already acquainted with the subject, may have the appearance of repetition; but they will perhaps excuse those apparent repetitions when they bear in mind that we are addressing the less informed.

SECTION V.

TIDES AND WAVES.

In order to be prepared for a clear and ready understanding of the tides, it is necessary to know something of the motions of waves; and then we can proceed to consider the real tides of the sea,—which are much more influenced by terrestrial disturbances than by the action of those luminaries that put them originally in motion, and of the utmost importance to all who navigate the seas, or are interested in navigation. The subject is, however, of so very complicated a nature, and involves so many details, which often seem contradictory of all theory, that we shall be able only to give a few remarks on those parts of it to which general principles appear to be the most applicable; and even here we may have occasion to advert to the imaginary state of things, in which there should be no interruption from dry land, or the inequalities of the bed or bottom of the sea, in order better to explain the effects produced by them.

The tide, as we have already shown, follows the apparent motion of the moon round the earth. The moon is about 50 minutes longer every day in coming to the meridian of any place than the sun; and thus we shall not be very far from the truth if we call the lunar, or tidal day, 25 hours in length. If we suppose the moon over the equator, and the tide, aided by the full effect of the moon's conjunction with, or opposition to, the sun, then the two points of high water, or poles of the spheroid of tide, will be exactly 180°, or half the circumference of that circle, apart from each other; and the circle of low-water passing through the poles, and depressed at its greatest depth about seven feet below the two high-waters, will be intermediate between them, or 90° distant from each high-water every way. From high to low water, the slope will be gradual, through a sort of curve of contrary flexure, nearly flat at the top of the high-water, nearly flat at the bottom of low-water, and having its greatest curvature in the middle. The ascent from low-water to high-water will be exactly the counterpart of this, or rather the very same line viewed from its opposite extremity. The whole circumference of the equator is about 25,000 miles, and thus there would be, under the supposition which we have made, 12,500 miles from high-water to high-water, or from low-water to low-water; or there would be 6250 miles between high and low water, taken at any part of the succession of tides. The difference of level upon the last-mentioned length,—that is, upon any quarter or quadrant of the equator,—would be, as has been said, about seven feet, or, more correctly, about 82½ inches. If we compare this with the length, it is very little more than one-hundredth part of an inch difference of level per mile, and therefore so small a quantity as that it could not be observed; therefore we might easily suppose, that if the earth were completely covered with water, and the inhabitants floating upon that water in ships, they would have no notion whatever, that there could be any such thing as tides, or any disturbance of the equilibrium of the waters.

Upon the average of this estimate, 100 miles of sea could only have a general tide of from an inch to half an inch; and this is the reason why small seas, which have little connexion with the ocean,—such as the Baltic and the Mediterranean,—have hardly any perceptible tide. The difference of atmospherical pressure upon such seas may also obliterate any slight appearance of tide that would occur if the pressure were uniform over the whole surface.

But as the moon's apparent daily revolution is performed in very nearly twenty-five hours, and the circumference of the equator is very nearly 25,000 miles, it is evident that the tidal water at the equator would have an apparent motion westward at the rate of about 1000 miles in the hour; and the tidal wave would actually have this rate of motion. In other latitudes, the rate of motion would be less than this, (in the ratio of co-sine latitude to sine 90°,) which would give about 600 miles in the hour in the latitude of Britain, though the tide in this latitude would be comparatively very small, not exceeding three feet, when raised by the most powerful action of the sun and moon jointly. The circumstances which we have now mentioned are the direct effects of celestial influence, founded upon data which is well known and perfectly accurate; so that, were it not for the terrestrial disturbances and the variations in apparent place of the sun and moon, they would be the actual phenomena.

One thousand miles an hour is an exceedingly swift motion; and it is impossible for us to imagine that there could possibly be a transfer of the water at this rate. The estimated velocity of those hurricanes, or violent winds, known chiefly in tropical climates, which uproot the forests, "sweep the earth with the besom of destruction," and cause the waters of the ocean to foam and reek as if the bottom were on fire, move only at the rate of about 100 miles in the hour. But the usual estimate of the different forces with which bodies, having different rates of motion, strike against obstacles, is directly as the quantity of matter, and as the square of the velocity. Sea-water is about 841 times as weighty as atmospheric air at the mean temperature; but call it 800 times, and it follows that, in the same bulk, water contains 800 times as much matter as air; and, on this account alone, if we are to suppose them moving with equal velocity, water must strike an obstacle with 800 times the force that air does. But again, 1000 miles in the hour is ten times as fast as 100 miles; and the apparent motion of the tidal wave, under the equator, is ten times as swift as that of the destructive hurricane. The effect is as the squares of the velocities; therefore, on account of its velocity alone, the tidal wave,—if that wave were the water actually in motion,—would strike an obstacle with 100 times the force of the destructive hurricane. Combine this with the former, and we have a proportion of one for the hurricane, and 80,000 for the tidal wave; so that, if the tidal water actually moved, it would strike with the force of 80,000 hurricanes; which would not only be sufficient to dash every thing which opposed it to atoms, but would absolutely set fire to the elements of the water; and thus the sea would be instantly destroyed by the violence of its own motion.

There is, however, scarcely any tendency to lateral motion in the tidal water; and in that part of the Southern Ocean where the circulation round the globe is uninterrupted, there is probably not a single drop of water which performs a revolution upon the parallel even in the course of a thousand years. The tide is a mere wave; and a wave has nothing to do with the absolute motion of the water in which it takes place.

This is a point necessary to be attended to by those who are but little acquainted with the phenomena of motion in water; because, in the case of waves, especially of waves raised by the action of wind upon the surface of the water, there is an apparent motion of the waves, and of the water in which they are formed, in the same direction in which the wind blows. Thus, if one stands on the bank of the estuary of a tidal river, while the wind is blowing strongly upward from the sea, the whole surface will be worked into waves, which, if the shores are unbroken, and the place moderately free and wide, will appear to chase each other to leeward, or up the river before the wind, in regular ridges and furrows between, but in equal race, where no interruption breaks the water, so that the one never overtakes the other; and if one has, at the same time, a view of the shore against which they beat, they do not accumulate there, but are lost in succession the instant that they appear to arrive.

Every one who has at all examined the effect of the wind in such a place as we have mentioned, must have seen that the waves are much more turbulent when the tide and fresh are both setting strongly against the wind down the river, than when there is a motion with the wind up the river. Indeed, it must be perfectly evident to every one, that if the water could be made to move just as fast as the wind moves, there could be no wave, or other disturbance, any more than if both were at perfect rest, for this simple reason,—that if one thing moves exactly as fast as another of its own accord, the one of them cannot possibly exert any force in pushing the other, nor can the motion of either be in the least disturbed by the other. It is the difference of motion between the wind and the surface of the water which occasions waves, and this difference may be less than the whole motion of the wind, or equal to it, or greater. It will be less if the water is moving in the same direction as the wind; and hence a land-wind, blowing down the channel of a river, does not curl the water nearly so much as a sea-wind of the same velocity blowing up against the current. In large and placid estuaries, upon fine summer days, when the land-breeze is blowing gently down the stream, the tide and fresh will slide on under it as smooth and glassy as a mirror; but if the slightest turn of the sea-breeze catches the descending tide in the estuary, the surface is instantly blackened by a curl or ripple of the water, let the sea-breeze be ever so light. If one be so situated as to command a view of several miles of such an estuary, near the confluence with the sea, there is often a very beautiful sporting of the little winds upon its surface. This appears frequently in longitudinal strips, smooth under the land-wind, and a little curly under that of the sea; and, if there is a strong light, the one appears bright and almost white, and the other of a leaden gray colour. If the banks are much diversified by hill and dell, and dry field and dense forest, there is often a counter-play across the stream, and a little wind from the humid surface on the one side will dance across to the dry surface on the other, as if it were tripping along the waters with fairy feet. This summer play of the estuary has none of the terrible majesty of the deep in storms, when the vengeance of the troubled air of winter is let loose upon it; but it is very beautiful, and, to those who will take the trouble of studying it, highly instructive.

The simple facts which we have mentioned will serve to convince any one that there is no actual motion in the direction in which waves apparently move; and, as the disturbing actions of the sun and moon, which raise the waters of the sea into tide waves, act upon the perpendicular, or line directed to the earth's centre, and not in any way laterally, they of course form no exception to those smaller waves which we can examine in their whole extent. The great breadth and small height of the tide-wave are also such that, in an uninterrupted sea, there is no disturbance of the water, and no shifting,—not to the thousandth part of an inch, even of the very minutest thing which swims in its waters, or floats on their surface.

But, though the water does not move with the waves either of the wind or the tide, and though it often moves in a different or an opposite direction, which motion increases the height of the waves in all cases, and is the sole cause of that constant wave and ripple which appears upon the rapids of streams and rivers, and swift currents of the sea, yet the waves themselves have a progressive motion in addition to their undulating or wavy one. It may be proper slightly to notice those two motions separately, in order better to understand their joint effect.

The motion of a wave, considered in itself, and without reference to its progress, is like the vibration of a balance, one end of which may be supposed at the top of the ridge, and the other at the bottom of the trough or hollow. The sloping side of the wave is thus the length of the vibrating or waving line; and in still water,—that is, water which has no current, and no wind blowing over it,—though it is thrown into waves, the two sides or slopes of the wave may be considered as exactly equal to each other. In this case, if we are to suppose each wave to be cut off at the half of its height, which would be at the middle of the slope on each side, then the quantity so cut off from each wave would exactly fill the hollow. We never have, however, an opportunity of observing waves in this their simplest state, because all waves which are produced by causes acting near the surface of the earth, are in so far impelled in a lateral direction, and the waves are consequently a propagation of motion through the water to some depth, though not a motion of the entire quantity. Hence we seldom see simple waves, for the sides of the large ones are ridged and furrowed in all directions by smaller ones, which, when the water is much agitated, produce such splashing and confusion as to baffle all attempts of description. Sometimes, indeed, in consequence of the set of currents against each other, what may be called the master-waves run counter to each other in this way, and a state of the water ensues which is very dangerous to navigation. Sailors call this a " short sea," a " broken sea," or a " tumbling sea," in opposition to a " long sea," in which the waves play without interruption. In this tumbling sea, the meeting waves often dash against each other with such violence that, by the collision, large jets of water are thrown up to the height of several feet. This motion is very annoying to vessels at all times, because it kicks them right and left, so that it is exceedingly difficult to keep them to any sort of regular course. When a strong gale blows over it, it is highly dangerous, more especially to square-rigged vessels, which cannot " come up through the wind," from the trim and form of their sails; and thus, as the tumbling sea often " broaches them up through the wind," the sails are taken aback, and the vessel founders, while the crew have neither time nor power to help themselves. The coasts of Holland are especially dangerous in this way in certain states of the wind and tide.

But, though we seldom meet with a simple wave in reality, it is necessary to understand the motion of such a wave, and how a number of such motions can combine in order to produce that compound motion which we actually see, before we can have any accurate knowledge of waves. The real extent of vibration of the wave is half the height, produced by the gravity of the ridge reacting when the forces which raised it cease, and thus being changed into a hollow. This part of the change is produced by the force of velocity which the ridge has acquired in descending to the mean level, which serves to elevate the former hollow to a height proportionate to the degree of agitation. The oscillation of the wave upon the central point of its rise is thus very similar to the oscillation of a pendulum, in which the force which the bob or weight at the bottom of the pendulum acquires in descending to the perpendicular from the one side carries it upward on the other, and so on alternately as long as impulse is given to the pendulum by the force of the weight or spring of the clock, which acts in very nearly the same manner as the wind does in exciting common waves, or the influence of the celestial bodies in producing the waves of tide. The force of the wave is therefore equal to that acquired by a heavy body in descending through half the height above the bottom of the hollow; and if we consider half the length of the ridge as a pendulum vibrating, the entire change from top of the ridge to bottom of the hollow, in the same portion of water, will be equal to the time of two vibrations of this pendulum, one of them answering to the elevation above the mean level of the water, and the other to the depression below it. A seconds' pendulum is, in round numbers, about thirty-nine inches long, and therefore a wave of this breadth will perform its vibration in a second of time; and, as the times of vibration are as the square roots of the length, it will be easy to calculate the time of the vibration of a wave of any breadth. It is to be understood, however, that when the wave is acted upon by a violent surface-wind, which breaks its crest, the calculated time of vibration will not correctly apply to it; but, in all cases where the wave is unbroken, the absolute height, while the breadth remains the same, will not greatly affect the time of the vibration.

The tidal wave differs a little from wind waves, because it is the result of a force acting perpendicularly on the surface of the sea; whereas common waves, whether arising from winds or from currents, are all occasioned by lateral disturbances. In the case of the earth uniformly covered with water, of one disturbing luminary, and that luminary over the earth's equator,—which is the simple and elementary view of the principle,—the two poles of the spheroid would be constantly in the straight line passing through the centres of the earth and the luminary; and the circle of low-water, or bottom of the trough of the great tidal wave, would be always at right angles to this line, or one-fourth, or quadrant, of the earth's circumference distant from each point of high-water. In reality, the axis of high-water would be a little behind, or to the eastward, of the actual line joining the earth and the luminary, because of the time required to change the position of the waters by the disturbing influence. But then this would not affect the situation of high and low water with regard to each other, because the low-water would require as long time to subside as the high-water required to elevate. Consequently, there could be no swing of such a wave upon the middle points of its slopes, because the ridge and the hollow would follow each other exactly at the same distance,—that is, at six hours' distance in time.

If this were the actual state of things, the tides would be regulated entirely by the laws of gravitation, and their amount, and the times of their occurrence, could be determined with the same exactness as any other astronomical phenomena of which all the elements are known to us; and, as the case stands, this is still the primary cause of tide, and the practical determining of the time and degree of tide for any place resolves itself into an investigation of those diversities in the surface of the earth by which the real tides are made to differ so much from what they would be were there nothing to interfere with the attraction of the luminaries.

With one luminary, and that luminary revolving constantly over the equator, or, which is the same thing, with the earth turning round on its axis, the point of high-water would travel a twenty-fourth part of the earth's circumference, or 15° in longitude, every hour of time. So that, if we supposed twenty-four meridians drawn from pole to pole, in this state of things, all points under the same meridian would have corresponding times of tide, whether of high-water, of low-water, or of anything intermediate. Those meridians would of course answer to the twenty-four hours of a day, and if we took any one of them as a first, and supposed high-water there at twelve, it would be high-water at the next one westward at one o'clock, at the second one at two, and so on, an hour later at each, until the same high-water came round again to the first meridian at twelve next day. But while this, which we shall suppose the upper tide, or the one on the same side of the earth as the luminary, is thus travelling westward till it completes its circuit in twenty-four hours, the under tide, twelve hours in time, or 180° in longitude, distant from it, would be travelling round in the same manner, and arrive at each of the twenty-four meridians exactly twelve hours later than the former one. It is evident that here the words "former" and "latter" may be made to change places when we speak of the common succession, just in the same way as it is equally correct to say that night follows day, and day follows night.

If we supposed the one luminary to be the sun, which enlightens the earth as well as disturbs the waters of the ocean, then one of these tides would always happen in the middle of the day, and the other in the middle of the night, or as soon after these as were sufficient for changing the form of the waters. The moon also illuminates the earth, though with fainter and more varying radiance than the sun; but still, for the sake of seeing the influence of each separately, as clearly as we can, before we examine their joint influence, we shall suppose for a moment that only the moon exists, and travels over the earth's meridian at her apparent rate. The earth would then have a day and a night answering to the moon, and the moon's upper tide would be shortly after mid-day, and her under tide shortly after midnight, in the same manner as those of the sun; but as the moon takes about fifty minutes longer to perform an apparent daily revolution round the earth than the sun does, every successive lunar tide would arrive at the same meridian five-and-twenty minutes later than its predecessor, or the same tide would come round again to the same meridian in about twenty-four hours and fifty minutes of time by the sun. At this rate, if we suppose twenty-four meridians, equally distant, to be drawn, as in the case of the sun, and suppose that the moon is over one of those meridians at twelve o'clock, then the moon will be over the next one at about two minutes after one, over the third at abour four minutes after two, and so on with the others, requiring an hour and two minutes to pass between every one and the next. The lunar tide would take some time after the moon's passage of the meridian for the production of high-water, just in the same manner as the sun's tide ; and, as the disturbance produced by the moon is to that produced by the sun very nearly as five to two, it would of course require a little longer time in producing this greater effect, though the difference would not amount to much.

Both solar and lunar tides would have their corresponding elevations and depressions the same under the same meridian; only, as the moon takes two minutes longer to pass from one meridian to another, 15° apart, than the sun does, the lunar tides must separate eastward from those of the sun, or fall behind them, at the rate which has been stated. Each tide would, however, follow exactly the same laws, only different in extent and in rate of motion in longitude round the earth.

Places which have the same state of the same tide-wave at the same time, are said to be *co-tidal*, which simply means that they have their tides together; and if it were not for the disturbances occasioned by the diversity of the earth's surface, all places situated under the same meridian—that is, having the same longitude—would be *co-tidal;* and, in this state of things, every meridian would be a *co-tidal line.* In consequence of the disturbances, and of those disturbances being different at different seasons in the two hemispheres, as divided by the equator, and at almost every place in those two hemispheres, the real co-tidal lines are very different from this, and run in all sorts of directions, and at all sorts of distances, with regard to each other. These are, however, matters for after consideration; and the first thing to be done, in order to get any thing like a satisfactory view of those most complicated phenomena of the sea, is, to understand well the simple actions of the two luminaries. We trust that what has been stated in this section will at least assist in this part of the process; and therefore we shall, in the next section, proceed to examine the celestial disturbances, which arise from the varied positions of the sun and moon with regard to the earth. In order to render this as simple as possible, we shall not mix up with it those variations of the quantity of tide which are produced by the different distances at which the luminaries are at different times. We already hinted that such differences necessarily exist; and it is enough for general purposes to bear in mind this simple fact of their existence.

We may briefly sum up the substance of the celestial influence thus:—The moon causes one spheroid of tide, and the sun another. The line joining the two poles of the spheroid, or points of high-water for each luminary, is always directed in the same manner toward that luminary, and consequently the angular distance of the poles of the spheroids is always the same as the angular distance of the luminaries, the centre of the earth being the centre at which the angle is supposed to be taken; the centres of the two luminaries, the points to which the two lines forming the angle are understood to be directed, and the arc of the earth's circumference between the points where those lines meet the earth's surface, is the measure of the angle; and the arc of the equator, intercepted between meridians drawn through those points, is the difference between high-water of the solar and the lunar tide, at the rate of 15° longitude to an hour in time, or four minutes in time to 1° of longitude. These are the simple elements, by the application of which we are to examine how the astronomical causes of tides are modified by the revolution of the month and the year.

In applying those principles to the state of things as it actually occurs in the waters of the ocean, we must bear in mind not only that the actions of the sun and moon are opposed to, and destructive of, each other, in the proportion of the sines of their angular distance, but that the whole of the terrestrial causes which affect the tides are disturbing causes, acting in opposition to the gravitation of the luminaries; and that thus the practical question of the tides becomes a question of differences, —a species of question which is always more perplexing than one of simple aggregates.

SECTION VI.

YEARLY AND MONTHLY VARIATIONS OF TIDE.

In examining the periodical variations of the tides, as dependant on the sun and moon, we may consider the apparent motions of those luminaries as if they were real ones, and the earth at rest; because this mode of viewing the subject in nowise alters our perception of that difference of gravitating effect upon different portions of the sea which is the cause of tide. So perfectly is this the case, that for any instant of time so brief as that we could not imagine a division of it into two parts, the tide resulting from this varied gravitation is precisely the same as if all the three bodies were in a state of absolute rest; and as we may consider all time as made up of successive instants of this excessive brevity, that which applies to one instant will, by repetition, apply to any number. The reason of this is obvious: the fact of these bodies or some of them, or all of them, being in motion, does not alter their momentary distances, positions, or quantities of matter,—though, as distances and positions change, the result changes at the same rate; and these are the changes which we are about to investigate.

Let us imagine, then, that there is a radius vector, or carrying ray, with one extremity placed constantly at the centre of the earth, and the other at the centre of the sun, and that there is another one similarly placed with regard to the moon; and it is perfectly evident that each radius vector will always meet the earth's surface at the point where the luminary is vertical for the moment; and if we trace the successive points where the radius vector of each luminary meets the earth's surface, we shall have in the case of the sun, the grand cause of the yearly or seasonal variation of the tides, and in that of the moon the grand cause of the lunar or monthly variation. Then, having done this, if we apply the one to the other we shall get the real or resulting variation, as dependant upon the attraction of the sun and moon. Having done all this, if we next turn to the map of the world, we shall, in as far as we are acquainted with its inequalities, and the way in which these oppose and disturb the celestial tide, find ourselves in possession of almost all that can be obtained in a general view. This last part of the subject is, however, an exceedingly complicated one, and one upon which our information is very limited, and very imperfect so far as it goes, so that a sort of general notion of it is all that we can attempt, and we may fail even in that. It will, however, form the subject of the next section, and consequently this one will be reduced to the consideration of three principal points. First, the annual march of the sun's radius vector, and the solar tide; secondly, the monthly march of the moon's radius vector, and the lunar tide; and thirdly, those approaches, coincidences, separations, and oppositions of the two, which vary the tides both seasonally and monthly.

First, the annual variations of the solar tide. As the axis of the spheroid of tide is constant to the radius vector, though always a little eastward or behind it in longitude, for the reason which has been stated, and as this axis also passes through the centre of the earth, it is evident that the poles will always have the same declination as that of the sun, or travel along the same parallel over which the sun is vertical at noon; taken for an entire day, the sun's path is not exactly on a parallel, but shifts with an increase or lessening of declination during the day,—the details of which will be found in our volume "THE EARTH," or in any work in which the apparent motions of the sun are described. At the equinoxes, both solar tides will be on the equator; at the northern tropic, answering to our midsummer, the greatest height of the upper tide of the sun will be on the northern tropic of the earth, and the greatest height of under tides on the southern tropic; and as they will travel round in twenty-four hours, the same as when the sun is on the equator, and also be on opposite meridians, or 180° distant in longitude, they will be twice 23½°, or 47° of latitude apart from each other. This state of things will be exactly reversed at midwinter, as the upper tide will then be on the southern tropic, and the under tide in the northern. But the effect will be the same, though happening at opposite times of the day.

The annual variation of the tide, or, more strictly speaking, of the celestial cause of tide, as depending on the sun, is therefore briefly this:—If we begin the year at the winter tropic, or a little after, so as to have the maximum effect of tropical modification there, in which we shall not be very far from the truth if we take the first of January, the solar action at this time parts the tidal waters into the two hemispheres, or sends the high-waters to the greatest distance from the equator. As spring advances, and the southern declination of the sun diminishes, the two high-waters approach each other, each by a difference of latitude equal to the decrease of declination. This goes on till the vernal equinox, very slowly at first, but increasing as the equinox is approached, and then coinciding on the equator. This is an accumulation of the waters of the sea into the middle latitudes, and a withdrawal of them from polar regions. The time of maximum effect here, also, will be after the absolute time of the equinox; and as the change in declination is more rapid than at the tropic, the maximum effect will be proportionally later than at that time. In the second quarter of the year, answering pretty nearly to the months of April, May, and June, the two high-waters will again separate, at nearly the reverse of the rate of their approaching each other in the first quarter; and the only difference between the modification of the waters at the end of the first half of the year and the beginning will be, that the upper tide will be the northern one during the summer, and the southern one during the winter. The remaining half of the year is an exactly symmetrical counterpart of this—that is, it is carried on at the same rate, and to the same extent, as this one, only apparently in the opposite direction, the declination of the sun being to the south, whereas during the first half of the year it is to the north.

It is easy to see that the result of this action upon a globe with its surface covered by water, uniformly deep, would be an accumulating of the waters in the regions of the equator at the spring and autumnal equinoxes, and a more uniform distribution of them over the general surface at the summer and winter tropics. What difference in absolute measurement this would make it is unnecessary to calculate, because it could not be applied to the real state of the tides. But it is necessary to know that there is this annual variation in the cause of the solar tide, because, whatever may be the other circumstances which still farther modify the tides as actually observed, this must have some influence.

This collecting of the waters toward the equator at the time of the equinoxes, and distributing them into the hemispheres at the time of the solstices, co-operates with that movement of the comparatively fresh water at the poles into lower latitudes to which we alluded in a former section. This transfer of the ocean water does not amount to much elevation, unless where its progress is very much interrupted, and therefore it proceeds very slowly, so that, in all probability the surplus which is in this way sent northward at our winter solstice, and which in fact begins at the autumnal equinox, must take some time in performing its march; but that it contributes to the supply of autumnal water there is no doubt, though this water may not, in consequence of the waves of tide, and resulting currents, reach the extreme north till so late in the season as that it may assist in those spring storms which break up the ice; so, also, the withdrawal southward, the impulse to which begins to be given immediately after the winter's solstice is passed, does not, in all probability, take effect in the Arctic Seas until that time of the year when the icebergs begin to float southwards. Still it is not a little remarkable that, without any reference whatever to heat and cold, the seasonal influence of the sun, in mere gravitating action upon the ocean waters, should co-operate with the seasonal variations of temperature occasioned by that luminary, in bringing about the same results. This is a very striking proof that the system of nature is one, and that no two phenomena, however dissimilar in appearance, separated from each other in spaces, or distant in time, are without connection in themselves, and perfect knowledge from the beginning of that connection, by Him who ordained them.

Secondly, the monthly variations of tide, as depending on the moon. These, taking the simplest view of them, vary with the moon's declination in the same manner as the solar tides do with the declination of the sun; and as the moon performs the revolution in her orbit in about twenty-nine and a half days, the whole variations of declination, and consequently of position of the moon's radius vector on the earth, as depending on the moon's orbital motion only, will be gone through in that period, or in other words, in a lunar month. In this case, however, and before we can arrive even at a first approximation of the real position of the poles of the spheroid of lunar tide upon the surface of the earth, in respect of latitude alone, we must have recourse to some other elements.

The elements which we have to take into account, in order to obtain a first approximation here, are the real orbit of the earth, or its counterpart, the apparent annual path of the sun, and the motion of the moon in its own orbit. The latter answers to the month, and the former to the particular season of the year. The declination of the sun regulates the mean declination of the moon for a lunation; but the moon's own change in declination from the sun regulates the moon's real declination at particular periods of the month.

It will be borne in mind, that the obliquity of the earth's orbit, or measure of the greatest declination of the sun, is about 23½°, and that the change of declination is very slow near the tropics, and increases in quickness towards the equinoxes. Also that the orbit of the moon makes an angle of 5½° both ways with that of the earth, the nodes of the moon's orbit, or opposite points in which its plane intersects or crosses the plane of the earth's orbit, being the points of no declination, and thus answering in the lunar orbit to the equinoctial points in the terrestrial, which last are the nodes of the plane of the earth's orbit, as told on the plane of the earth's equator, or on any plane at right angles to the axis of the earth's rotation. The points of the moon's orbit intermediate between the nodes answer to the tropical points in the earth's orbit. So that, if we suppose a revolution, or month, of the moon to be begun when the moon is in the ascending node, or coming northward in declination, then the moon will, during the first quarter of her revolution, gain 5½° more north declination than the sun, which will bring the moon's radius vector to the same distance farther north than that of the sun. During the second quarter, the moon will return, and gain the descending node; so that at half the revolution the declination of the moon will be the same as that of the sun, and the radii vectores will fall on the same parallel. The remaining half of the lunation will be symmetrical to this, only it will lie the other way, or southward, while this lies northward. In the course of a month, therefore, the moon will make 11° difference of declination from north to south, and from south to north back again, independently of the general declination which the orbit makes during that period accompanying the change of declination in the sun. This motion will cause the poles of the spheroid of lunar tide to separate 11° from those of the solar, and again to close during the course of every lunation—that is, of every complete revolution of the moon, from one node of the orbit back again to the same. But this revolution may or may not correspond with the lunar month, as shown in the phases of the moon, according to circumstances. This is occasioned by the motion of the moon's nodes—that is, by the revolution of the moon's orbit upon its upper focus, the common centre of gravity of the earth and moon, which is completed in eighteen years and ten days. If the new moon is in or near one of the nodes, the full moon will be in or near the other, and the quarter moons will have the one 5½° more declination than the sun, and the other the same quantity less; if the new moon is at the maximum declination, the full moon will be at the maximum the other way, and the quarters will be the period when the sun and moon will have the same declination.

If the globe were uniformly covered with water, those disturbances occasioned by the differences of declination between the sun and moon would not be very great, because 5½° of the earth's circumference would, in that case, show very little difference in the height of water corresponding to either tide. Thus, it is not necessary for popular purposes to go into the details, or to notice the minor and more complicated causes of irregularity, but it is necessary to know something of their existence. It is the more necessary to do this that the effects of these disturbances are often much greater in consequence of their combination with the disturbances occasioned by the earth's surface than they would be if the earth were uniformly covered with water.

Thirdly, the joint effects of the solar and lunar tides. In order to understand the general result here, we are to bear in mind that, in the course of a moon—that is, from one new moon or conjunction to the next, which is very nearly twenty-nine days, twelve hours, forty-four minutes, and three seconds,—the radius vector of the moon makes a complete revolution of the lunar orbit, from coincidence with that of the sun to coincidence again, except as the declinations of the two bodies may be different at the times of new moon. From new moon to the first quarter, the angle formed by the two gradually opens to a right angle; from the first quarter to the opposition, or full moon, the angle increases still, till at the full moon it amounts to 180°, or a semicircle; and, unless for the difference of declination, the two radii vectores are in the same straight line on opposite sides of the earth. From full to the third quarter the angle which had opened out to the semicircle eastward continues to increase in that direction, and consequently to diminish westward, till, at the beginning of the fourth quarter, it is again at right angles to the radius vector of the sun; and during the fourth quarter the angle westward continues to close, and vanishes by coincidence at the next new moon, after which it begins to open again on the east. This state of things continues to be repeated every lunation, modified by the apparent annual motion of the sun, the motion of the moon, of the moon's orbit, and all the other minor causes of celestial disturbance. In consequence of these, the tides of every lunation are a little different from those of every other, until the lunar cycle of 223 lunations, or about eighteen years and ten days is completed, and then the next cycle goes on with very little difference. It is of no consequence from what particular new moon this cycle is begun, and it applies to all the phenomena of the moon as well as to the lunar tides, only there are many little corrections to be made when such accuracy is required as is necessary for practical astronomy, or for determining the longitudes, and general positions of places on the earth, from the times at which those lunar phenomena takes place.

When the sun and moon are on the same meridian, and have exactly the same declination, whether it be at new moon, and both on the same side of the earth and of the equator, or full moon, when they are on opposite sides of the earth and of the equator, their poles of high-water fall on the same points, and then, and then only, is the difference between the elevation and the depression the greatest possible, or seven feet,—five produced by the moon, and two by the sun. This rarely happens, however; and as from their different rates of daily motion the lunar tide gets behind the solar one in its westward progress, the high-water which results does not wholly follow either the one or the other, but occurs at some point intermediate between them. This, when mixed up with the changes in declination, causes considerable differences, both of the heights of tides and of the length of time between tide and tide at the same place. These variations are called the *priming* and *lagging* of the tides, the first name being given to their quickening, and the second to their falling back from the line at which they occur, after the moon's passage of the meridian, at the *spring tides*, at full, and change.

When the sun and moon are exactly 90° asunder in longitude, as counted on the earth, the high-water of the one falls on the low-water of the other, and the difference of elevation and depression is the least possible, the high-water at the same time following the moon more exactly than it does when the radii vectores make with each other an angle different from a right angle. It will be recollected that the centres of the four elevations formed by the two spheroids of tide are points, though the elevated mass of water is comparatively flat, and that the positions of low-water are circumferences, or go entirely round the earth; and this tends to make the general surface more uniform than if the high and low waters were surfaces of exactly the same kind.

A very little consideration will enable any one to see why the tides must prime and lag, or be accelerated in time of occurrence at certain periods of the lunar month and retarded at others; but as the subject of the tides altogether is one which is, we believe, not much studied by people generally,—deeply as a commercial nation is interested in it,—we shall state, in very brief outline, how this consideration is to be made. In doing this we shall not embarrass our view with any of the minor causes of inequality, even in the celestial influence, but merely hint that their existence must be borne in mind. They are principally the difference in decli nation between the sun and moon, the change in declination, during the interval between the tides, and the moon's distance from the earth, with the rate and nature of its variation during the same interval. It will be well, also, to bear in mind, that the more nearly the declinations of the luminaries are to being the same, the tide will be the more regular; and, the less change there is during the interval, the priming or lagging will be the less: and also, that as the resulting tide depends so much more upon the moon than upon the sun, that in all its states the tide, which is observed, must be considered as a lunar tide. This being the case, it necessarily follows, that the nearer the moon is to the earth, the more closely will the actual tide obey the moon; in other words, there will be less priming or lagging when the moon is in perigee, than when it is in apogee. The mean between these takes place when the moon is at the middle of the half of its orbit, or at the extremity of the shorter axis of its ellipse; and this is the state which we shall consider, it being the average of all the states.

At new and full moon it is evident that there can be no alteration in the time of the tide, because whatever may be the difference of their declinations, the two luminaries are then on the same meridian, and time, as measured by the earth's motions, always refers to the meridian. So also, when the moon has arrived at the quarters, or, as they are technically called, the quadratures, there can be no variation in the time of tide, because the high-water of one luminary, and the low-water of the other, are both on the same meridian; and the solar tides being exactly midway between the lunar tides on both sides of the earth, cannot possibly disturb them on the one hand any more than on the other. In this state of things, the tendencies of the sun to accelerate and to retard the lunar tides are exactly equal to each other; and, consequently, the tide hour must, at these times, be exactly the same as though there were no tide except that of the moon, just as is the case at new and full moon.

The hour at which high-water at new and full moon occurs at any port or place on the earth's surface, is called the *establishment of the port.* Diversified as the earth is by land and water, it is determinable only by observation for any particular place; but when once determined, it is understood to be invariable, unless where there are obvious causes why it should not. When we would rightly understand the tides at any port or harbour, so as to turn their motions to the best account for the purposes of navigation, this "establishment of the port" is the foundation of the whole, and cannot be too accurately determined. There are some corrections to apply to it, which we shall be better able to get some notion of afterwards, when we apply the general principle of the celestial causes of tide to the varied surface of the earth; but the reader will not fail to observe, that there is in this constancy of the establishment of the port,—that is, of the high-water at new and full moon invariably happening at the same time,—a complete proof, if such a proof were required, that the celestial theory of the tides is perfectly true, how much soever the time, direction, and amount of tide, at any particular place, may be changed by terrestrial causes.

We shall suppose, for the sake of simplicity, that the establishment of the port is twelve o'clock at noon. In this case the upper high-water of both hemispheres will make the noon spring tide at new moon, and the under high-water of both the high-water at midnight; while at full moon the amount will be the same, only the upper tide of each will coincide with the under tide of the other. In this state of things, low-water will be at six in the evening and six in the morning. At the end of the first quarter, the solar and lunar tides, being six hours apart every way, and the moon having made exactly a quadrant, or six hours, eastward, or in the direction of the left hand from the sun, the high-water will be at six in the evening, and the next at six in the morning; twelve midnight, and twelve noon, being the times of low-water.

From new moon to the end of the first quarter, the solar tide is really separating from the lunar one, by getting westward of it; but as the solar tide is not seen separately, the lunar tide appears to get eastward from the position of the sun, until it gains an angle of 90°, or six hours, at the end of the quarter. Let us consider what has to be done by the two influences, which were in union at the new moon, but are now directly opposed to each other, in as far as the raising of tides are concerned; and in this we shall discover why, during this first quarter, tides should prime, that is, not got so fast eastward in time, as the moon does; and if we are able to see this for the first quarter of the new moon, it is easy to understand that it will apply for the first quarter after full moon, or third quarter of the lunation, because the circumstances of tide, at the beginning and end of these two quarters, are exactly the same; and the difference between them must consequently be brought about in exactly the same manner, and during the same time. This, by the way, is a general principle worth attending to in all matters, and may be expressed in these words: If, upon two different occasions, the same cause produces exactly the same effect in the same time, the operation of that cause has been the same in both; and if the same cause is made to act with the same energy, during exactly equal times, it must produce exactly the same effect in each of them. This, simple as it appears, is the foundation of all reasoning, and the law of all action, whether we consider the end from the beginning or not. But to return to our particular case.

At the spring-tide of new moon, the two tides are united into one spheroid; and the process which has to be performed during the quarter is, to break down this spheroid into two parts which, at the end of the quarter, shall have the axes of their elongations, or separate heights of tide, at right angles to, or directly across, each other. Now, as water has weight or gravitation, as the parts of it have some attraction for each other, and as their motion is attended with some friction or rubbing against each other, this weight, this attraction, and this friction, cannot be got the better of without some labour, or the exertion of some force; and as this force has the work of breaking down the one spheroid of spring-tide into the two which occasion neap-tide to perform, it must have some time to perform it in. As the radii vectores separate in angular distance, the accumulated water will, as it were, lay hold of and exhaust a certain portion of the energy which has the direction of each; and though the superior influence of the moon will keep the resultant high-water at no great distance from the radius vector of that luminary, the effort required for separating the two spheroids will keep this resultant high-water at some distance to the westward of the moon; and doing so, the high-water must be before the moon in point of time.

If this happens in consequence of the force necessary for breaking down the spheroid of spring-tide of new moon, it must do the same in breaking down that of full moon; and therefore, at corresponding periods of the third quarter, the tide must be just as much in advance of the moon in time as it is during the first quarter. It would be foreign to our purpose to go into the investigation of how much the tide would be in advance; and, indeed, no single investigation can reach the whole case, as it cannot embrace all the inequalities; but we shall state the average as given in WHEWELL's admirable paper on co-tidal lines, read at the Royal Society, May 2, 1833.

We have taken the establishment of the port at twelve o'clock; and in this case, when the moon gets 15°, or one hour, eastward of the sun, and the undisturbed lunar high-water would be at one o'clock, the solar-tide holds it westward for a distance answering to sixteen minutes; so that, instead of at one, it is high-water sixteen minutes before one. When the moon has made two hours of easting, and the undisturbed high-water would happen at two o'clock, there is fifteen minutes in time of additional deflection westward by the solar-tide, and the time of high-water is thirty-one minutes before two, or nearly half-past one instead of being at two. When the moon has made three hours of easting, and the undisturbed tide would be at three, there are ten minutes more of deflection westward by the sun, and the high-water, instead of being at three, is at forty-one minutes before three, or nineteen minutes after two. When the moon has made four hours' easting, there is a farther deflection westward of three minutes, and the high-water which, if undisturbed, would take place at four, takes place forty-four minutes before four, or sixteen minutes after three.

From the times which we have stated, and which may be taken as measures of the sun's disturbance or of the force necessary to break down the spheroid, it will be seen that this is greatest at the commencement,—being sixteen minutes for the first hour, fifteen for the second, ten for the third, and three for the fourth,—in all forty-four.

At or near the fourth hour in angular easting of the moon, the moon's hold on the tide, which has been gradually gaining upon the sun's in the proportion which we have stated, has acquired so much the mastery, that it, as it were, shakes itself free from the trammel of the solar disturbance, and starts eastward; for, at the fifth hour of easting, the disturbance westward is thirteen minutes less than at the fourth hour, and the high-water, which would be at five in an undisturbed tide, is at thirty-one minutes before five; at the sixth hour of angular distance eastward, which is the quarter, or neap, or total separation of the spheroids, the tide starts eastward with still greater velocity, for the high-water now occurs at six; and thus, during the last hour's angular distance, the tide gains thirty-one minutes of easting, and consequently falls back as much in observed time.

One hour's angular distance of the moon answers to about two days and a quarter, which is the average length of period answering to the times of tide as we have stated them; and of course in all the tides which occur during this period, the interval between high-water and high-water will keep lengthening from beginning to end.

Such is the cause why the tide happens earlier in solar time during the first quarter, and why the interval between high-water and high-water gradually increases toward the end of that quarter. Exactly the same series is followed in the third quarter; and the real cause is the force necessary for separating the two spheroids, or breaking the joint one which forms the spring-tide, into the two which, applied reversedly upon each other, occasion the neap-tide; and it will be seen that the effort necessary for this purpose is greatest at the commencement, and diminishes in the proportion of the minutes as above stated. The separation of the one tide from the other has thus some resemblance to the motion of a heavy body descending a slope, for the lunar influence increases in power just as such a body increases in velocity; and upon the same principle that the body acquires a velocity in the descent which is sufficient to carry it some distance up an opposite ascent (as any one may see in a carriage descending one slope and ascending another), the moon's energy acquires a momentum during this quarter which enables it to do some extra labour during the next one. Let us next see what labour it has to perform.

The spheroid of spring-tide was complete at the new moon; the parts of it have been separated during the first quarter; it must be completed again at the full moon, or end of the second quarter; and the labour of putting it together is what has to be performed during this second quarter. The qualities of the water remain exactly the same as in the former case; and, in average tides, a spheroid has to be found, during the second quarter, exactly similar to that which was separated during the first. Thus, there is precisely the same quantity of labour to be performed as in the former case, only it is reversed, and each hour of angular distance will be exactly the reverse of the former, counting from the neap-tide, or the same counting *to* the spring, as it was counting *from* it in the first quarter. When the moon gains seven hours of easting, and the tide would be at seven, the acquired velocity carries it eastward to thirty-one minutes past seven; when the easting is eight, the time is forty-four minutes past eight; when the easting is nine, the tide is forty-one minutes past nine; when the easting is ten, the tide is thirty-one minutes past ten; when the easting is eleven, the tide is sixteen minutes past eleven; and when the easting is twelve, which is the north, the opposition, or the full moon, and as such the completing of the spheroid again, the high-water of tide is at twelve, exactly as it was at the spring-tide of new moon.

We need not repeat the details, for any one can see that they are exactly the reverse of these of the preceding quarter; and as little need we follow the variations of the tides from the full moon up to the next new moon; because the circumstances of that new moon, considering them as average, are precisely the same as those with which we started. Here again, there is a very general principle which we may pick up by the way, as it is useful on many occasions. It is this—if any change is produced by any cause, and if by the operation of the same cause that which was changed is brought back again to exactly its original state, then the second branch of the operation of the cause must be exactly a reversal of the first branch; and conversely, if all the change which has been produced is exactly reversed, that which underwent the change must be brought back to exactly its original state.

This view of the causes of the accelerating and retarding of the tides in time during the different portions of a lunation, is a matter worthy of being well understood, because it will act as a key to many of the apparently conflicting and contradictory phenomena of the tides which result from the terrestrial disturbances. It will be perceived that though this tells upon the tide as produced by the moon, its real cause is not in anything connected with that luminary, but depends entirely upon the effort which is necessary to produce a change of form in the oceanic waters; and that it is not a property of the ocean considered as the great collection of waters, but simply of water itself as a substance; consequently it must apply to every case in which two portions of water, or two disturbing influences, acting on the same portion, tend to produce a tide, a wave, or any other fluctuating motion. Now, every disturbance of the sea, whether tide, waves during the storm, seasonal transfer of water, or whatever else it may be, which alternates, or is high at one time and low at another, must act upon this principle, in as far as water considered as a substance is concerned. So that, if we understand this thoroughly, the remaining part of our inquiry will be narrowed to an investigation of the causes themselves by which the disturbances are produced; and this will assist us greatly in our rapid glance at the very complicated phenomena of the tides as they actually occur.

If the greatest or the least influence of the two bodies takes place when both luminaries are on the equator, and the tidal waters of both collected to that parallel, the tides will be greater than at other times in the case of coincidence, and smaller in the case of opposition; and in proportion as the average declination of the two is greater, and the upper and under tides separated farther into the opposite hemispheres, the resulting tide at any one parallel will be less.

Such, in brief outline, would be the state of the tides if there were nothing in the physical condition of the globe itself to disturb the celestial action; and all this would take place in that solemn and silent manner in which the whole workings of the system of the heavens is carried on; and though the changes of surface in the ocean waters would be incessant and diversified, yet there would not be one ripple or dimple over the whole extent of it; but the whole, under perfect subjection to the opposing influences of celestial and terrestrial gravitation, would lie more smooth and glassy than the most sheltered pool, when not even the most delicate spider's thread could detect a breath of the air over it; and were it possible for an observer to be launched on the surface of such a globe, and to float on the waters, he would have no more feeling or perception of the motion of the tides than a dweller upon the earth has of its compound motion on its axis and in its orbit.

This is a very beautiful confirmation, both of the truth of those laws which have been discovered as regulating the grand motions of the universe, and of the perfect unity and simplicity, and consequently the vast sublimity, of this mighty structure. The most distant or the most voluminous planet, the careering comet, the revolving system, the attendant planets which encircle every star which sparkles in the nocturnal sky,—all those systems, and the combination extended to a magnitude which no line of the imagination can measure, and no plummet of the fancy can sound, are one, and their Maker and Governor is one. This is the temple which the Almighty has of his good pleasure builded as a subject of admiration, and delight, and instruction, to all his rational creatures; and such being the case, how shall they, how can they, escape his just displeasure if they come not hither sincerely to worship and reverendly to adore!

This sublimely tranquil state of things is very different from the phenomena of the sea as they present themselves to us, not only at different places, but at the same places on successive days and hours, and even minutes; for it would take a long enumeration to describe the states of even a single mile of the surface for the lapse of a very short period of time, and this not only from the effects of winds, regular or periodical, steady or variable, the discharges of rivers, and the formations and meltings of ice, but even with regard to the height, the succession, and time of the tides, and the directions in which the alternations of high and low water make their voyages upon the seas and along the shores.

But, notwithstanding all this, every description of tide is either directly or resultingly the effect of those attractions of the heavenly bodies; and all the departures from those laws of celestial motion which have been hinted at, are occasioned by obstacles opposed to the natural forms which the oceanic waters would successively assume in consequence of the operation of those laws; and if it were possible to understand the nature of those obstacles, and of the oppositions which they present, with the same clearness that we can understand the varying influences of the moon and the sun upon the waters, the whole tidal phenomena of the ocean would become as simple, and seem as perfectly consistent with the general laws of the universe, as any one part of the system of the heavens. But those obstacles, as arising from the opposition of the land, from that of the varying depth and character of the ocean's bed, from the mechanical structure of the water itself, from the friction of its parts upon each other, and from the influence of the atmosphere upon it in evaporating, and in the endless variety of power and direction in the winds,—a subject is presented to us in the mere motions of the sea-water, even the tidal ones, which all our observation, and all our comparison and reasoning, can never hope to exhaust. For though the human race should remain upon the earth for millions of years, and the observation of facts, and the philosophical induction of principle from those facts, should increase at the same rapid rate at which it has increased with the present and two or three of the immediately preceding generations, the sea would remain, in great part, an unexplored marvel at the conclusion of that long period of time.

Still, it is satisfactory to feel convinced that we have the truth of some of the principles established upon evidence which is as extensive as the universe itself; and that, building upon this foundation, the smallest discovery which is accurately made, and the smallest deduction which is legitimately drawn, is something added to the volume of genuine science, and may be made the instrument of further additions. This is the grand triumph of the pursuit of knowledge over all other pursuits, that every addition, however small, is a productive seed, and every step that can be taken is an ascending one, in consequence of which the view is enlarged. But pleasing, and not unprofitable, as these reflections on the delights of the path of knowledge are, we must leave them, and return to our more immediate and more humble avocation.

SECTION VII.

TERRESTRIAL DISTURBANCES OF THE TIDES.

THE view which we have endeavoured to give of the action of the sun and moon in producing tides in the waters of the ocean, and in varying and modifying those tides monthly and seasonally, is absolutely necessary to a clear understanding of these most important phenomena of the sea, though the tides themselves, as actually observed, are very different from what this theoretical view would lead us to suppose. But still the influence of those luminaries is the primary cause of every tidal motion which takes place in any part of the sea, how much soever the effect may be modified by circumstances connected with the earth. Except the different gravitating influence of one or both of those luminaries upon different parts of the earth's surface, we are not aware of any cause sufficiently powerful for disturbing the general mass of the ocean waters; though there are many circumstances which tend very much to change the apparent action of those causes.

We have mentioned that the tide in itself is not a circulating motion of the waters, at a rate which is even an assignable fraction of that at which the tide-wave apparently travels westward,—though, even if there were no interruption, it is possible that there might be a slight transfer of the water westward. When, however, we turn our attention to the form of the lands by which the tide-wave is interrupted — the various breadths of sea through which it has to pass—the numerous banks and shallows which diversify the bottom—the currents of the atmosphere upon the surface—and the water discharged by the larger rivers,—we can easily understand how much the actual results must differ from what would take place if the tide-wave rolled on, without interruption, wholly under the influence of the celestial bodies. Water has friction, not only against the banks and bottom, but against the air, and different parts of water have friction against each other. To convince ourselves of this, we have only to examine any brook or river, or any other portion of water which has motion; and if the current is at all perceptible, then how apparently smooth and even soever the channel may be, the water will be found running in many directions in the different parts, although the whole mass of it be moving in one direction. A current of this kind is indeed a useful study, and helps one to generalize the nature of those greater operations of which a very small portion only can be seen at any one time, or in any one place.

Even if the water-course is a canal with a smooth bottom and perpendicular banks, or a trough made of the most polished materials possible, it will be found that the current does not run with the same velocity in every part of the section taken across it. If the canal is of such length as that the water has time to assume its own motion, and is not affected by that at the inlet, it will be found that the very middle of the upper part of the water moves fastest, and that the motion gets slower and slower towards the sides, and also toward the bottom.

The differences of rate in the several parts depends on many circumstances—such as the proportion which the depth bears to the breadth, the velocity of the whole current, the texture of the banks and bottom, and several other particulars, which are matters of observation for every individual case,—so that they cannot be very easily reduced to one single principle; nor is such a principle necessary for our purpose, as it is sufficient to know that, even in this the very simplest case of moving water, the parts nearest the sides and bottom move more slowly than those most distant. Indeed, in every natural channel, there may be said to be a thin film of water which has no motion at all, namely, that which wets the banks and bottom, and does not run out, even when the channel is allowed to be emptied, but remains, and is got rid of only by evaporation. What portion this may be, in any particular case, depends on the circumstances of that case, and is greatest of course where the banks and bottom incorporate the most with water; and if water were made to run in an oiled channel, or any other kind of channel which it could not wet, it would flow more uniformly, and therefore, in its whole volume, more rapidly. Upon this principle, it is desirable that the insides of the bores of pipes in which water is conveyed should be as smooth as possible, because, the smoother they are, the smaller force will propel the same volume of water through them in an equal time.

From this fact of the banks and bottom laying hold of the water immediately in contact with them, and keeping it stationary, it is evident that the water must have all sorts of velocities, between the maximum of the current and absolute rest in that portion which wets the banks and bottom, though how much this may diminish the velocity of the whole is matter of observation for the particular case. It is very probable, too, that, under most circumstances, the wetting of the banks may facilitate, rather than impede, the general current, inasmuch as it resolves the motion into water sliding upon water, and not water rubbing directly against a hard substance. Instances of this last operation occur when streams and rivers cut into their banks, and when the sea encroaches upon the coasts of the land; and as in these cases it is invariably the solid which yields to the liquid, and often yields in wide-spreading ruin and devastation, we may not only learn that there is great power in the motion of water, but we can see that, were it not for this adhesion of a certain portion of the water, upon which the rest slides along with a more easy flow, the waters, which have so much the advantage of the land in respect of surface, would have equally the advantage of it in respect of power, and it would be continually torn to pieces. It would be very desirable, if our limits permitted, to notice some of the inroads which are making by the sea upon the land, even in the British Islands; but, in the meantime, it is sufficient for our present purpose to know, that there is such a principle of adhesion between water and the banks and bottoms containing it as that they cannot be separated without considerable exertion of force; and that, as the banks and bottom are quite passive in this matter, the force necessary for this purpose is wholly derived from the destruction, or rather the transfer, of a portion of the force of the moving water.

It is obvious that the motion of a tide wave, in so far as that wave is a transfer of water, must be affected by bottoms and banks upon exactly the same principles as the current of a river is affected by them; and here again, by examining the circumstances of the river, which we can get under our observation at one view, we shall be able to form a correct notion of what takes place with regard to the sea, the parts of which are too wide asunder for coming within the range of one horizon. If there is a bank, a stone, or any obstacle to the current of the water, whether that obstacle rises above the surface or not, we always find a disturbance and disruption of the water at the upper part of the obstacle, and a closing again when it is passed; and if the breadth of the obstacle is considerable, there is a eddy formed at the under part or tail of it, where the water has a circulating motion, and where it deposits mud and gravel, so that the bank, if once begun, augments by the mere action of the water. In the sea, the case must be exactly the same, only on a larger scale; and if one island, bank, or other obstacle is placed in the channel through which a tide or current has to pass, such an obstacle will, in proportion to its length, double the friction by presenting four banks instead of two to the water. Every additional island will, in proportion to its size, again offer two banks; and therefore the retarding of tides or currents, by means of clusters of islands or banks, must be very much greater than if all the little channels between them were united into one free channel of a section equal to the whole. This is the reason why tides are often so very different, in height nd time of occurrence, upon opposite sides of clusters of islands, which seem so small that they might at first sight be expected to offer but little resistance.

If one watches the current of a stream as it sets against shores of different forms, one can judge of the kind of opposition which different forms of coast will offer to the motion of the oceanic waters, whether in tide or in current. A projecting point turned toward the current will of course divide it in two,—as, for instance, if the current of the Atlantic, a little south of the equator, is westward, one part of it will be turned northward in the direction of the West India Islands, and the other southward along the shore of Brazil.

If the current is directed against a coast which lies nearly across it, it will still be divided into two parts, or have a point of divergence somewhere on the side toward the current. Thus, New Holland offers, on its eastern shore, about two thousand miles of an uninterrupted line, lying pretty nearly on the meridian, and thus opposed to the tide wave of the Pacific. Accordingly, the current is divided somewhere near Break-sea Spit, about latitude 25° south; but as extensive reefs trend away north-eastward from this point, the north-east current,—that is, the current which flows northward,—is very much broken and interrupted.

If the current is directed against a bay, or creek, at the head of which there is no outlet, it will adapt itself in so far to the form of the bay; for the friction of the shores, and the greater shallowness of the water there, will, as it were, lay hold of it at both extremities, and though it meets both sides of the entrance of the bay at the same instant of time, it will bend inward at the middle, get a greater momentum there than the average, and thus the water will rise higher at the head of such a bay than in the open sea. The additional height to which it will rise in this manner depends of course upon the original force of the current, and the nature of the opposition with which it meets; but it may be very considerable, and, by actual observation, it is found to rise in the Bay of Fundi to nearly ten times the height which could be produced by the united action of the luminaries upon a globe uniformly covered with water. This, which is perhaps the highest rise of tide any where known, shows pretty clearly how powerful the disturbing influence of the earth must be, since the fact of the revolving current of the Atlantic being taken in the nook, formed by the projecting peninsula of Nova Scotia, produces a result ten times as great as could be done by the maximum influence of the sun and moon jointly.

In the case of a channel parting two lands from each other, the waves of tides, or currents, will take a bend forward in the middle, in the same manner as in the case of a bay, only, if the mid-channel is clear, the current will lag more in the irregularities of the shores, and proceed more regularly in the channel. If there is a bend in the course of the channel, and the tide, or current, sets in at one end, it will ultimately be thrown against the bight, and an eddy, or reversal of the current in part, will be formed on the other side; and, just as is observed in rivers, the shore against which the current sets will be the one which it wears away, and the place of the eddy will be that where the rubbish is formed into a bank.

It would occupy too much space, to trace all the varieties of effect resulting from the different ways in which coasts, and islands, and banks, turn the direction of currents, whether of river-stream, of ocean-current, or of tide-wave; but as they all depend upon the properties of the same liquid water, any one who chooses to study a river, or even a little brook, may understand the general principle more thoroughly than he could do by reading a hundred volumes of attempted description of it.

We may mention farther, however, that every opposition which a wave, or any other portion of water, in motion, meets with, must destroy part of the velocity of the moving water, whether its motion be a progressive one, or an alternate elevation and depression. We can observe this in cases where the interruption does not reach the surface,—as in the breakers on submerged banks and rocks, which, though they may be so far influenced by the wind, yet do not wholly depend upon it; but the waves, as they swing upon their centres of oscillation, literally thrash the bottoms of the shallows at every descent; and this is the chief cause of the turmoil and breaking which occur in such places.

So also, if we were to suppose the tide wave, as produced by the heavenly bodies, to come in its unbroken and silent march across an entire hemisphere of water, and then to be opposed by a long coast of land, it is pretty evident that it would rise higher against that coast than it would do if it passed on without interruption. This is merely a modification of the cause which we mentioned as producing so very high tides in land-locked bays; but it is worthy of notice. The land, if extensive, stops the momentum of the water, and the tide wave runs up, so to speak, against the shore, just as water poured forcibly into one end of a trough runs over the opposite end, or as a swift-running torrent will contrive to run some distance up hill. There is a torrent of this description in the north-east of Ireland, which comes down with so much velocity upon one slope, that it runs up a short one opposite without stopping; and though it has been facetiously said, that this running up hill is an Irish trick in this particular rivulet, yet the water even of Holland, dull and sluggish as it is in its own oozy channels, would conduct itself exactly in the same manner, if brought to the same place.

We need hardly mention, that if, by the momentum which it has acquired, the water of the tide wave rise higher than it would by the mere gravitation of the luminaries, it must sink proportionally lower in the alternations; and that this will apply to tides, currents, waves, and all other motions of the sea having periodical fluctuations. This is still merely one result of that very general principle in natural action by means of which an excess of action the one way involves in itself the elements of a return in the other, and which constitutes so much of the beauty of Nature's working, though it is one which beginners in the study are somewhat puzzled with. In our volume of The Heavens we endeavoured to explain this in as popular a manner as we could, as it applies to the orbital motion of a planet; and this case of the sea wave, whether of tide, or of any thing else, is exactly parallel in principle. The momentum which the tidal water acquires by being borne up by the shore against which it rises, grows upon it during the rise; and the velocity which it acquires carries it beyond the height at which it would arrive if it were raised out of an uninterrupted mass of water by the action of the luminary. But as the radius vector travels onwards, and the luminary lets go its hold upon this portion of the water, the excess of elevation which it has gained re-acts in producing the descent; and as this re-action is measured by the excess of elevation, the depression below the mean surface which it occasions corresponds exactly in quantity of water to the previous elevation above that level. What proportion the absolute height of the ridge of the wave may bear to the depression of the trough, must depend upon the breadth of the wave; but the absolute vibration, whether it be performed in longer time or in shorter, is always in the exact proportion of the force of the agitated water, and performed on the centre of oscillation in the vibrating mass.

In so far as the mere action of the luminaries, and the power of the shore of the land to increase the elevation of wave, or tide, are concerned, it is the same on the west side of a country as on the east side; because the attraction of the luminary always has its centre in the point where its radius vector meets the surface of the earth, and thus the disturbance of the water is the same at equal distances all around this point. The currents of the water, produced by the opposition that it meets with in those absolute motions which are given to it by the constant or the long periodical winds, may, however, occasion considerable differences in the tides on the different sides of a continent; but it requires a careful examination of the positions of the coasts, and a full knowledge of the sea, and the currents at the particular season, to determine even the average of those variations.

There is another circumstance, in addition to the interruption of the tidal wave, which tends to accumulate the waters round the margins of the land, especially when the land is much elevated. This is the local attraction, and perhaps, also, a little attraction of a capillary character; but though there is no doubt that this exists, we have no means of ascertaining its amount in any one particular case. Indeed, the sea, taken altogether, is so vast a subject, and our local observation can extend so short a distance over it, that almost all we can do is to hint at the principles, without saying any thing about the effects, which must be left to local observation; and, indeed, it is in a great measure from this kind of observation, guided by the general laws of equilibrium and motion in fluids, that we arrive at the principles themselves.

In all our investigations of the surface phenomena of the sea, we must have reference to the atmosphere. Though air is so much lighter a body than water, there is very considerable friction between them, arising partly from the nature of the substances themselves, and partly from the fact of seven-tenths of the whole volume of the atmosphere being supported by the surface of the sea.

The first of these will readily be understood, when we reflect on the great and constant power which the air has of raising water from the sea by evaporation. This, so to speak, must make their surfaces, as it were, dove-tailed into each other, and give them a much more forcible hold upon each other than if the air merely rested on the surface of the water, without any of this compenetration, or actual mixing of the substance of the one with that of the other.

The pressure is, however, considerable, as the mean level of the sea is that from which we estimate the weight of the atmosphere, and must be taken at the rate of sixteen pounds on the inch, or thereabouts. It is true, that the air is a very yielding substance; but it gives way in consequence of its elasticity, and consequently, the rebound, or re-action of this elasticity is exactly equal to the yielding; and therefore, whether the surface of the sea is smooth, or the ridge, or the trough of a wave, the mean pressure of the air upon it may be considered as almost the same in all states of the water's surface. This great atmospheric pressure, under which the sea works, may be regarded as a very essential element of its effective working; and if the atmospheric pressure were by any means destroyed, the whole would be thrown into confusion,—the water would be so brittle, so to speak,—that is, so easily splashed into drops and broken fragments,—that it is very doubtful whether it could be rendered available for any purpose, either of nature or of art; and it is highly probable that, if it were not for the pressure of the atmosphere, the waters of the ocean might not be able to retain their place on the surface of our globe, but might be dissipated through the regions of space, and the earth might—as seems to be the case with the moon—become a sapless and unprofitable thing amid the works of creation.

In truth, there is something very wonderful in the reciprocal action of the air and the sea. The air takes up from the sea a sufficient supply of water for the wants of the growing and living world, by means of that surface intercourse upon which evaporation is founded; and yet, at the same time, the weight or pressure of the air tends to keep down the great body of the sea-water, and restrain the violence of the ocean billows; so that, while the air gives wings to the ship, it keeps steady the volume of the hull in the water, upon which, as a fulcrum resistance, those aërial wings are enabled to act. This is a wonderful adaptation, and it is as useful as it is wondrous; nor can we view, but with feelings of the highest admiration and of the most sincere gratitude, those instances of perfect adaptation of instrument and purpose which force themselves upon us at every time when we pause to view the working of the system of nature. No matter how small, or how great, how momentary, or how enduring, the impress of the Almighty is stamped upon all that he has made, in characters so legible that they who run may read, and with applications so benignant that they who read can scarcely fail to understand, and to adore.

If we were to suppose a current of the atmosphere sweeping over the unruffled surface of the sea, we could not readily suppose that the action of the atmosphere would have any effect in transferring the water from one place to another. But when we consider to what an extent difference of temperature tells upon the air,—in increasing its volume by greater heat, and by diminishing it by greater cold,—and how little the water of the sea has its volume increased or diminished by the same means, we cannot fail to perceive that, in this difference of constitution and obedience to the action of heat, there is a provision made for the continual agitation of the one by means of the other. The least increase of the temperature in the air at one place causes an elevation of the sea at the same, and the least diminution of temperature causes a depression. By these means, the level—that is, the uniform spheroidal shape of the surface—is disturbed, and those motions of the air, which are inseparable from differences of temperature in different parts of that all-obedient substance, press upon the inclined planes which are thus produced, and throw the surface into vibrations. Both substances are fluid; but the far greater motion which the air has when the heat acts upon it than the water, prevents them from being, for almost any measurable length of time, in the same relative state with regard to each other, and thus a disturbance is produced at the surface where they meet each other, which soon breaks that surface into waves. It is of no consequence whether the breaking is occasioned by the moving of air over the still water, of water under the quiescent air, or of motions of the two in opposite directions, or with unequal velocities, so that there is a difference in the rate at which the two move. While the surface of the water remains glassy, and the under surface of the air is equally smooth, if we except that hold which they have of each other, there is no cause of disturbance; but the instant that a perfectly uniform surface is departed from, and either of them is in motion with regard to the other, the water presents an inclined plane to the air, and the motion acts upon this plane, so that the surface of the water is thrown into waves, which waves, independently altogether of the hold which the two surfaces take on each other, cause a simultaneous play of the air in similar waves. Thus, if we suppose a length of about thirty-nine inches of a wave to be vibrating, every foot in length of it will have to overcome a pressure of the air amounting to between three and four tons, or rather more than ten tons in the square yard; so that, easily as it appears to us that they are raised, waves are the result of no common effort, nor need we wonder that our stoutest ships should rock on them more lightly than a twig, a leaf, or a little bird, rocks in the wind. As little need we wonder at the force with which those waves impinge against obstacles, or the havoc which they occasionally commit, for even a moderate one is armed with more power than our fables were in the habit of ascribing to a giant; and though still air and placid water are among the most gentle things in nature, yet, when the sea is once lashed into billows, there is a power excited in the surface of it utterly beyond our powers of calculation; and this power consists not only in the weight of water which is moved and the rate of its motion, but in the great weight of air which has to be upraised by every swell, which descends into every hollow, and which, in the case of a large wave, is much greater than the weight of the most goodly ship which we can launch upon the waters.

This hold which the sea and the air reciprocally take on each other is well worthy our attention; and we can easily perceive that, by means of it, if the wind shall blow strongly and long, the surface of even a large ocean may be deflected from its level, because the pressure of the air acts as a fulcrum to its impulsive motion upon the windward sides of the waves. This is of great advantage in the transferring of the ocean waters from one region to another; and there is no doubt that to this power which the air has of moving the sea, the purity—the absence of stagnation and corruption—for which the sea is so remarkable, are in some measure owing.

Nor is it unworthy of remark, that in this mutual action of air and sea we have something very analogous to what we meet with in our own simple machinery. When we wish substances that naturally have much friction on each other to move smoothly and easily, we are in the habit of greasing their working surfaces, or covering them with black lead, or something else which is calculated to take off the friction; and, as if to point out to us how beneficial water is in contributing to motion generally, we very often find that water contributes greatly to diminish this friction between one solid and another, great as its comparative friction on the air is. But if we interpose ever so thin a pellicle of oil,—that is, of any of the fat oils which are not easily evaporated,—between the air and the water, it is astonishing to what extent it will diminish the friction, and take off the agitation of their surfaces. Oil, when put upon the surface of the sea in the manner which has been stated, has of course no effect whatever upon the simple elevation of the tide wave as occasioned by the difference of gravitation; but its effect in preventing the small waves from curling and breaking, and even from rising, is much greater than one who has not witnessed it would be apt to suppose. Nor is it unworthy of remark, that there seems to be a purpose in even this effect of oil upon the surface of sea-water. The oil which has this effect is of course lighter than water, and it belongs to that class of substances which the water does not wet, and which, therefore, have not that tendency to come on shore, to which we have had frequent occasion to allude, as being common to all dead and wettable substances which float on the sea. This oil is contained in very large quantity in the bodies of many sea animals, to which it serves as a protection against the cold temperature of the water, and it answers other purposes in their economy. This oil is, in all probability, produced most abundantly in the high latitudes, and descends into the middle latitudes along with the waters in their seasonal transfer. In this way it tends not a little to mitigate the violence of sea storms, or, at all events, the turbulence of the broken water which these would occasion: and, as it appears to be somewhat seasonal in its distribution, it probably has more influence in regulating the seasonal evaporation from the sea than we are aware of. But, even in the case of it, there is a provision that the quantity, though regularly supplied, shall not exceed a certain amount, the measure of which we do not know, but which we may safely conclude is the one best adapted to the working of the system. There are many birds which subsist in a great measure upon this oil, even when it is floating in so small a quantity as not to be discernible from a ship's deck. The storm petrels, (*Thalassidroma*—careerers over the sea,) which are found, perhaps, more seaward than any birds, except some of the long-winged fishing ones, subsist in a great measure upon this oil. They do not take it up immediately with their bills, for it is too thinly spread for admitting of this, but the feathers on their breasts are of a peculiar texture, difficult to be wetted with water, but very easily so with oil; and thus, as they swim along, or skim the surface, partially immersed in the water, they gather the oil upon their feathers, and remove it with the bill while they are at rest upon the waves. The quantity of oil which, from their numbers, these birds must collect is very considerable; for, though they are small birds, not much larger than swallows, one will sometimes, when alighting upon ships, which they are apt to do when beaten about by long-continued storms, discharge half a pint of oil or more from its stomach. It is partly from the absence of this oil, and partly from the less specific gravity of the water, that fresh water waves break more readily, and are altogether more turbulent, than sea waves; and it is partly, perhaps, for the first of these reasons that sea waves over clear bottoms are understood to break more than when the bottom is foul. There are many characters, however, connected with waves as they appear in different latitudes, at different seasons of the year, and in different states of the weather, respecting which we require more extensive and careful observations than have hitherto been made.

When once the surface has been regularly formed into waves, by the action of a wind, it offers a considerable purchase to the motion of that wind to drive it forward in a horizontal direction; for though every individual portion of the wave is alternately up and down in the course of the undulation, yet the quantity of elevated ridges turned to the wind remains pretty constant; and thus the whole surface water is pressed to the lee-shore. If the wind is of long continuance, and ranges over a large extent of a wide sea, the increase of elevation on the lee-shore may be considerable; and it generally happens that an elevation of this kind, which has to come round from the main sea through channels, may, in the case of an island, raise the water on the windward shore higher than that on the lee-shore. It is to be understood that, in speaking of windward and leeward shores, the windward shore is that from which the wind blows seaward, and the lee-shore that to which it blows from the sea; so that the windward coast of the island, or land, whichever it may be, joins the lee-shore of the sea, and the lee-coast of the land joins the windward shore. This follows as a matter of course from the wind blowing from the one to the other, which are the opposites in direction; but still, if some attention is not paid to this, confusion, or contrariety of meaning, may be the result.

The wind, by acting in this manner on the surface, will often produce a considerable difference of level in the two ends of a lake. Loch Ness, in Invernesshire, is peculiarly well situated for the display of this action. The valley, of which it occupies between a half and a third of the extent, divides the country from south-west to north-east, like a great ditch, which is sixty or seventy miles long, not more than two or three miles broad where widest, and cleft down till the bottom of it has but little height above the level of the sea, even where highest, though the line of it lies across a very mountainous district of country. The south end of this valley, which is the widest part, opens to the current of wind from the Atlantic; and therefore, though winds come down in gusts and squalls through the lateral glens, the general set in the valley, during the summer months, is from the south-west; and as the current is confined between the steep banks on the sides, it tells upon the surface of the lake with great force, so that the lower part is elevated two or three feet, and a flood of the discharging river is produced to that amount; and when the wind subsides, after being violent for several days, it is found that the river is lower, as if occasioned by drought. This is on a small scale, no doubt, but still it enables us, in part at least, to see how similar action may be carried on to a greater extent; and there are instances of this action in all the long and narrow seas closed at one extremity, though seas of this description have little or no tidal motion in them.

SECTION VIII.

EFFECTS OF THE LAND ON TIDES.

The circumstances which we have very briefly noticed, or rather simply named, in the last section, may perhaps serve to give those who have not attended to the subject some notion of those characters of obstructing lands, obstructions in the sea itself, and opposing motions in the atmosphere, which tend to disturb the succession and amount of tidal waves in the sea. It will be recollected that we already mentioned, that, in the average case, and with no obstruction, the two high-waters would be half the circumference distant from each other; or that, taking the lunar tide as the resulting and only separately-perceptible one, it would travel round the earth in about twenty-four hours and fifty minutes—the length of a lunar day. It is evident, however, that any obstacle, whatever it may be, which opposes the westward motion of this tidal high-water, must diminish the speed of the part which it opposes, so as to throw it behind the parts which encounter no opposition. By this means, those interrupted portions of the tidal waves, by having a slower motion than the others, must be brought nearer to each other in space; so that, without any reference to the absolute transfer of the water by a current, the tides will travel over the different seas, in various directions, and with various degrees of velocity, according as they meet with more or less interruption,—the least interrupted ones always moving quickest, and in the most regular order. Nowhere on the surface of a globe having its middle latitudes so interrupted as the earth has, can there, however, be a tide travelling with the maximum velocity which the tide would have on an uninterrupted globe, and with the moon revolving round its equator. This rate, as we believe we have already mentioned, is about a thousand miles in the hour, as the moon's radius vector does not get round the whole circumference in twenty-four hours, but very nearly round twenty-four thousand miles of it. Thus, this maximum of uninterrupted tide would still have a velocity perfectly inconsistent with a transfer of water, or, indeed, of any substance having gravitation. There is, however, a slight tendency of the tidal water westward, without reference to any impulse which it may receive from the motion of the air. The trade winds also give a constant westward motion to the tropical waters of the broad oceans, in consequence of the pressure and friction of the air upon the surface; and as this tendency westward inclines to the south on the north side of the equator, and the north on the south side of it, there is a tendency to an accumulation westward in the waters of the tropical oceans. This is arrested on the west side of the Pacific by Asia and New Holland, and the various islands and reefs between them; and thus there is, among the islands there, a sort of heaping up, or accumulating of the ocean waters, beyond their mean level, in the central parts of the Pacific. The Indian Ocean is fully as much swept over by oblique monsoons as by trade winds; and therefore the surface action communicated to it by the atmosphere is more in the direction of north and south, and the tides of the Arabian Sea, and the Bay of Bengal, into which it ultimately divides, must take something the form of those elongations of the Indian Ocean. When the south-western monsoon sets in this ocean, it is attended with the heaping up of the waters toward the northern part, to such an extent as sometimes to inundate a considerable portion of the low-lying country; and though the Red Sea is too narrow at the entrance for being much affected by tides, it partakes, to a certain degree at least, in this accumulation of the waters.

In the Atlantic, there is an accumulation of the waters on the shores of America to the northward of the equator, which finds its way as far north as the polar ice, and forms a part of the circuit of tide in that part of the sea. The portion of the Atlantic which is turned southward at the point of divergence, on the north-east of Brazil, is much smaller than that which is turned northwards, and therefore it does not reach so far as the southern extremity of America, but meets a counter current which finds its way through the straits, and also a little way to the southward of Cape Horn. This counter current meets the South Atlantic current in an oblique curve, extending from about the Falkland Isles, which diminish the velocity of both, and then the line of junction trends north-westward to the coast of Patagonia, which it meets somewhere about 45° south latitude.

In the eastern part of the Pacific, against the shores of America southward, there is a very peculiar revolving motion of tide. If we take a point on the coast of Guatimala, about 90° west longitude, and imagine a curve to be drawn nearly straight south to the equator, a little west of south, to about latitude 40° south, and then bending south-east until it blend with the returning current at the southern extremity of America, we shall have some vague notion of the central axis upon which this tide turns round; and from this axis it sets southward along the South American shore, and north-westward along those to the north, assuming more nearly the direction of the parallel as it advances. This is one of the most peculiar motions of tide, on a great scale, in any part of the globe. It is a sort of line of divergence from which the tides part both ways, not apparently in consequence of any thing connected with the bottom of the ocean in this particular spot, but merely from the failure of the current of the South Atlantic in getting round Cape Horn, and the consequent revolving motion, and centrifugal dispersion of the water, which takes place here. It is probable that here, and considerably to the westward, there is, in consequence, little alteration in the level of the sea at high and low water; for the rise of tide in the Society Islands, 50° or 60° farther to the west, is found to be only eleven inches; and on some of the Coral Islands farther to the east, it is possible that there may scarcely be any difference of tide at all.

This last circumstance is well worthy of careful attention and constant bearing in mind, by every one who wishes to understand well those real phenomena of those tides of the sea upon which the safety and success of navigation, and the consequent prosperity of commercial nations, and indeed the spread of civilization and the well-being of man throughout the whole earth, so greatly depend. It is so contrary to what we should be led to conclude, from the mere astronomical causes of tides, and so diametrically opposite to the assertions set forth in those books which unfortunately get first into the hands of young people, and thereby give error the advantage of making the first, and therefore the deepest, impression, that it is especially worthy the attention of every one who sincerely professes to give instruction on the elementary features and action of the earth. The usual account, and we believe we may say the only one, which is accessible to common readers, or, at all events, to which they *have* access, which comes nearly to the same thing, is, that the great tide accumulates in the great sea, while the little sea has little tide, and the lake no tide at all. The last is true, as to lakes, with the exception of the ocean-like accumulation of fresh water between the United States and Canada; but in places having a free communication with the ocean, the quantity has nothing to do with the difference of height between high and low water. This is well illustrated in the Bristol Channel, where, at Hartland Point, where the breadth is considerable, the rise is only about twenty-six feet, whereas it is seventy in the narrow channel at Chepstow.

These are only partial instances; but similar ones are to be met with in all parts of the world; and it is worthy of remark, that they are always the higher the less immediately they are derived from what may be considered as the primary or astronomical tide, occasioned by the gravitating influence of the celestial bodies. But we shall be merely better able to understand a point or two connected with those minor local disturbances, after we have just glanced at the general positions of co-tidal lines on the globe.

We should, however, be doing injustice to the present portion of the subject did we not call the reader's attention to the general effect of the terrestrial and atmospheric influences upon the distribution of the tidal motions of the sea, as one of the most wonderful instances of the manner in which all the powers and parts of nature work together for the use of man, and how strongly these instances of the goodness of his Creator, which meet him at every point, and in every circumstance to which he can turn his attention, ought to impress him with veneration and reverence for that august Being.

Owing to the various causes which we have enumerated, and the truth of their operation is borne out by the facts as actually observed, there is very little tide in the central and open parts of the great oceans where the currents of the water revolve without obstacle, and the winds play freely over the surface. And, in so far as man and his navigation are concerned, there is little need or use for such action of the water there. The trade-wind, or the monsoon, wafts the ship within the tropics, and the returning current of the air, and also of the water, in the northern oceans, which play freely in the higher latitudes, favour the return voyage when these higher latitudes are gained. Thus a ship, from the British Isles to the central parts of America, has only to stand so far to the southward as to gain the trade-wind, which carries her across with equal speed and safety; while, on her return, she has only to make the requisite northing in order to gain the British shores with not much more difficulty. So, also, if the season is properly chosen for a passage to the south of Africa, or beyond, there is the trade-wind to the shores of Brazil, and the returning current to the Cape; and if the seasons are duly studied for all the other broad expanses, there is a fitting season for the passage of each in that direction which is most advantageous to the mariner.

We have seen that the peculiar motion of the tidal waves upon the eastern part of the Pacific reduces the difference between high and low water there to less than one foot; and it is highly probable that the revolving currents of tide waves in the other oceans produce similar effects. We can understand why this should be the case when we look at the surface of revolving water in a river pool; it is always highest at the sides, and depressed in the middle; and, if the motion is rapid enough, it produces a hollow, or even a descending whirlpool. There is, of course, no motion of the water of oceans capable of producing such an effect as this; but there is no doubt that the ocean-waters are every where accumulated on the coasts of the land; and that though there are great differences produced at different places, in consequence of the meetings or the partings of different portions of tide, the very irregularities into which the tides are thrown cause a great deal more of rising and falling, and ebbing and flowing, in the sea, than could by possibility take place if there were no such obstacles and interruptions.

Farther, these increased tidal motions take place exactly where they are most required,—that is, where man can study them most easily, and turn them to the greatest possible advantage.

It is on the coasts only that tide navigations are useful; and such navigations are most useful in those very places where, from the circumstances already explained, tides run with the greatest violence, and rise to the greatest height. Such places are the channels among islands, the estuaries of rivers, and deep bays against which the current or wave of the tide sets. Those places have double shores, and thus their navigations have double usefulness, serving equally the inhabitants on the one side and on the other. The high tides, and corresponding depths of low-water, which alternate at such places, afford a daily navigation independently of the winds, which very much increases the value of those portions of the sea. Nor do they contribute less to facilitating both the departure and the approach of vessels which navigate from such shores to the wide seas: because an alternating inclined plane is produced, which at one time facilitates the departure of the ship, and at another time the return. No doubt there are many coasts on which those tidal motions of the water are fraught with danger; but this danger falls chiefly upon those who are ignorant, or who do not work their craft properly to the tide; and danger, when it is danger that may be avoided by skill, is one of the very best teachers of wisdom. There is another general advantage of this circulation of tide and current in the great oceans, and propelling of it in accumulated masses into the narrow seas, and creeks, and estuaries, which ought not to be overlooked. Shore-tides are by this means carried into the northern seas, at least, as far as the Polar ice; and if such is not also the case in the southern hemisphere, it is the less to be regretted that there seems to be no use for navigation in any very high latitude there. Had it not been for those interruptions, the spring-tide, even on the British shores, would have been of so small extent, that it would not have floated an ordinary barge; and thus the parts of the world which are really the best adapted for commercial purposes would have been cut off from the benefits of what may probably be regarded as the best and most useful of all navigation,—tide-work and coasting at short distances, where the whole district can make a very certain and ready pathway of the sea.

There is no doubt that these motions of the waters also tend greatly to that blending of the water of different latitudes, and that transfer of heat along with it, which render the ocean a universal and beneficent visitant to the inhabitants of all latitudes. We have sufficient evidence of this in the climate of our own islands, and of that of the whole of Western Europe, as compared with those other portions of the northern hemisphere which have not the benefit of a circulating current of the ocean, originating in the warm latitudes; and if we compare the dreary coldness of the winter and the parching drought of the summer, in the central parts of North America, in Siberia, and in Russia eastward of the White Sea, with the comparative mildness of our own seasons, or with those of Norway, or Norwegian Lapland, or even Iceland, we shall learn to know the advantages of those circulating currents of the tides which distribute the difference of climate, and diffuse comparative uniformity of temperature, to all places within the sphere of their influence. When we carefully consider this, and remark how the apparently irregular distribution of sea and land conduces to man's advantage, we can perceive, even in the most chance-appearing features of our globe, traces of wisdom which is infinite, and goodness which is divine. Rugged as the coasts of the land may appear, unequal as is the bed of the sea, and devious as are the motions of the tide-waves and currents of the ocean, they are all parts of a system which is perfect and harmonious: that which seems confusion to us, is in itself order; and that which we attribute to chance, is as certain a result of laws which never fail, as the daily appearance of the sun, the monthly variations of the moon, the pulse in our own arteries, or the breath of life in our nostrils. This same word "chance," though we sometimes allow it to become a stumbling-block, is nothing more than a simple confession of our ignorance. It is the word "change," —alteration of state, a new appearance;—"change," when we are able to see in what manner it is brought about; and "chance," when we are not. Science, conducted upon right principles, has already conquered much of what was once considered the empire of chance; and no part of the fancied dominions of that imaginary power is invincible, if we would use aright those powers which have been given us for this very purpose.

SECTION IX.

DISTRIBUTION OF CO-TIDAL LINES.

We already mentioned, but we may again repeat, that places are *co-tidal* when they have high-water of the same wave of tide at the same hour; and that an imaginary line drawn through all places which have this is a co-tidal line. But we reckon time by the apparent motion of the sun, and the tides follow that of the moon, with those variations at different times of the lunar month of which we attempted to give some explanation in a former section. The co-tidal lines cannot therefore be constant to the same instant of solar time for any two consecutive days or even tides, though they vary little for the times of new and full moon, as there is then a perfect coincidence of the solar and lunar tides.

These new and full moon tides are, therefore, the ones from which the co-tidal lines are estimated. They might be any number, or any difference in time apart; but the usual and most simple is that of hour distances in solar time, which, in the case of no disturbance of the tidal motions, would be the hour meridians, twenty-four in number, and 15° in longitude apart from each other. We estimate general time from the meridian of Greenwich; and therefore it is convenient to be at least able to reduce the tides at other places to Greenwich time, besides knowing when they take place, as estimated in the local time. But this is easily done by means of the longitude, at 15° to the hour, subtracting from the local time if the place is eastward, and adding if it is westward.

If there were no disturbances, the determination of the time of spring-tide for any one place would, by means of the longitude, give that for all other places; for every place having the same longitude would have the same time of tide; and this would hold true for the monthly variations, as well as for the spring-tide. In this simple state of things, the tides would, with the exception of the priming and lagging, and the time necessary to produce high-water, obey the moon's meridian passage; and they would all be the original or primary tides, produced by the moon's influence at their respective times.

But the disturbances of which we gave a short outline in last section, throw matters into apparent confusion, and make them really complicated; and hence the necessity of careful local observation, before the position of the co-tidal lines can be determined. The data are still too imperfect for reaching the minute particulars, but the general principles, upon which the solution of the problem depends, are not so difficult but that they may be understood by ordinary readers.

In order the more clearly to understand the principles of this problem, it may, perhaps, be as well to distinguish tides into three general classes; and the last class will admit of farther subdivision, in consequence of some local disturbances afterwards to be mentioned. The first are *original* tides, or those which are immediately produced by the luminaries, are true to the time of the luminary, and travel westward on the parallel. The second are *derivative* tides, or those which are produced by the motion of the former, northward or southward in latitude, into the different seas and large bays which have their position north and south. The third may be called *resulting* tides, and they are produced by the running of one tide against another, by the confluence of a river with the sea, or by any other circumstance which brings two portions of water, put in motion at different places, and by different causes, into collision with each other. It is obvious that, in so far as these last mentioned are sea tides, they take place at the points of confluence; and the action of the wind, or other local pressure, which gives either of them more than its usual impetus, will shift the point of confluence; and so, also, any thing which increases the volume and velocity of both will increase the force with which they unite, and, consequently, the rise of tide. We must, however, endeavour to get a beginning with an original tide, or, at least, the nearest approximation to it which can be obtained.

Upon turning to the map, we find that no tides can sweep fairly round the globe upon a parallel any where to the northward of Cape Horn, or, rather, of the open water a degree or two southward. There are islands, too, midway between Cape Horn and what may be considered as the average annual limit of the antarctic ice; so that the clear passage here cannot at any time exceed five hundred or six hundred miles. When we look westward, rather more than a quadrant westward from the longitude of Cape Horn, we meet with New Zealand, and some little isles to the south of it, which must interrupt the tide wave as high as 50° south latitude. At Van Diemen's Land, the interruption is not so far south as this, and at the Cape of Good Hope, it is farther north still; but the peculiar form of this boundary of the southern zone of clear water renders it impossible that the tides—that is, the co-tidal lines—can all lie even upon it, at equal distances, or in the direction of meridians. Besides, we are not very well acquainted with the form of the southern outline of this zone of water, and therefore we are unable to say what interruptions of tide may be there. There is, however, no good reason for supposing that the ice nearly clears away there in summer, because the hemisphere altogether is less heated by solar action than the northern one; and the highest latitude, 74° 15′, reached by Mr. Weddell, is less than has been reached both on the north of Europe, and on that of America.

Therefore, though the tide wave in this open zone of sea most likely proceeds completely round, yet the projecting land on the north, and the ice on the south, must lay hold of its margins and retard its progress, so that even here there must be more than twenty-four co-tidal lines, at hour distances in solar time; and these must, from the alternating interruptions of large continents and free scope given by extensive oceans, be irregular in their distances. It is thus impossible to regard this uninterrupted zone as the origin of much of the tidal action which is propagated into the central and northern parts of the seas. Farther than this, the point of low water, as answering to the luminaries, revolves upon the very centre of this zone both at the summer solstice and the winter; and as the maximum disturbance at so high a latitude is not above three feet at spring-tide, and as the minimum is 0 alternating at the quarters, the whole average tide produceable in this zone could not amount to above a foot of water. That the manner in which the tide circulates, and the influence which this has upon the atmosphere, produce that separation of the tropical and polar portions of the southern hemisphere the effects of which are so conspicuous in the climates and characters of the vegetation in New Holland, Southern Africa, and the south of America, we are ready to admit, because the theory accords exactly with the facts; and thus an important problem in physical geography, which formerly appeared contrary to all system, admits of a satisfactory solution. But we must look somewhere else for the primary or original tide of the ocean waters; and the puzzle, in the present state of our knowledge, is,—where shall we look?

This can only be guessed at; but still we must have some sort of hypothesis to string our facts upon, until we collect as many as shall have the consistence of philosophy; and therefore if we can find out, at sea on any of the very wide oceans, and on or near the equator, a co-tidal line which answers to twelve o'clock, and which has the general direction of north and south, we may conclude that we are not very far distant from the point at which the original tide begins.

There appears to be some such point as this in the Pacific Ocean, somewhere about 140° west longitude, and perhaps about 15° south of the equator; and any one who inspects the map will at once perceive that this is the most likely place for the production of the original tide. It is true, that we must not be scrupulous as to the exact point, because there is little difference of level in the spheroid of tide for many hundreds of miles; and as all the disturbing forces act in opposition to the original producing force, we cannot suppose that the result of the force at the commencement can amount to nearly so much as it would do if there were no disturbances. This view of the matter corresponds with the observed fact; for this is precisely the part of the Pacific in which the difference between high and low water does not exceed a foot, which of itself shows us that the only cause of tide there is the influence of the celestial bodies, and that all the disturbing influences, being of an opposing character, tell against this primary cause, and diminish its effect.

If we look at the map, America lies to the eastward in an unbroken line, from the ice of the North Pole to not very far from the ice of the South Pole; and there is a counter current of tide, which sets eastward, by the southern extremity of America, with so much force as, by opposing the South Atlantic tide, to form that confluent line to which we alluded in last section. It is thus evident that no water can come from the eastward of America to form any tide in the Pacific; but that the whole supply must come from the north, the south, and the west. Hence it is impossible for the action of the moon to produce a tide in this ocean, until it shall have gained as much westing from the American shore as shall give the requisite supply of water on the east, as well as in the other directions. In consequence of this, the first effect of the moon's radius vector upon the shores of America will be the production of low water by the withdrawal of the water westward to make up the tide in the Pacific; and this accounts for the line of divergence on the west coast of South America, to which we alluded, parting the tide into two portions,—the one proceeding northward, in the direction of the Aleoutian Islands, and agreeing in co-tidal lines with the lunar tide westward, but lagging behind that in speed, in consequence of the interruption of the shore, against which it sets obliquely; the other part proceeding eastward to the American shore, turning south-eastward, then east round Cape Horn, and ultimately north, until it is extinguished by the Atlantic tide.

This portion, which moves in the contrary direction, is what may be considered as a *parted* tide,—a portion, in short, of which the moon's radius vector, which is on the Pacific, loses hold, and which, in consequence, retreats backward to seek the opposite extremity of the tidal spheroid. It is worthy of remark that, under the equator, and for nearly 10° on each side, this portion parts eastward, very nearly in the direction of the meridian; and the northern part of it runs so slowly into the Gulf of Panama, that there are eight or nine hours' tide within the bight, though the in-bend of it is not two hundred miles, and it opens freely to the sea. The position of the co-tidal lines here is worth attending to, as indicating that the lofty ridge of the Andes, which stands very near the shore, exerts an attractive influence, —for the co-tidal lines preserve very nearly the general direction of the coast of the land until about 30° south latitude, and as between seven and eight hours are required from the line of divergence to this distance, the influence of the moon's radius vector on the Southern Ocean must have by this time come to its minimum.

The line of first lunar-tide, as we may call it,—the position of which we have endeavoured to point out,—meets the coast of North America near Acupulco, in about latitude 13° north, and 100° west, which is 40° to the eastward of what we may consider as the pole of the primary spheroid of tide. What its direction southward is cannot be very readily ascertained; but as in this longitude there is no interruption between it and the free zone of water, we may perhaps regard the southern part of it as lying nearly on the meridian.

We have been somewhat particular in calling attention to this line, because, according to the present state of our knowledge we may regard it as the original high-water spring-tide; and if we carry this with us round the successive co-tidal lines which have been established by observation, we shall be enabled to obtain a clearer view of the general succession of tides than we could otherwise get with the same ease and the same brevity.

It is probable, after all, that the commencement of this westward motion of the tidal wave ought to be taken from about 90° west of London, where the eight o'clock tidal lines part; (and it is worthy of remark, that the next eight o'clock line appears to be the one on which the tide of the Atlantic obliterates the return part of this tide;) but though there is a motion of high-water westward for about four hours previous to the high-water twelve—in longitude about 140°—yet this seems the proper commencement. The situation of it is over the coral reefs, for a considerable distance to the westward of this; and as the interruptions offered by those gigantic labours of exceedingly minute creatures are very great, the motion of the tidal wave over them is exceedingly slow, and the middle part of it, in about 20° south latitude, gets very much in the rear, not only of solar time, but of the absolute motion of the moon. From the twelve o'clock tidal line to the Friendly Islands, for instance, is only about 30°, or two hours in solar time; but it takes the tide wave six hours to travel that distance in this particular longitude, though it advances much more rapidly both to the north and to the south. This lingering of the high-water behind the radius vector of the moon, which amounts to two-thirds of an average time between high and low water in free seas, helps to explain the smallness of the tide in this part of the Pacific, because the tidal wave is so much detained by the interruptions of the reefs and coral islands, that it is thrown absolutely two-thirds upon the lunar production of low-water before it arrives at the Friendly Islands, or about longitude 170° west. This is an important point in studying the height of tides, especially on the wide oceans of the middle latitudes, where there is no clashing of currents to increase their height. If the high-water travels only at one-third the velocity of the moon's radius vector, that radius vector will very speedily have the effect of lessening its quantity, because it does not require a great number of hours to bring the absolute influence of low-water to the point where the wave of high-water is for the time; and this must destroy the tide, or, at all events, reduce it to a very small quantity.

This part of the subject is, however, so intricate, and would require the induction of so many particulars to bring it into a popular shape, that we are afraid to enter into any details of it; but the reader will easily understand, that if any effect of an increasing cause shall linger at any spot until that cause becomes a diminishing one, the effect must be a counteracting by itself of the operation of the cause; and, upon this principle, the moon, which raises the tides, may sink them down again, before they have reached the maximum height which the elevating influence would give them, if they should linger behind the moon's radius vector, in travelling round the earth. We must repeat again, however, that this part of the subject is so intricate, that it can hardly be made intelligible by words:—still it is one upon which any reflective reader cannot find much difficulty in forming a tolerably correct notion for himself.

Interruptions, similar in kind to this, influence the tides at every part of the earth's surface; for wherever there is any retardation in the bottom of the sea, which keeps the tide-wave behind the moon's radius vector, the moon, after passing beyond that distance which is requisite for causing the maximum of high-water, re-acts upon the tide wave, and pulls it down, so that the wave, though it goes on to its greatest amount in point of time, has that amount diminished by the full effect of the variation of lunar action upon it. Hence we can see that every obstruction which is occasioned chiefly by shallows and interruptions, which offer no elevation above the surface of the water against which the arrested current or wave can run up or accumulate, must diminish the height of the tide. We must, however, pass over these somewhat intricate portions of the subject, and proceed to the more simple matter of tracing the progress of the tidal wave, which we have supposed has its origin in the part of the Pacific to which we have alluded.

But there is a preliminary consideration necessary to the clear understanding of even this comparatively simple matter, and that is, the particular effect of an interruption rising above the surface, such as an island. The extent to which such an interruption will affect the progress of the tidal wave depends, in a great measure, on the size and character of the island. If the island is one of those small volcanic ones which rise abruptly from a great depth in the sea, it will offer much less interruption than an island with long and shelving coasts which extend far under the water, though the violence with which the tide wave will assail the abrupt island must be much greater. This, by the way, is one of the chief reasons why the action of the sea is always most severe upon its bold shores. It comes there in the full swing of its mass, whereas the shelving shore cuts it off gradually at the bottom, and reduces the final stroke upon the line of coast to a comparatively harmless ripple; while the pressure of the water up the inclined plane has a tendency to urge a portion of the substance of that plane shoreward, and thus increase the beach,—which, by the way, is the manner in which deposits are produced on those parts of the low shores where we generally find them collected, at the expense of shores which are more elevated.

If the island which lies in the direction of the tidal wave is in the open passage, that wave will form a loop, by advancing past each end of the island, and lingering behind the middle of it; the co-tidal line will part upon the side of the island which the tidal wave approaches, and unite again on the opposite side; and if the island is of such a form as that the point of confluence is at some distance from it, a parted tide, similar to that which we mentioned as being found on the west coast of South America, will retreat back upon it, in a direction opposite to that of the general motion of the tide wave.

If the passage for the wave is clear by the one end of the island, but interrupted by the other, the tide will of course pass more rapidly by the clear end; and it will depend upon the nature of the interruption whether the interrupted tide shall not be extinguished by the return of a tide the other way before it has cleared the interruption. We shall find some instances of this in our attempt briefly to trace the progress round the globe, or rather towards final extinctions in the different oceans and seas of what we have considered as the primary tidal wave; and with those hints at the manner in which interruptions affect it, we shall commence our very brief examination.

As the mean apparent revolution of the moon round the earth is about half a degree in angular distance slower than that of the sun,—that is, as the moon's radius vector appears to travel westward at the mean rate of about $14\frac{1}{2}^{\circ}$ in the hour,—we can easily compare the progress of the wave of tide westward, as indicated by the observed co-tidal lines, with the motion of the moon, and thus discover in what time any of the derivative tides which proceed northward into the oceans and seas, or are entangled among other interruptions, are absolved from the continued action of the moon, and left to other causes.

Now, by the time that the tidal wave, in the latitude of the islands and reefs in the Pacific, has gained the longitude of the Friendly Isles, or about 175° west longitude, the radius vector of the moon has got about 60° in advance of it, and is over the longitude of New Holland, and the islands to the north—among which, from the number of the reefs and shoals in the passage, the moon can have but comparatively little influence in the raising of a tide; and thus, while the same wave of high-water has only made about 30°, or two hours solar time of westing in longitude, the moon's low-water is about the meridian of 140° west, where we have supposed the original tide to have its rise. By the time that this wave of tide has reached the eastern entrance of Torre's Strait, on the north of New Holland, the radius vector of the moon has performed half of its revolution round the earth, and is on the east coast of Africa, so that the high-water of its other extremity—that is, the influence which, acting freely, would produce high-water—is brought upon this tidal wave. The immediate application of this return of the gravitating influence upon the same wave of tide is of course to increase its power, but the obstacles in the strait are so many, that about fifteen hours are required before it can struggle through a distance in longitude of only about an hour and a half, as estimated in solar time.

From the point at which we started, to the west end of Torre's Strait, is only about six or seven hours in longitude, but it takes twenty-eight hours in solar time, and the radius vector of the moon has passed twice over the high-water in its progress across this short distance, so that it is actually three tides old, as compared with the tide of the moon's tidal passage on free water. By the time, therefore, that this wave of high-water with which we set out reaches the western part of Torre's Strait, toward the Indian Ocean, there is another high-water which has advanced some distance into the strait, and a third, which has made four hours in time, or nearly an hour and a half in longitude of westing, from the point at which we started; thus, this motion of the tidal water has not only ceased to have any influence upon the contemporaneous tides of the Pacific, but is itself confined within narrow limits, and almost obliterated. Let us examine what becomes of the other portions of the same wave of tide in different latitudes.

The tides of the North Pacific have not been much observed in their succession, excepting on the west coast of America, where their motion is northward, in lines more and more at right angles to the coast, so that the co-tidal line with Break-sea Spit on the east coast of New Holland, falls on the American shore about 52° north, while the following one is on the coast of Guatimala, and in the main ocean a little to the east of Easter Island. This last of course gains the central point of tide from which we started before the other can gain the east coast of Asia; and thus the tides on that coast have always at least one high-water between them and the tide immediately produced by the moon.

The tides upon the Asiatic shores of the North Pacific are thus either second or third tides, as compared with that immediately raised by the moon; and, according as the trend of the shores may vary, we may expect that they will sometimes clash with each other. When, in these clashings, the one volume of tide greatly exceeds the other, the smaller is obliterated; there is only one high and one low water in the course of twenty-four hours; and the rate of falling back in the time of high-water is of course double of what it is where there are two returns of high-water in the course of the day. This is the case in the Harbour of Tonquin, which has the Island of Hainan between it and the sea, with a wide entrance at the south, and a very narrow one at the north. At other parts of this coast, it is probable that, from the form of the ocean, and the number of islands at some distance from the shore, which present a pretty continuous barrier, there may also be duplicate tides, where the one makes a high-water at the half-ebb of the other. These considerations belong more to the subject of resulting tides, and can be noticed with more advantage afterwards.

The whole tide in the North Pacific may be considered a derivative tide, which plays in that ocean only, the co-tidal lines lying south-west and north-east, with a trend northward in the middle, and the successive waves of tide being extinguished on the shores without any general circulating current of the waters, or any return, excepting that which is taken up by the moon's attraction in raising the primary tide. There is no escape of tidal water westward from this ocean, for we have seen how slowly the dying tides creep through Torre's Strait, and there is no tidal play between Java and Sumatra, or between the last of these islands and the Malay peninsula. The original tide in this ocean is, as we have said, very small; and, as there is nothing in the ocean itself to increase it, except the currents of land-locked channels, we may perhaps consider that there is less tide here than in any other part of the sea; but the points at which it has been observed, or indeed can be observed, (as there are no tell-tales of tide in an unbroken sea,) are so few, that our information is very limited, and of the most vague and unsatisfactory character, so far as it goes. There is this to be said of it, however, that the tides of the North Pacific have little influence upon those of any other part of the sea.

When we turn our attention to the south part of the Pacific, we find the state of the tides very different. It inosculates with the zone of free circulation round the globe by the margin of the Antarctic ice; and from the longitude of Cape Horn to the same again there is free scope for a breadth in latitude of not much less than 30°, or about 2000 miles, even where most interrupted, while there are the expanses of the Indian Ocean and the Atlantic, (exclusive of the Pacific itself,) with only the intervening land of Africa between.

The Indian Ocean and the Atlantic are, on the equator, or average line of passage of the moon's radius vector, rather less than 60° in longitude each, or only one-third of the extent necessary for the formation of a complete tidal spheroid; and therefore the original tide raised in either of them by the moon's influence can be only a small fraction of a full lunar tide, much less, in fact, than that on the Pacific, which, as we have already seen, is not great. Hence those two oceans drink the revolving tide of the southern hemisphere in no stinted draught,—to such an extent, indeed, that they (the Atlantic especially) have higher tides in the northern latitudes than are to be found in any other parts of the sea.

The tides in these two oceans are of different characters, as each is modified by the peculiar form of the ocean in which it takes place. The Indian Ocean is a bay,—at first one, although ultimately dividing into two; and, upon the average, it narrows through the whole length as it proceeds northward. The lands which bound the extremities of its opening toward the south are not very far from being on the same parallel, though, including Van Diemen's Land, the eastern one is rather farther to the south; and this renders the set of southern tide into the Indian Ocean less powerful than that into the Atlantic. The general outlines of the sides of the Indian Ocean have also nearly a symmetrical trend—or the eastern one about as far to the west of the meridian as the western one is to the east—as they proceed northward. The eastern line is from Cape Leeuwin, on the south-west of Australia, to the bottom of the Bay of Bengal, and the western one from near Algoa Bay, on the south-east of Africa, to the bottom of the Arabian Sea. The southern points are almost exactly on the same parallel of latitude, and there is not much difference in the northern ones; so that in length and direction they are nearly equal sides. It is true that the western one is continuous land the whole way, while there are islands and apertures in the eastern. This difference is, however, of minor importance, as there is little or no transfer of water either from the Pacific to the Indian Ocean, or from the Indian Ocean to the Pacific, through these openings; and thus the tides of the Indian Ocean are as completely what may be called "bay tides" as if there were continuous land from Cape Leeuwin to Chittigong on the east side, and from Algoa Bay to the bottom of the Arabian Sea on the west. Thus there is nothing in this ocean to produce any thing like a revolving tide; and the co-tidal lines enter it in curves bulging out to the north, with nearly the velocity of an entire spheroid of tide in the mid-ocean southward, but closing-in to much shorter distances between the co-tidal hour lines as they approach the two terminal branches in the north.

The tidal lines on the Atlantic are more intricate, and we shall defer the notice of them till we have mentioned a few of the times in the Indian Ocean. In order to do this with proper understanding, we must return a little to the eastward.

The original tide wave reaches very near the eastern coast of New Zealand in six hours, that is, the co-tidal line there is a six o'clock line, as counted from the point at which we have supposed the tide of high-water to begin (as it actually does take place) at twelve. It will be understood that this twelve is the time of spring-tide, and may be either the upper tide of both luminaries at new moon, or the upper tide of the moon and the under tide of the sun at full; the only difference will be, that when we come to the six o'clock line at change it will be after noon, while at full it will be after midnight, or in the morning.

This being kept in mind, we may revert to the lines. The six o'clock line approaches near to the east point of the most northerly of the two islands of New Zealand, but it is retarded in its approach, so as to have a flexure toward the east. Between six and seven, the tide parts, so that there is a point of divergence, and the co-tidal lines of seven, eight, and nine, travel along the north and south parts of the islands. The north part is soonest got round, and Auckland's Isles also disturb the nine o'clock line to the south, so that this line makes a bight toward the west side of the northern island, though it does not meet the south nine o'clock line. The current westward, through Cook's Strait, has also some little effect; and thus the point of convergence of the north and south parts of the ten o'clock line is thrown considerably to the westward of New Zealand—to nearly one-third the way to New Holland, and the united tides on this line run confluent for some distance. Their approach to New Holland and Van Diemen's Land parts them again, however, and the northern portion is applied to the east coast of New Holland, so as to make ten o'clock high-water off Break-sea Spit, while the southern part, which has not been interrupted, gets in advance, and the trend of the ten o'clock line, farther south of Van Diemen's Land, is to the south-west. The eleven o'clock line falls on the south-east of Van Diemen's Land, also, at Cape Pillar, and the wave takes about an hour to traverse the south of that island, so that the twelve o'clock line touches the south-west point. The wave of tide is now twelve hours old, from the time of its being raised in the Pacific; but it has only travelled so far in longitude as answers to between four and five hours (four and three-quarters, very nearly,) in solar time. The southern extremity has, of course, made much farther progress in longitude westward, in the middle of the clear zone of circulating water; but the actual progress which it has made has not been ascertained. The same wave of tide has been much more retarded in its northern part by the reefs and the east coast of New Holland, so that it is still three hours in time short of Cape York, at the entrance of Torre's Strait, which is nearly on the same meridian with the south-west point of Van Diemen's Land.

It does not appear that any westward current of the tide through Bass's Strait, between Van Diemen's Land and New Holland, has much influence upon the motion of the tidal wave, or the position of the co-tidal lines to the southward; and thus it is probable that the tide of the wide sea to the south may get as speedily round as to meet that in the Strait, as the co-tidal lines begin to be retarded by the portion of the coast somewhere about Port Lincoln, in Southern Australia.

The five o'clock co-tidal line touches the coast of New Holland somewhere near Cape Leeuwin, so that, by this time, the southern portion of the wave, in the comparatively open sea, has got fully an hour and a half in longitude in advance of the northern position, which is dying away among the shoals and islands in Torre's

Strait; and from this point, as the Indian Ocean has fairly opened to the southern position, the difference becomes more conspicuous.

The main set of the wave, and consequently the position of the co-tidal lines, is now in the direction of the Arabian Sea, by which means the lines are turned in their western parts in a direction nearly parallel to the east coast of Africa; and though this sending of one wave after another directly against the coast is a means of retardation, and the other, or eastern extremity of the lines, are laid hold of by the coast of New Holland, yet the northward progress of the middle parts in the free ocean is much more rapid than any thing with which we have hitherto met in the course of our survey. In the course of four hours this tidal wave makes a progress of more than 40° northward, so that it is north of the equator; and its motion here is not a very great deal slower than that of a spheroid of tide in an uninterrupted ocean, round the globe, though it is not in the same direction. The southern portion of the wave has now gained a considerable degree of westing in longitude, perhaps as much as to 15° or 20° east. In the region to the south of the Cape this wave of tide is now twenty-one hours old, which answers to about 304° of the moon's motion; and it has moved from about 140° west to 15° east, which is, upon the whole, about two-fifths of the theoretical velocity of the tide wave, if there were no interruption.

A very little to the north of this nine o'clock co-tidal line, the narrowing of the Indian Ocean, and the division of it into the Arabian Sea and the Bay of Bengal, begin to be felt: the tidal line becomes parallel to the coast of Sumatra, and it takes ten or eleven hours to reach the bottom of the Arabian Sea, on the south coast of Persia, and an hour more to reach that of the Bay of Bengal. Thus the tide of high-water which reaches the extreme parts of the Indian Ocean, leaving the bays and estuaries wholly out of the question, is now nearly three tides old, while its progress in longitude, down to the bottom of the Bay of Bengal, or even to that of the Arabian Sea, is not equal, in absolute amount, to one tide; so that the tide which reaches these parts is three tides old; and as, from the form of the sea, it does not return to the south in any revolving current, it dies away on the shores toward which it sets.

This twelve o'clock line on the Indian Ocean cuts the equator a little to the westward of the island of Sumatra, touches the eastern coast of Ceylon,—is found on the west coast of that island, touches Cape Comorin, the south point of India, reaches about 12° north of the equator, in the middle of the Arabian Sea, passes the Mahe Islands to the north-east of Madagascar, lies a little to the west of the Isle of Bourbon, passes the Cape at the distance of about 10° to seaward south-east, cuts the meridian of Greenwich about 55° south, and is opposite the centre of the Atlantic about 60° south. This is the second twelve o'clock line from the commencement, the first lying to the eastward of New Holland, in the middle latitudes, though several of the lines are extinguished against the shore of that country.

This is also the line which is found in Torre's Strait, opposite the west part of Melville Island, in about 130°

east longitude; so that, if we could trace it to the shores of the Antarctic Sea, it may possibly extend about half way round the globe. It is rather an important line, being the last in the Indian Ocean which is not greatly disturbed by the approach of the tidal wave to the coasts and islands; and it is also a fact worthy of notice, that those portions of this eastern tide, originating in the Pacific, which have been traced to their extinguishment, appear to die at nearly the same age in time, whatever may be the distance which they have travelled.

The three points at which we know the extinguishment, without any interference or production of resulting tides, are—first, on the north-west of New Holland, somewhere between the middle line of that coast and the island of Java; secondly, the bottom of the Bay of Bengal; and thirdly, the bottom of the Arabian Sea. In the first of these cases, the tide is extinguished by the more powerful tide which sets north-eastward against it; and in the second and third cases, the tides are extinguished by the shore, where there are some sources of disturbance as to the ultimate co-tidal lines, independently of the monsoons, which, when they blow strongly, must also affect the hours of tide a little. The Bay of Bengal receives a vast quantity of water from the Ganges, so much so, indeed, as to make the bottom of the Bay a sort of point of confluence, as between water and water, in which cases the tides are always liable to occasional disturbance. The Arabian Sea, also, receives a great volume of water from the Indus, and it is confluent with the Persian Gulf, which is, though narrow, at least a thousand miles in length. Of course there must be some resulting tides, and some irregularity of the last co-tidal lines here, as well as in the Bay of Bengal. Notwithstanding this, however, the last tide in each of the three cases seems in general to be eight hours older than the twelve o'clock line to which we have alluded; so that, at the time of its final extinction, it is thirty-two hours old; which answers to between two and three passages of the moon's radius vector over that part of the Pacific where we have supposed it to originate; and this equality and age of those portions of it which are extinguished without the production of any revolving current, or resulting tide, is a very strong confirmation of the hypothesis which we have assumed of its origin, and seems clearly to establish, that, whether arrested on the shores of New Holland or on those of Asia, it is one original tide. If, in addition to this, we should find something analogous in the Atlantic, the whole would not amount to the establishment of what we have advanced, as a demonstrated theory of the tide; but it would, at events, be a step forward in the matter. Let us, therefore, next examine the co-tidal lines in the Atlantic.

The tidal wave sets freely into the Atlantic from the south-east, with the bights of the first lines advanced to the middle, or rather, perhaps, toward the north-east point of Brazil; and if we begin it at the twelve o'clock line already described, it travels for the first two hours with the full velocity of a complete spheroid of tide under the equator. This is worth attending to, as it indicates some new impulse in this ocean by which the motion is accelerated. That there must be such an impulse becomes evident when we consider that this motion of the tide in a northward direction is greater than that which the tide wave could have in the sea to the south of Africa, even supposing it to sweep freely round the globe there. Whence, then, comes this accelerating power by which the tide waves are propelled into the Atlantic with such velocity? Shall we look for it in the moon's attracting influence? This cannot well be, because a tide raised in one ocean would of course render unnecessary, and therefore resist, the ingress of tidal waves from another ocean; so that if, when this twelve o'clock co-tidal line arrives at the meridian of Greenwich, there were a lunar tide in the Atlantic, a conflict between the two would be the result; and it is probable that the tide from the south-east would struggle on for its eight hours with a power and velocity still diminishing, until it were extinguished at the end of this period, as it is by other causes, in the Pacific. Indeed, we cannot, in all cases, say *other* causes; for the extinguishing of the tide from the east, which takes place on the north-west coast of New Holland, is in many respects a parallel case,—it is the stronger part of one tide putting down the weaker; and we may readily suppose, even reasoning from the analogy of this, that an original tide in one ocean would put down and extinguish a derivative tide from another, especially if the original tide were produced near the equator, and the derivative tide had to come from as high a latitude as 35°.

But let us consider what the position of the moon's radius vector is when the tide-wave reaches the twelve o'clock line to the southward of the Cape. This is the second twelve from the commencement of the tide, about

140° west longitude in the Pacific; it is therefore exactly one solar day since that tide was formed, and began its march westward. In other words, the earth has made one complete revolution on its axis, and no more; and the moon has fallen rather more than 12° behind the apparent place of the sun,—but call it 12°, for the sake of simplicity,—and that extremity of the moon's radius vector which produced the original tide in the Pacific will be 12° eastward of its former position, or over the 128th degree of west longitude. The opposite extremity must be 180° from this every way, and therefore it must be over the fifty-second degree of east longitude, which is in the Indian Ocean, about 8° off the east coast of Africa. These are the two poles of the spheroid of lunar tide; and to whatever extent this spheroid may be formed, or how much soever it may be disturbed, these are the points to which alone the moon has a tendency to collect the centres of the elevated waters; and the low-water, in as far as the moon is concerned, must be midway between them, which would be found to be in the longitude of New Holland and New Guinea for the one, and in that of the east coast of Brazil for the other. Consequently, in so far as the moon is concerned, it must be low-water in the central Atlantic at the same time that this twelve o'clock tide wave is approaching the Cape.

Now, we need hardly mention that this is the most favourable state of things for admitting the tide which comes round the south of Africa into the Atlantic, because, instead of having to force its way against an ascent, it has the advantage of a descent; and, if we consider a little, we shall perceive that the very same position of the moon's radius vector which thus facilitates its advance into the Atlantic, operates as an impelling power in pushing it onward. The same co-tidal twelve o'clock line is then on or near the equator in the Indian Ocean, or the high-water there has approached within about 8° of the coast of Africa, and of course the maximum height of tide is there, inasmuch as it is the situation of one of the poles of the lunar spheroid. Thus there is an accumulation or raising of the water by a flood-tide in the equatorial parts of the Indian Ocean, and a depression of low-water in the Atlantic, while the wave of tide which is about to enter the low-water ocean has the height and strength of the high-water in the other; and as its motion westward in the southern part has been uninterrupted for twenty-four hours, it has acquired a considerable momentum. These circumstances are quite sufficient to explain why the south-east tide—that is, the tidal wave from the south-east—sets so strongly and quickly round the Cape into the south part of the Atlantic. Let us next examine its progress within that sea.

The west coast of Africa does not deviate greatly from the direction of a meridian, from the Cape to the bottom of the Gulf of Guinea, which is a distance of 40°, or about 2,800 miles; and the set of the tide wave is rather away from than against this line of coast. The consequence is, that for the extent which has been mentioned the shore of Africa lays comparatively little hold on the tide wave, and high-water proceeds from the Cape to the bottom of the Gulf in little more than four hours, or at the rate of 700 miles an hour.

On the American coast the case is different; the general trend of that coast is north-eastward, and the current which we mentioned as coming eastward from the Pacific feels its way northward for about 15°, and meets the great tide of the south-east nearly upon a meridian, somewhere not very far from 60° west longitude. The consequence is, that the motion of the tide wave here is retarded, so that the co-tidal lines are much closer. Cape Frio, to the eastward of Rio Janeiro, in about 20° south latitude, is the point of divergence where the Atlantic tide is broken into the main tide which continues to set north-west, and the minor tide which sets westward, and tells in a high-water travelling southward from Rio to some point between the estuary of La Plata and the Gulf of St. Antonio. The precise point will, of course, depend upon the relative force of the two parted tides, which are separated from the main tides, and left to come here and settle the boundary of their own dominions. It is worthy of remark, that here again this portion of the tide from the east, which is extinguished by the opposing one, loses its distinctive character about the eight o'clock co-tidal line, or has exactly the same age when it expires as that portion which expires nearly 120° to the eastward on the coast of New Holland, and this seems a farther confirmation of the hypothesis which we have assumed. It is the five o'clock co-tidal line which parts at Cape Frio, though it parts a little before the hour; and both extremities of the tide wave are now on the respective continents, without any thing except the forms of the shores to retard their progress; but, measuring the breadth obliquely across the equator from the nearest points of Africa and America, the distance is much less than that from Rio to the African shore, under the equator. In direct distance it is indeed only half as much. This has the effect of retarding the four, five, and six o'clock lines in the mid-passage, so that they have a curvature southward at the middle; and thus the waters are retarded in approaching the narrow part of the ocean, and as they continue to be followed by the rapid motion from the south, there must be some tendency to heaping up.

There is now, however, another cause which tends farther to elevate the tide in this equatorial part of the Atlantic. It is the six o'clock line which extends from Bahia on the American shore, to Cape Palmas on the African,—that is to say, it is six hours, or nearly so, after low-water, as produced by the direct action of the moon on the Atlantic, and, consequently, it is high-water as regards that action; so that in this state of things we have a wave of tide setting in from the south-east, and the attraction of the moon giving additional strength to this wave under the equator, which also gives it the advantage of an inclined plane in descending into the north part of the Atlantic. Hence, though the clear passage is only about 1800 miles from continent to continent, there is, from the combination of those circumstances which we have mentioned, a more powerful tide prepared here for setting northward than we meet with in any direction on any other part of the globe, if we except resulting tides which are produced by peculiar local causes. The line of change in the tidal wave of the Atlantic, from the southern hemisphere to the northern, is not the co-tidal line of high-water at six o'clock, but a line about midway between that and the seven o'clock line, so that the middle of the high-water takes about six hours and a half in passing from 48° south latitude to the equator, which is about 600 miles an hour on the oblique line; but it is greater than this at the beginning, and less towards the end, though in the half hour from six to half past six it moves as far as in either of the two preceding hours, and, consequently, with double the velocity. If we take the middle of the curves formed by the co-tidal lines, the distances between them, and, consequently, the rates of motion in the tide, increase as the wave proceeds northward; so that high-water reaches the bank of Newfoundland in nearly 48° north latitude in five hours, or at the rate of about six hundred and sixty miles an hour, and this with considerable uniformity. The direction of the middle of the tide is north-west till Newfoundland is arrived at, but the projecting land there turns it to the north-east, and it sets in the direction of that part of the Arctic Ocean which lies to the north of Europe, diminishing in rate as it proceeds eastward, but still having considerable velocity. The line which we have now attempted to trace, from about 20° west of Greenwich on the equator, to Newfoundland in about 48° (say 45°), and thence in the direction of Spitzbergen, may be regarded as the grand axis or line of greatest motion in the Atlantic tides, and until it reaches 50° north, and turns eastward, it does not occupy more than twelve hours in its passage from the Southern Ocean in what may be considered as its junction with the Antarctic Ocean, or the place where the Atlantic begins, to this latitude of 50° north, where the Atlantic may be said to end in the Arctic Ocean. Thus, there can never be upon this axis of tide in the Atlantic two high-waters at the same time; for if one is just entering it at the south, the former one will be just leaving it at the north; and the low-water will be very near the equator. On the other hand, if there is one low-water entering at the south, the former one will be leaving at the north, and high-water will be on the equator. The great tide which sets northward in the Atlantic, when equal at both extremities, thus consists of one great trough of the tidal wave if it is low-water on the equator, and of one great ridge if it is high-water; and the extent of this, measured on the axis, is rather more than a quadrant of the entire circumference, in one continuous and unbroken tide, in a northerly and southerly direction. There is not another such tide wave as this in the whole extent of the ocean; and this is the reason why the Atlantic shores are better adapted for tide navigation, or coasting trade, than those of any other of the great portions of the sea.

This particular character of the Atlantic tides is well worthy of attention; and of itself is a perfect study, though one which we unfortunately have not space for working out, even though we were in possession of the requisite data. The effect of this great tide setting constantly northward, with greater velocity, more uniform power, and a longer range in latitude, than any other tide upon the earth's surface, causes a continual transfer of the antarctic air into the southern part of the atmosphere over this ocean, and as continual a transfer of tropical air into the latitudes of the north. We need not add that such air, coming, as it does, from the regions of maximum evaporation,—for the whole Indian ocean tends to supply it,—must bring a great deal of humidity on its wings; and, when we look at the map and examine the coasts which abut upon both sides of the Atlantic, whether as main ocean, or as inland sea or bay into which this main ocean is broken—the west coasts of Europe, the east coasts of America—we find in them characters which are unknown in almost any other region of the globe—characters which bespeak a fertilizing influence which elsewhere is of far inferior energy, or does not exist. There are rich vegetation, lofty trees, giant reeds and grasses, flowers of every hue, and fruits of every taste, upon the shores of other lands; but it is the Atlantic which, in a pre-eminent manner, distils in rain, and blesses the neighbouring lands with heaven's most fertilizing dew. Around the Atlantic are the lands of lakes and of living waters, of cooling fountains, of crystal streams, and of wide-swelling rivers; and it is on the borders of this extraordinary ocean that the meadow and the savannah are evergreen, and all the elements of plenty to man in civilized life are found in the greatest abundance, and in the most unbroken succession.

This were enough to convince us how important it is to study the great features of that planet on which our lot and our mortal life are cast; nor ought we of those islands to forget that we are placed in the bountiful Atlantic, and that it is the restraining influence of this sea, as an instrument that the Creator has prepared for our good, which softens the drought of our summers, mitigates the rigour of our winters, and so gives us fields which we can cultivate at every season of the year: thus admonishing us, by the constant succession in which the bounty of nature is brought before us, of our duty to be "up and doing," and thereby show our gratitude, and that, in so far as mortal men can be worthy, we strive to be worthy of those blessings which are poured down upon us every day and every hour.

But it is not in that fertility and mitigation of climate of which we have spoken that the peculiarity of tide in the North Atlantic is alone conspicuous; that tide, considered as a phenomenon of the sea, and without any reference to the characters of the adjoining lands, or the nature and value of their produce, is equally interesting and useful in a maritime point of view. The northern part of this great ocean does not narrow and gradually extinguish the tide, as is the case with the terminating parts of the Indian ocean, and probably also of the North Pacific, though we are not so well informed with regard to the tides there. It opens very considerably to the north-east during the summer, and it is by no means improbable that a certain portion of its waters circulate here below the ice, and return into it again in a similar manner on its western or American shore, in the high latitudes. However this may be, there is much less narrowing northwards than in the other oceans; and on the parallel of 60°, if we include Davis's Strait, there are full 60° in longitude quite uninterrupted. The degree of longitude here is half the length of that at the equator; the breadth at this northern extremity differs only a few miles from that where the North Atlantic joins the

South. Then, whether we examine the one coast or the other, the inland seas, bays, and creeks are innumerable, and the islands with channels between, which admit of free navigation, are not few; and most of the bays and openings are so placed as to meet the tide, and thus have the advantage of higher flood than in other seas. We may, in short, consider this great central tide of the Atlantic as analogous to the flowing of the life-blood of an animal through the main artery, and the several bays and irregularities of the coast as the ramifying branches into which this tide of life is distributed, and by which it is rendered beneficial to all. That the great facility hereby given to commerce should be placed in the same locality of the world where the materials of commerce are most abundant, and that the inhabitants of the Atlantic shores should have been the first, and the most successful, in cultivating the useful arts, and in carrying on an advantageous traffic with each other, shews pretty clearly for what purposes the special bounties of nature have been bestowed through the instrumentality of this ocean's working. Nor ought we to forget that the shores of the North Atlantic are the birth-place and the chosen abode of freedom, in the best and only genuine sense of the term. Even in Europe, as we recede inland from the Atlantic, the distinction of despot and slave, both on the great scale and on the small, becomes more and more conspicuous; while, on the Atlantic shores, though there are of necessity both natural and conventional distinctions of men, yet, upon the average, and in such numbers as to make the opposite the exception, and not the rule, the substantial pursuit of every man's life is his own maintenance and enjoyment. It is the same on the American side, though freedom there is of younger growth, and, though shooting up more rapidly, perhaps not so firm in texture. But still there never was, perhaps, a nation under the canopy of heaven which grew so rapidly as the American States have done, since they ceased to be a colony and became a country. Herein there is a pretty strong argument against colonies, and in favour of the people of every detached land being their own rulers and the makers of their own laws, as they best know their own characters and their own necessities, and are the fittest judges of what should be encouraged and what repressed. This argument, however, is foreign to our subject; and we shall only further remark that the lands on the Atlantic shores are those in which Divine Truth is known in the greatest purity, and where it exerts the greatest influence on the hopes and the happiness of mankind. We shall now return, and briefly glance over the rate of march which the ends of the co-tidal lines have upon the respective shores of the North Atlantic.

From six to seven, the wave passes with considerable rapidity along both shores, reaching Sierra Leone on the African side, and Ceara on the American side, at seven o'clock. The east end of the wave is now taken hold of by the islands and irregularities between Sierra Leone and the Cape Verde Islands; and it takes three hours to pass over rather less than 10° of latitude, which is not much more than two hundred miles an hour, while, in mid-ocean, the rate is upwards of six hundred. The western extremity of this line does not advance above

5° in latitude northward, but it parts westward nearly 10°, having in the course of the hour crossed the estuary of the Amazon, and reached Cayenne at eight o'clock. The great flood of fresh water which is continually poured into the sea here by the Amazon,—and which is greater than that discharged by any river, excepting perhaps the flood which the Mississippi discharges into the Gulf of Mexico,—in all probability influences the tidal wave, throwing the height of it farther to the north, and the extremity farther to the west.

The nine o'clock line assumes a character still different, and indicates a separation of the tide in the western part. Its eastern extremity makes very little way among the African islands, and a little off the shore of Africa it is detained by the Cape Verde Islands. On the west, too, it makes very little northing, and not much westing. An obstacle is here at no great distance before it in the Caribbee Islands, which, before another hour's march has been passed over, break the wave,—allowing that portion to pass through the openings which circulates round the Caribbean Sea and the Gulf of Mexico, and directing the rest in the line of the centre of the curve. By this means the ten o'clock line, which touches Cape Verde on the African side, and the Caribbee islands at nearly the same latitude, pushes northward in a curve of two branches, the one parallel to the American shore, and the other nearly in the direction of the north of Europe. At the angle between the Caribbee Islands and the larger or westward chain of the West Indian group, the tide is very much disturbed. The islands there (the Virgin Islands) are small, with intricate passages between; so that the flood-tide sets through them in a variety of directions, though its general course is southward, or away from the main-tide in the opposite direction. The eastern extremity of the eleven o'clock line makes considerable progress on the African coast, and reaches Cape Blanco. The western branch trends round by the north side of the West Indian Islands, and reaches nearly to the Bermudas; and this is the last co-tidal line, or top of high-water, which is unbroken in its northern part, as it reaches to about 46° north, over the Bank of Newfoundland, and not very far from that island. This line is a preparation for separating the eastern or European tides of the Atlantic from the western or American ones; and the next co-tidal line belongs partly to the one division, and partly to the other.

The twelve o'clock line reaches westward on the American side as far as the west end of the Bahamas, or nearly so; while northward it touches upon Nova Scotia. There is a continuation which enters the estuary of the St. Lawrence between Cape Breton and Newfoundland, and there are several successive tides in that estuary before Quebec is arrived at. The western extremity of the eastern branch of this twelve o'clock line is on the east of Newfoundland, but the eastern extremity on the coast of Africa is very little to the northward of Cape Blanco; and on this part of the coast of Africa it takes five hours of tide to gain a northing of the same number of degrees in latitude; so that at this state of the tide, while the wave in the free sea is still advancing six hundred miles an hour, the tide on the African shore is advancing only between sixty and seventy. This, of course, turns the eastern tide more in the direction of approaching Europe, in a continuous wave extending south-east and north-west. This twelve o'clock line is three tides, or a day and a half, old, from the commencement in the Pacific; and of course all the tides which each the shores of Europe, and of the United States of America, are older than this.

The one o'clock line on the American shore parts westward, and touches that shore at Charleston, while the northern extremity of it still abuts on Nova Scotia. The two o'clock line on the same side touches the American coast at the entrance of the Chesapeak, meets Cape Cod, and still abuts on Nova Scotia; thus dividing off two ways, with New York on the one hand, and Boston on the other,—the latter running up to the Bay of Fundi, where we mentioned that the tides are so very high. The remaining tides on the American shore, which last two, three, or four hours, according to circumstances, are local tides, distributed into the numerous irregularities of the line of coast, but, generally speaking, setting in upon the shore as flood, and receding back from it as ebb, which are the directions of tides best suited for the purposes of navigation. The gulf stream, which issues from between Florida and the Bahamas, and runs with perceptible rapidity to near the Bank of Newfoundland, does not sensibly influence the motions of those tides; and, indeed, as it consists of warmer water than the seas into which it proceeds, it must be lighter, and consequently a surface current only, and therefore borne on the tide wave without any disturbance of the great tidal motion, in the same manner as one often sees a little whirlpool borne on the current of a river without in the least disturbing the motion of that current. As a farther proof that tide waves and surface currents have no very great general effect upon the motion of the body of the waters, we may mention the north swell which sets against the northern shores of the West India Islands. There are currents which set among those islands, both in the direction of the inward seas and of the gulf stream; but, notwithstanding this, it very often happens that though the weather in the West Indies, even as far to the southward as Jamaica, has been tranquil, and the wind at south of east for several weeks, there will sometimes come a violence of sea upon the northern shores, which has been produced by some long-continued wind upon the Atlantic farther to the north, but which feels its way, notwithstanding all the tides and currents, darkens the sea for many miles with unbroken waves where the water is deep, then breaking in thunder on the shores, tossing about the pebbles of the beach and the small fragments of the rock as though they were chaff, and dashing in angry spray to the height of more than a hundred feet. While those northern swells last, they put an end to all intercourse between the smaller islands; and as some of these depend upon others for food, the people are occasionally reduced to great extremities by this violence of the sea, at the same time that there is no disturbance whatever in the atmosphere.

We shall now very shortly glance at the progress of the eastern, or European, tides. The one o'clock line, besides being detained on the coast of Africa, is held back by the Canary and Madeira Islands, and again by the Azores, in the southern part of its course; but it is regular in the northern, its advance being most rapid in the middle latitude. The two o'clock line is also held back by the Canaries, but approaches regularly towards Europe in the remainder of its length, though no part of it reaches the coast. The entrance of the Mediterranean gives the tidal wave scope eastward, though there is little or no tide in the Mediterranean itself; and thus there is a point of divergence near its entrance, and a portion of the tide sets south-eastward against the shore of Morocco. The three o'clock line touches Cape Finisterre, but does not fall on any other part of the coast. The four o'clock line makes the tide in the Bay of Biscay, bends a little way up the channel, and reaches the Island of Ushant, and approaches near the Scilly Isles, and the south-west point of Ireland, but does not touch any part of the British shores. From this there are generally eight hours tide in the Channel,—that is, the tidal wave takes eight hours to reach from the entrance to some point between Dover and Ramsgate, where this tide is extinguished, as a British tide, by the one which meets it from the north; it however passes slowly along the coasts of Holland and Germany, and meets the north tide, which is here a much stronger one, at a point near the north end of Jutland. The time of passage from Dover to this point of confluence is somewhere about twelve hours, so that both here and in the Channel there may be a complete tide, from high-water to high-water, or from low-water to low-water, as much as there is in the whole length of the Atlantic. If we turn to the seas and channels between Britain and Ireland, we have eight or nine hours of tide to near Port Patrick, where again there is a confluence with the north tide.

When we go westward to the ocean, where we left the four o'clock line near the south-west of Ireland, we find the five o'clock line at Achile Island; the six o'clock line at the north point of Ireland, and near the southern points of the Hebrides; the seven o'clock line near Cape Rath, the north-west point of Scotland; and the eight o'clock line at the north of Orkney, having now changed its position, and lying in the direction of south. west and north-east, by the tide turning round on the British Islands as on a centre. Hitherto, the march in the open sea has been comparatively rapid, but it slackens as the tide wave advances up the eastern coast of Britain. The nine o'clock line is opposite the middle of the Orkneys; the ten o'clock line touches Duncansby Head; the eleven o'clock near Wick; the twelve o'clock near the Ord of Caithness; the one o'clock at Stonehaven; the two o'clock at St. Abb's Head; the three o'clock at Newcastle; the four o'clock between Whitby and Scarborough; the five o'clock between Hamborough and the Spurn; the six o'clock at the Dudgeon Lights; the seven o'clock at Cromer; the eight o'clock at Yarmouth; the nine o'clock at Lowestoffe; the ten o'clock at South Wold; the eleven o'clock at Orfordness; and the twelve o'clock across the entrance of the Thames, near Margate, where this tide and the tide of the Channel meet. There are many points of great interest connected with the minor and local phenomena of those tides as well as with their general succession; but they belong to navigation, as a practical art, rather than to that general knowledge which is useful and necessary for every one; and besides, we have no space left for them. We trust, however, that we have said enough in this and the preceding sections to show that the sea is well calculated to reward and gratify every one who chooses to make it a subject of inquiry; and that the great waters is so far from being the waste portion of our planet, that it is the one upon which the fertility of the land substantially depends; that it is rich in its own productions, and splendid in its own phenomena; and that, in no part whatever of creation, are the power, the wisdom, and the goodness of God, more forcibly, more instructively, or more delightfully set forth.

SECTION X.

CONCLUSION.

In the survey which we have taken of the more general and striking phenomena of the sea, we are brought exactly to the point at which the details of this extraordinary portion of creation can be begun to be studied to advantage; because what we have endeavoured to explain embody the leading properties of sea-water as an element of the disturbances of that water arising from the different characters of the two hemispheres, and from the alternating seasons of those hemispheres, from the varying influences of the sun and moon, in their union and their separation, as months and years roll on, and from the interruptions offered to the movements of the ocean, whether of mere tide wave or of current, by the opposing land. Thus we are in possession of at least the outlines of the powers and capacities of the sea as an element; and the next stage of the inquiry would be an examination in detail of all those other parts of creation upon which the sea, as an active element, can have influence. This part of the subject branches out into so many details, that it actually becomes the subject of many sciences, each of which would require not one volume only, but several volumes, for the enumeration of its mere outlines.

The consideration of these, if our limits admitted of entering upon it, would resolve itself into two distinct branches—the contemporaneous influence of the sea, and its progressive influence. The first of these would, of course, relate to what we observe as produced, or in the vigour of production, at the time of observation, and would be told in the present aspect of the productions of the sea itself, and of those lands which the sea may be supposed more directly to influence, at the very time when our attention were directed to them, without any reference to the past, or any anticipation of the future. The second would have reference to that which has already happened, of which the memorials are in the solid parts of the earth, and from which, as experiments which have already been made by the grand active powers of nature, we may, in part at least, infer what shall happen in future periods. In the first of those inquiries our labour is simple, because the whole is before us, and our data, both as to the substances and the different kinds of action among those substances, are grounded upon the present and palpable evidence of our own senses. But in the other there is a shadowy and mysterious difficulty, which carries us backward on the one hand, and forward on the other, beyond any periods of years which we can number. When we look at various kinds of stone, we can trace the form of waves in them; and though we cannot say positively that those waves have consisted of fresh water, or of salt water, because the water and all its products are gone, we find something so perfectly analogous to what is directly seen in those furrowed banks of sand and gravel which are produced by the action both of river currents and of sea tides, that we cannot for a moment doubt that the cause of those monumental wavings which we find in the mass of the rock, is precisely the same as those effects of waves which we see newly imprinted upon the beds of rivers and the shores of the sea.

In the vertical sections of many of those sandstone rocks, which it is perfectly evident have been formed by the action of water, we meet with the same identical appearances which present themselves when we examine the surface of banks of sand and gravel which have been evidently formed by the action of agitated water, whether of river flood, or of tidal or other current in the sea. We find that the crests or principal elevations of those traces of waves, or of the action of waves, in the rock, are composed of the smallest particles; that the larger ones, which, from their superior gravitation, are better able to resist, are lodged in the troughs or hollows; and that in the section of a portion of rock of this kind there is clear demonstration that the waved or furrowed appearance has been produced by the opposing forces of the motion of waves in the water, and of the gravitating influence of the portions of solid material. There are so many instances of this species of formation in different kinds of rocks, that we are not left in the smallest doubt as to what has been the means by which they have been consolidated; and though we do not call in the aid of fire to assist in the process of solidification, we can easily understand that, under a sufficient pressure, even of water, those rocks may have acquired the consistency which we find them to possess.

It is farther worthy of remark, that when rocks of this kind consist chiefly of sand, there are no remains of shells, or other products of marine animals, in their whole structure; and this accords exactly with what we meet with in those parts of the existing sea in which sand banks are formed. A bank of pure sand or silicious matter, formed by the sea, contains no more of the elements, or the means of life, than a similar bank formed on the land; and shores which have their bottoms of this character and consistency are remarkable for the few animals which they possess, as compared with banks of a different character.

In adverting to the sea-banks, it may not be amiss to state, and to bear in mind, that the shells and crusts, which are the products of sea-animals, are often found in large beds, after they have been ground to pieces by their attrition against each other and against the bottom. Those animal productions are, generally speaking, of more tender fabric than the rocks which afford the silicious and other earthy matters; but the difference in specific gravity is so small that they mingle freely with each other; and hence we find, that in many of the rocks which are evidently of aquatic origin, there is a remarkable union of the carbonate of lime with this silicious matter, and that this lime contributes, in no small degree, to the cementing of the particles together. This is obviously the origin of those freestones which contain an admixture of carbonate of lime with particles, or small crystals, of silicious sand; and the species of stone which have this composition are generally very valuable in building, because the nature of such stone renders it in a great measure indestructible by the action of the atmosphere, at the same time that it is soft and easily worked.

Of what we may consider as the immediate influences of the sea, without any reference to long successions in time, there are many instances to be found on examining the map of the world, and attending to the set of sea currents, sea tides, and sea influences, against the shores of the land. In noticing these, we must of course attend to the circumstance of whether those influences of the sea are permanent or periodical, because we may expect corresponding differences in the results. Now, on the coasts of India, the west coast especially, which is visited by a monsoon blowing from the south-west, and bringing the influence of the sea along with it, we find that, while this monsoon lasts, there is a very exuberant vegetation. On the countries situated to the north-east of the Bay of Bengal there are two monsoons, each of which brings a great quantity of moisture; and, though the ground there is in many places swampy and unhealthy, vegetation is exceedingly vigorous. In the oriental islands, too, where both monsoons may be said to be from the sea, there is perpetual verdure; and it depends upon local circumstances whether the eastern or the western monsoon shall be productive of the greatest luxuriance. If the country is comparatively narrow, and the sea wind sweeps over it, without being interrupted by mountains or any other physical obstacle, it often happens that the sea wind, if it blows from a colder latitude to a warmer, blows in vain, in as far as fertility is concerned, and actually parches and withers the ground almost to the same extent as if it were a land wind. But if, on the other hand, such a monsoon blows from a warmer to a colder latitude, it becomes a moist and fertilizing current of the atmosphere in proportion as it gets into a higher and colder latitude. We have remarkable instances of both of these results in Southern Africa, in which country the south-east monsoon, which blows entirely from the sea, is one of the most drying winds with which we are acquainted, inasmuch as it comes from a cold sea to a comparatively warm land. But, on the other hand, the north-west monsoon, which in that country blows from the tropical, or at all events the warmer, regions of the Atlantic, produces torrents of rain, and the country is covered with a corresponding vegetation. In the southern parts of America, the effect of the south-east wind appears to be nearly the same; and this we might expect, as the position of the countries with regard to the wind is not very dissimilar; but in this part of the world the Andes interpose their barrier, and the character of the interior is somewhat different.

It is in the North Atlantic, however, that we find the most remarkable effects of the influence of the sea. The tidal wave there, as we have already explained, sets northerly, trending towards the north-east as the high latitudes are approached. This is accompanied by a general set of the atmosphere in the upper regions, which the smaller rotatory motion, as higher latitudes are gained, turns into a south-west wind, and this wind descends nearer and nearer the surface as it gets farther to the northward. The general effect of this is the distribution over the North Atlantic of a current of air which comes from the equator—the parallel of maximum heat and evaporation, and which, consequently, is more and more disposed to part with its humidity as it advances farther and farther towards the north.

We have already alluded, in general terms, to the character which this northward movement of the influence of the Atlantic stamps upon the countries on both its shores in the middle latitudes, and especially upon the coasts of Europe farther to the north, after the general set of its influence has been turned more directly toward that continent. The effect of this is very remarkable both in summer and in winter. In the former of these seasons it brings frequent showers, which not only water and refresh the vegetation, but tend to keep the air much cooler than it otherwise would be, from the almost continual presence of the sun in the high latitudes. In the winter its beneficial effects are even more conspicuous,—so much so, indeed, as to to cause a difference almost equal to twenty degrees of latitude between the parts of Europe which enjoy this influence of the Atlantic, and the parts of America from which, in consequence of its trend to the north-east, it is turned away in those latitudes.

But the constant set of tropical influence to the northward through this ocean tells upon the northern part of the ocean itself, as well as upon the adjoining lands. Though there is not in any sea an actual transfer of the water bearing any proportion in velocity to the motion of the tidal wave, yet there is some transfer. On the American shore this amounts to the gulf stream, the set of which is distinctly visible, and it continues, though at a diminishing rate, along the margin of the polar ice, in the direction of Spitzbergen and the north of Asia.

There is no return of this water from the north along the western shores of Europe; for, though there is a return of the tide wave southward, on the east coast of Britain, it does not get beyond Dover, while, on the coast of the continent, the tide wave from the south proceeds northward to nearly the entrance of the Baltic. But as little does this water accumulate in the north,—for if it did, the current would in time be stopped. It must therefore circulate; and the only way in which it can circulate is round the northern extremities of both continents, so as to return south through Davis's Straits; and there is no doubt that it is the circulation of this water through the whole of the Arctic Sea which renders the cold in the north of America so great.

The genial influence which is thus constantly carried into the northern part of the Atlantic is not, therefore, again carried out to any other part of the globe, but remains in this ocean, or in the influence which is produced on the adjoining lands. And we find the beneficial effects in the ocean itself and in those seas which inosculate freely with it. The result of this is an exuberant fertility of the waters of the north, to which there is nothing corresponding in an equal latitude, or indeed in any latitude.

In proof of this, we may mention the countless myriads of the different species of cod, of herrings, and of other fishes, all of which are of great value to man, but which are few in number, if not altogether unknown, in almost every other sea. This is the only part of the sea where fish are obtained in such numbers as to be an article of commerce with distant countries; and though the numbers that are captured for this purpose are very considerable, they are not missed. We have mentioned, incidentally, in a former section, the vast productive power of the common cod, and we may now mention that even that power is exceeded by the productiveness of another and more northerly species, the ling, which is, in some respects, a superior fish to the common cod. Between nine and ten millions of eggs have been counted in the roe of a single ling; and there seems to be little doubt that the full-grown fishes can, upon the average, bring that number to maturity. The productive powers of the fishes of other seas are not so well known; but it is probable that there are none equal to this; and there are certainly no fishes in any part of the world which, taken altogether, are equal in value to the white fish of the Atlantic. There is another circumstance worthy of consideration in this singularly productive sea,—that, in the temperate latitudes of it, it does not appear that there is a single poisonous fish.

But interesting as is the contemporary state of the sea, and great as is the advantage which the concentration of its influence upon any particular spot is capable of conferring, it is nothing to the operation of those general powers of nature which, under ordinary circumstances, slumber silently in the deep,—but of the working of which there are sometimes displays, and the effects of which are very conspicuous upon almost every known land.

By the influence of water derived from the sea, the powers of growth and life in the animal and the vegetable kingdoms are sustained, and kept in an active and working state; and it requires only a little observation to convince any one that the same agencies are at work for the production of new lands, though in this the process may be presumed to be slower in proportion as the result is greater,—which is in strict obedience to the general law of production, as displayed in every department of nature.

If we look anywhere around us, we cannot fail to observe that all the solid parts of our planet which are not immediately under the laws of growth or of life, or which are not buried to such depths that they are out of the reach of action of every kind, are in a state of constant decomposition. The process may be much slower in some cases than in others, but though slower it is not the less sure; and as decomposition takes place, the parts into which rocks and other solids are reduced are always brought nearer to one common level, from which there is not, in the substances themselves, any power whatever of return. In many parts of our own country, we have proofs that the granite itself, which we consider as one of the strongest and most enduring of rocks, has yielded to the influence of the weather, to the action of the atmospheric air, and of humidity originally derived from the sea. The silicious, or flinty, parts, which cannot be reduced to an impalpable powder by any common action of air or moisture, and which, consequently, do not form a paste with water, are left free and detached on the surface, while the clay, on which water has greater action, and which it reduces to a state of much more minute division, is separated, left behind in some instances, and borne off by the water in others, but deposited in different situations from the silicious matter. This silicious matter, which forms the principal ingredient in all those accumulations which we call pure sand, is a sort of intermediate between the exceedingly small pieces, or particles, into which the clay matters are divided; and all the three are deposited in different situations,—the clay in the still water, or in the eddies where it revolves, the larger fragments in the currents, and the sand in intermediate places, where there is still a considerable current, or a conflict of one current against another,—as, for instance, of the fresh of a river against the tide of the sea. In the case of rivers, the order of depositing those materials is very often this:—First, or highest up, the clay forms banks which broaden into meadows; secondly, the larger fragments, in what may be considered the principal place of conflict between river and tide; and thirdly, the pure sand, which is carried more to seaward, and may be said to belong to the shores and bottom of the sea more than to the banks and bed of the river.

In the formation of those seaward banks, the sea itself is concerned, not only in resisting the materials brought down by the river, but in adding materials of its own. When the sea invades one portion of the coast, as it does many parts of the east of England toward the south, it must of course deposit the materials in some part of its bed, or on some other shore. But we are at present speaking of those materials which the sea actually furnishes toward the formation of a bank, without receiving them from river currents, or seizing them by wearing away the land. Now the only matter of this kind which the sea is capable of producing is the matter of shells, which are formed by those molluscous animals which are so plentiful in the sea, or the crusts of other races, such as the different crabs and lobsters, and the habitations which more minute creatures make for themselves, and which, though of an endless variety of forms, are all popularly known by the general name of coral insects, though the use of the word 'insect,' as applied to them, is by no means correct.

The annual production of the sea in matters of this kind is incredibly great, as any one may discover by examining the rocks on any of our own shores, during the summer or productive season; for very often these are so beset with little shells that scarcely a pin's point can be brought in contact with the rock without touching them. These shells, and crusts, and coral formations, contain varied quantities of animal matter, but lime is the ingredient to which they all owe their hardness. This lime generally exists in the state of carbonate, the same as in chalk, common limestone, and marble, though, in the crusts, its combination is phosphate, approaching more nearly to that of the lime of bones.

Of all these substances, an immense quantity must every year cease to be part of the living world in the sea, and must be rendered up to the general store of dead matter there, in the same manner as withered leaves, sapless stalks, the cast coverings of animals, and the bodies of those which die but are not devoured, go to the general mass of dead matter upon the land. These, no doubt, undergo some decomposition as soon as the connection with life is at an end; but in the more compact ones, this process is slow, and it is slowest in those deep-sea shells, of polished surface and firm substance, which, from their resemblance to the finer kinds of potters' ware, are known by the name of porcelain shells.

Many of those deep-sea shells are so firm in their structure, that they are brought to the beaches, especially of the tropical seas, in an entire state, where they are gathered and eagerly sought after by the collectors of natural curiosities; and independently of their shapes, their colours, and their lustre, many of them are curiosities, inasmuch as they inhabit the sea at such depths as not to be known in the living state. Very many, however, of shells and shelly matters are broken by the agitation of the waters, and form a sort of sand which is truly a product of the sea, and which is very frequently cast on places similar to those which receive the sands which the land affords, so that the two are often blended together.

Whether the land or the sea contributes most to this annual accumulation, or we may say incessant accumulation, of matters in the bed of the sea or on certain places of its shores, we have no means of ascertaining, but from what has been hinted, it will readily be perceived that the accumulation must be considerable; and as we nowhere in nature meet with an accumulation of matter which appears to be final, we may naturally suppose that, at some period or other, those accumulations of waste which the motions of the ocean waters collect into stores shall be brought back again, in terms of the general law of nature, to perform new and important functions in the economy of our planet. And when we examine very many of those rocks which compose the solid parts of the land, and which are evidently not immediate products of growth or life of any kind, we find them composed of matters precisely similar, both in kind and in arrangement, to those accumulations which are constantly taking place in the sea. We find also, that they alternate, or rather lie around other matters, which, if they have not had a different origin, must at least have undergone some process—the operation of some very powerful cause—which has changed them to the state in which they are found, and at the same time elevated them high above the others. Of those last-mentioned rocks, granite, and those others which may be regarded as belonging to the same class, are the most remarkable, as appearing to have been produced by the most extended action, and as forming the central masses of the greatest mountain ridges that appear on the surface of the earth.

Nor need we be at any loss, or any doubt, as to the natural power—the agent in the hands of the Almighty—by which those grand results have been brought about. We have seen in a former section what terrible resistance the pressure of the ocean waters exerts at depths less than those which the most rational analogies assign to the free parts of the great oceans. We farther know, that the power of action in matter, taking it simply in that modification which we call heat, or fire, can be increased to a degree of intensity so as to overcome any resistance that can be named or imagined—so as, in fact, to divide—if it should be the purpose of Heaven so to divide—every particle of matter in the earth from every other, and so to scatter them throughout the universe that even the imagination would seek after them in vain.

This being the case, we can readily understand how this same kind of action, resisted by the pressure of the waters, might reduce the upper parts of any accumulation of matter in the bottom of the deep to the consistency of those rocks in which we find the fragments of other and earlier rocks adhering together, but not changed; and also how, when the resistance of these came to be added to that of the water, they together might bring up the confined action to a degree of strength at which it should not only totally change the appearances of the materials below, but rend asunder the upper crust of condensed strata in the deep, and ascend, carrying the fragments sloping on its sides to the height of the highest mountain now known on the earth's surface, or, in fact, to any height below that at which the solid materials of the mountain's base would give way to the pressure of the superincumbent mass, and the mountain would be crushed by its own weight, until it had sunk down to a level proportionate to the strength of its materials. It would follow, also, as a necessary consequence, that the space from which an extensive mountain formation were thus upheaved, could not remain long empty after the action producing the mountain had ceased; and the result of this would be a depression of substance below the common level, exactly equal to the elevation of the mountain above it.

We have no room left to pursue this very sublime and very wonderful power of action in nature,—a power by which, if it were let loose—and we know not in what chains the mercy of Providence restrains it—the lowest bed of the present Atlantic might be made to overtop the present Andes, and Africa on the one hand, and America on the other, might both be placed miles below the mean level of the tide. But we could not imagine any such action to take place without the instrumentality of the sea, as a means of resistance; and therefore, as the water derived from the sea is a grand element in the renovation of all the products of the land, after burning drought or withering cold has passed over them, even so there is in the sea the means of preparing new continents, and new islands, which may arise and be peopled with new races of animals, and clothed with a new vegetation, when the present lands shall have numbered the appointed years of their duration, and are gathered to their tombs in the deep. This is a subject fraught with the most spirit-stirring reflections, but, in the mean time, we are unable to follow them out.

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