THE HEAVENS.

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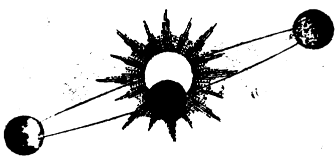
"A GUIDE TO THE OBSERVATIONS OF NATURE," &c. &c. &c.



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PREFACE.

This work has no pretensions whatever to be a system of technical astronomy. Indeed, considering the number and value of the works on celestial science which already exist, it would be both presumptuous and unnecessary to add one to the number. Splendid beyond all expression, and even beyond all imagination, as the heavens are, the science of them is at once the simplest and most perfect of sciences; and, to those who approach the study in a systematic manner, with all the systematic aids about them, there is, perhaps, none of which even a profound knowledge is more easily acquired.

But still it is very doubtful whether even the very perfection of this science is not the means of keeping the great body of the people in ignorance of it. There is an expense in the acquiring of good instruments, and a labour and skill in the using of them, which must preclude them from ever being available to the great body of mankind. It is to be feared, therefore, that very many give to the science of the heavens that sort of tacit or unreasoning assent without knowledge, which is felt in some other departments of science. At least, I can only say that my observation has led me to conclude, that the portion of astronomical knowledge possessed by those who have not, in some measure, devoted themselves to the study as a pursuit is exceedingly limited,—consisting of little more than the capacity of pronouncing a few words, of the meaning of which they know nothing;—and I think I have observed this to produce, upon the structure of the mind generally, and, through that, upon the whole conduct and character of the parties, the same sort of blighting effect, which never fails to be produced in every case where real ignorance is glossed over with the colours of apparent learning.

It has always appeared to me that this is partly owing to the nature of the subject itself, and partly to the form in which those books which profess to instruct the people in this science are presented to them. When we speak of millions of miles, and of weights which are more than twenty figures deep in tons, and state that the heavenly bodies influence each other at those vast distances, and that these mighty masses are balanced by their mutual action, so that they career about in the regions of space, of which, though the measures are expressible in numbers, they are beyond comprehension to the mind, we can hardly expect that those who are unacquainted with analogical reasoning can take so vast a step, as from an ordinary yard measure to the distance of the sun, or from a common weight used in the business of life to the volume of that mighty luminary. This is the difficulty of the subject itself; and I have sometimes thought, because I have perceived it in fact, that the book which professes to be popular tends rather to augment than to remove this difficulty. The results are stated, no doubt, with accuracy; but no notice is taken of the means by which those results are arrived at. We are informed that that part of the system of the universe, which is so much within the range of our observation as that we can measure it, consists of a certain number of bodies, or masses of matter, to which names are given; that each of those is of a certain figure and magnitude, performs certain motions of revolution and rotation, and seems variously adapted for being the abode of living creatures. We are informed of these, and many other circumstances, down to minute particulars, with the same confidence as though we could lay our right hand upon the sun and our left upon the most distant planet, measure all their distances with our span, and feel their weights in the palm of our hand. But the book professing to be popular gives us no insight into the process by which those results are arrived at. They are set before us as assertions —bold and beautiful assertions certainly—but still nothing but assertions; and as there is not, in our common knowledge and judgment of facts, upon the earth, any means of connecting that of which we are practically certain with those stupendous results, the mind falls down before the idol, and worships a false knowledge, for the very same reason that the benighted heathen worships a false god—utter ignorance of the One which is Truth.

I have farther observed that there is on the part of every one, and of the young especially, a desire to possess knowledge on this subject, of a more ardent character than that which is felt and expressed towards anything else which can occupy the mind; there is a feeling of immortality even in the simplest contemplation of those stupendous works of the Creator, which are exalted above the casualties and vicissitudes of sublunary things. Days and years roll on, plants spring up and wither, animals are born and die, the human body is laid in the dust, kingdoms and states are founded and fade away, old land is swept away by the action of the waters, new rises from the bottom of the ocean—all is changed, ever perishing, ever renewing; and from every evidence which we can collect, this appears to have been the state of the earth's surface ever since the Almighty called it into being. To this perpetual change of everything observable on the earth, there is a very remarkable contrast in the stability of the heavens; and there is nothing in the whole of that vast structure which leads to even the supposition that a single mass of it can perish, unless at the express and immediate command of its Maker. This feeling is quite inseparable from even the simplest and least informed contemplation of it; and hence it is, that, through the system of the heavens, the mind naturally takes hold of immortality; and in viewing the works of God in what must be considered as at once their most pure and their most splendid state, there is produced a knowledge of, and a reverence for, the God of nature, as a spiritual, and infinite, and an eternal being, which do not arise on the contemplation of even the most fair and fascinating of his earthly works.

I have also observed that though there is a wide gulf between our practical knowledge of earthly things and the knowledge of the heavenly system, there is great aptitude, as well as great desire, for passing this gulf, and that, so to express it, the most slender bridge suffices to carry the delighted reader across,—that there is, as one would say, an uplifting of the mind, in consequence of which we contemplate the motion of planets and of systems as being performed, as in truth they are performed, with less resistance and less labour than the crawling of a worm across our path,—that if we can but "show *how*," in one or two of the leading points of the planetary motions, the mind of the student, even with little technical preparation, will claim kindred with those vast bodies in their astonishingly rapid career, and feel that it is there at home, and working free from the burthen and trammel of the flesh.

This I have observed so often as to have become fully convinced that there is a popular road to this science which is both short and easy; and, acting on this conviction, I have endeavoured to make the present volume a very humble finger-post in this delightful path. I have done so, not by describing the end to be arrived at, but by attempting to describe the way; and I have endeavoured, regardless of whether I myself shall or shall not be considered informed upon the subject, to lay hold of and explain, with some breadth of expression, and with as much familiarity of style, as appeared at all consistent with the nature of the subject those great principles which I have found by experience to be the chief stumbling-blocks in the way of those who seek popularly for instruction. I am well aware of the difficulty of such an attempt, and I wish my hope of having succeeded were equally apparent; but others may follow and improve, and in the end this most delightful branch of human knowledge, which gives to the mind at once its most natural and most arousing exercise, may be freed from the mysticism of an unknown tongue—for such, in truth, is the language of exact science to the great body of the people.

I have endeavoured to point out how, by the application of those common means of measuring and of weighing with which every one is familiar, we may arrive at a knowledge of the distances, the magnitudes, the masses, and the motions of all the heavenly bodies, or be able to state, with certainty, that their distances are beyond all mensuration. I have endeavoured, for the first time I believe, to explain, in common language, the law of the planetary motions; and I have endeavoured to analyze the balancing forces which sustain the heavens into their simple elements, and to show which of these elements are constant, and which admit of variation. Hence, the law of variation in the different planets, and in every several planet in different parts of its orbit, are easily deduced. In order to get a foundation, I have shown, using some diagrams in illustration, the impossibility of the earth being a plane surface; I have, with as much plainness of expression as possible, endeavoured to point out the errors of distance, magnitude, and motion, both on the earth and in the heavens; I have attempted to show, from first principles, the nature and stability of motion in an elliptic orbit, and because I have always found the change of distance and of rate which takes place in the perihelion and the aphelion to be one of the perplexities, I have laboured this point with no inconsiderable degree of attention. If the reader shall collect and carry forward the remarks—

for summing up was incompatible with the size of the work, and would have been inconsistent with my plan—as far as the ninth section, he will be able to see how the general principles are made to bear upon what is practically observed; and that our knowledge of the heavens, as expressed in numbers, rests on a surer foundation, and is as accurate, as any similar expression in the most familiar business of life. The view which I have given of the bodies composing the system, as lying within the range of accurate observation, is very brief; and, indeed, in no part of the work have I entered into the detail of the particulars. I do not profess to teach astronomy by these pages, but I am anxious that the reader should learn this science, and learn it for himself, in the direct contemplation of what he observes around him. In this, as in all that God has made, it is nature itself which is THE BOOK, and one man can do little more for another than entice him to the direct perusal of this volume; and it has this charm above all human learning, however valuable, that it is impossible to study the works themselves without that impression of the Author, which gives to the study its highest value and its most exquisite delight.

How far I may have succeeded in my object is for others to judge; if the book shall not be favourably received, the fault must be mine. Yet here I would not willingly forfeit that good opinion which a liberal public has so repeatedly and so largely bestowed upon me.

ROBERT MUDIE.

Grove Cottage, Chelsea,
April 10th, 1835.

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THE HEAVENS.

SECTION I.

INDUCEMENTS TO THE STUDY OF THE HEAVENS.

It is scarcely necessary to mention that, in ordinary language, the Heavens is the general name for the material creation, with the exception of our earth and its atmosphere. Literally, the word "Heavens" means "that which is elevated;" and we sometimes make use of the word "firmament," which literally means "that which is solid," but which, as applied to the heavens, means "that which is self-sustained"—that which, by laws which the Almighty Creator has given to it, supports itself under every appearance of irregularity and departure from those laws, and which will continue steadfast to them, and secure under their operation, until it shall please Him, who at the first called all things out of nothing, to command them back again in whole or in part.

We are thus to understand that, in the language of science or human knowledge, "the Heavens" is a general name for every material body, of what nature, form, or size soever, which exists at a greater distance from the earth than those remotest parts of the earth's atmosphere in which the lightest meteor can appear. We are also to understand that "the firmament" does not mean any material existence, for all material existences are comprehended under the words "the Heavens" and the earth. But the firmament is a general name for that universal law which God has given to the material creation, for sustaining it and all the parts of which it is composed, to the accomplishment of the purposes of his will.

In this sense, and it is the only correct one, we may, when we make a distinction of the heavens and the earth, speak of the firmament of the earth as well as the firmament of the heavens; though, in reality, the two are one—the earth being part of the system of material nature, the workmanship of the same Author, and obedient to the same law. To our limited observation and comprehension, this law appears to be varied without end, new at every inch of space and every moment of time; but, as the Almighty Lawgiver is one and unchangeable, so the law which he has given to His works is one and invariable in its principle; though so diversified in its applications and results, that these are new every instant,—and every novelty brings a freshness of delight greater in proportion as the law is longer and more intimately studied.

The senses of the human body are weak in their perceptions and limited in their range, as compared with that mighty volume of instruction which God has bountifully spread wide for us in the beauty of the earth and the glory of the heavens; and, that our enjoyment of his bounty might be secure, he has made it the law as to our nature, that we can know the material creation and its modifications of the law only through the medium of those limited senses. But he has given us the capacity of receiving and recording the results of the experience of others; so that, in any age, one, who is placed in the proper circumstances, (and in a country like Britain these might be attainable by every one,) may possess himself of the results of the observation of all former ages, and derive from them, if not the same pleasure to the senses, at least the same mental instruction, and, if he apply it rightly, the same moral improvement, as if he had seen with his own eyes, heard with his own ears, and handled with his own hands, from the very earliest period of the record.

If God had given to us nothing more than this, it would be ample ground for our highest gratitude, and the most willing obedience to his laws on our part. But this enjoyment of the advantages of observation in all past ages forms but a very small part of the endowments which he has bestowed upon us, and for the exercise of which we are accountable to him. We can, in thought, actually live at any period of time, or at any place in the universe, of which we have any knowledge; and we can do this without labour and without expense, be our situation or our circumstances what they may. Our bodies partake of the qualities of the matter of which they are composed, and, therefore, they are confined to those qualities; and though the ear can take notice at some considerable distance, and the eye can see into space farther in miles than we can understand; yet, as no one sense of itself individually can give us knowledge farther than the mere material impression that is made upon it, if our nature extended no farther than matter, even in the most curiously constructed of our organs, we should be ignorant indeed—the feeling of the moment would perish with the moment, and the memory of the life would cease with the life itself.

But, in the possession of our intellectual part—of the immortal spirit—that "breath of life" which God was pleased to breathe into man, and no other inhabitant of the earth—we have a heritage secured against all the vicissitudes of material things, without the pale of their laws, and entirely free from that change and mortality to which, in the very fulfilment of those laws, they are subject. Nor is this all; for, even when within the body, the mind is unfettered by the laws of matter. Space and time are not elements in its working; for it is as easy for the mind to go to the most distant star in the sky, or to a distance ten thousand times more remote, as it is to go to the finger of that hand which belongs to it. It is only to think of any object, wherever situated, and whenever existing—past, present, or future—and, if we think with proper information, it stands as clearly revealed to the mind, and as ready to render up to the store of our knowledge whatever tale it may have to tell, as though it were present before our mortal eyes.

This is our glorious privilege naturally and as men. It is in this, and in this only, that we stand elevated above all the other living creatures by which we are surrounded. It is this which is "the talent" which God has committed to us in order that we may improve it; and we shall not escape the just judgment which he has denounced, if we "bury this talent in the earth" of mere bodily gratification. If we neglect it, and choose the world's possessions as all our desire and all our inheritance, we must, even in this world, abide the consequences; and, leaving religion and morality altogether out of the question, we must be the victims of continual misery,—inasmuch as every worldly reverse must be a blasting of all our hopes, and along with that a withering of all our powers of exertion. But, if our chief happiness is in the exercise and enjoyment of the mind, our hopes are elevated above all temporal contingencies, and we not only stand secure in the common calamities of life, but death itself is to us a ground of glorious hope and fond anticipation, as the event by which we shall certainly be absolved from all the care and trouble which the body costs us, and left to the full and uninterrupted enjoyment of knowledge which is unbounded, and happiness which is complete.

This ought to be the grand object of every man's hope—that to which everything else should be secondary; and, if we pursue it aright, it has this grand advantage, that it enables us to perform all our labours, and discharge all our relative duties, far better, and with much more heartfelt pleasure in the doing, than if we did not possess a single thought beyond them. Compare a civilized country, such as England, with many regions of the world, apparently much more bountifully endowed by nature, but upon which the light of knowledge, and, above all, the light of revelation, which has given to merely human knowledge the grand elements of its power, and the chief attributes of its beauty and its usefulness, and remark the mighty difference that there is between men who do exercise their minds in thinking, and thinking of remote objects and distant events, deducing general laws from the succession of particular appearances, and knowing the works of God, in so far as man can know them, in those relations in which he himself placed them, and those men whose thoughts are confined to the mere supply of their bodily wants and the mere gratification of their animal passions at the moment of their excitement; and you will require no further proofs of the incalculable advantages, both to nations and individuals, which arise from the exercise of thought, and the elaboration of that thought into science. Very many of our choicest possessions have been, and still continue to be, fetched from lands the inhabitants of which have been in possession of them for thousands of years; and yet they never derived the slightest advantage or gratification from them, save haply a very small portion learned, at second hand, from those inhabitants of Britain, or of countries resembling Britain, by which they have been visited.

From what has been said, and we may naturally suppose that many feel as has been said—though they will excuse the repetition, for the sake of many who have not so felt—it must be evident that, in order to arouse the mind to the greatest and most useful degree of exertion, we ought to lay hold on those subjects which give it the widest range. The mind from its very nature never can be fatigued and exhausted as the body is, and therefore we need be under no apprehension of tasking it too much. The grand object, the ultimate goal at which the mind can arrive in pursuing the knowledge of created things, is the knowledge of God the Creator, in as far as an infinite being can be known by a finite one. Therefore it is desirable that, as early in life as possible, every one should be put in the way of arriving at this knowledge by the shortest and surest means, not only for its own sake, which is paramount as being for eternity as well as for time, but as the proper foundation of knowledge of every description, of good conduct in every situation and scene of life, and as preparative for the proper understanding and the ready and hearty embracing of that religion which, as it relates to immortal things and not to anything connected with the material creation, splendid and instructive as that creation is, can be arrived at only by the same diligent study of the revealed word of God, which in nature is necessary to a right understanding of the God of nature.

Now there is no subject of which the contemplation is half so well adapted to the accomplishment of this end as the heavens. All the parts of that are of vast size as compared with anything which we can observe on the surface of the earth; all the distances of the bodies from each other, even the shortest ones, approach infinitude according to our ordinary judgment; all the motions are rapid beyond anything of which we see on the earth; and the power with which they move is beyond anything of which we have even the smallest conception. To give some notion of the immensity of this power, we may mention that if the earth which we inhabit were, in the course of its motion round the sun, to strike against any obstacle by which that motion could be stopped, the collision would be so terrific, and the heat thence so great, that not only would the earth be shivered to atoms, but all the parts of it, liquid or solid, would be instantly turned into vapour, altogether invisible and inscrutable by any of our senses, or any of our instruments; and it would in fact be, in so far as our observation is concerned, as though it were blotted out from the universe. As to the motion again, we may mention that many of the celestial bodies of which the progress, to our observation, is not above half the rate of that of the hour hand of a clock, yet career on at such a rate that if the largest mountain in the world were to pass us within a few miles at half the velocity, the swiftness of its motion would make it perfectly invisible.

We shall afterwards have occasion to enter so far into the particulars of some of those wonderful powers and motions as may appear to us necessary for awakening the desire of the more detailed knowledge of them, and inducing the reader to seek that knowledge in the systematic books, or by any other means through which it may be acquired; and, above all, of leading to the contemplation of this grand volume of the book of creation itself, as it stands open to every one having eyes to see, and a mind willing to understand; so that we shall in this section only farther observe that the laws by which the mighty structures of the heavens are sustained, and in consequence of which they perform those wonderful motions and possess those wonderful powers, are far more simple than those upon which man constructs the very rudest machine that he uses in the arts; and that though bodies which are larger as compared with anything on the surface of the earth of which we can have the least idea as separate pieces of matter, than the largest of those pieces is in respect of the lightest mote which dances in the sunbeam, yet so very perfect is the system, and so harmonious is the working of all its parts, that it does not so much as bend the most slender cobweb, or disturb any one function of life in those small animals, thousands of which would not make the size of a pin's head. This adaptation is so perfect, and altogether so superhuman, that it alone would demonstrate, in a way not to be questioned, the power and the attributes of an Almighty Creator and preserver. The finest piece of mechanism which human skill can contrive and human dexterity can execute, even when all the parts are formed of the very best materials, and fashioned in the most skilful manner, so that not one of them is loaded with a single grain beyond what is necessary for the performance of its purpose, wears out in a very short number of years; but in the system, in the countless systems, of worlds which God has made, there is no wearing out; the law which he has given sustains them, and not one atom of them can be lost, or fail in the accomplishment of its purpose. We have sufficient evidence of this even in those creatures upon the earth whose existence is frail, and whose days are numbered. There is an healing power in the individual up to a certain point and for a certain time, according to its nature; and if it is a living thing, whether vegetable or animal, there is a reproductive power always capable of continuing the race, in proportion as there is necessity for it in the general economy of nature. In the works of man there is nothing of this kind: he may use the most durable materials and the best workmanship; but in every case he must ere long put his repairing hand to his work, and the second production, if it does not cost him the same skill of invention, costs him the same labour of execution as the first. Not so with the works of God; the one creative word is sufficient to maintain them in perfection to all eternity, if it be the pleasure of their Maker that they shall so endure; and thus though we speak of the providence of God as a special act of kindness by him to his creatures, that is but another name for the never-ending influence of what he has seen meet to do as God the Creator. It is in the heavens that we find the most striking as well as the most stupendous verifications of this; and it is for this reason that the moral lesson obtainable from a rational contemplation of the heavens is so valuable. So far as human observation goes, there is no portion of the system of the heavens which is not in continual change, and change which, if it were to go on without interruption, would produce confusion in the system; but there is none of these changes which does not in its very nature involve the means of its own return. Take as an example the annual motion of the earth round the sun. This motion is performed in an ellipse, or oval, with the sun nearer the one extremity of its longer dimension or diameter than the other. Therefore the earth must, during one half of the year, be continually approaching nearer to the sun, and during the other half of the year it must be continually receding to a greater distance. If the first of these were to continue, the earth would, after not a great number of revolutions, come into contact with the body of the sun; and there is reason to believe that long before it reached that luminary all life on it would become extinct, all moisture would disappear, and the remains would be converted into ashes, or perhaps into vapour. If, on the other hand, the earth were to be continually receding from the sun, it would very speedily pass into the regions of space, congealed and frozen, so as never again to admit of life or of motion in any one of its parts. But both these catastrophes are prevented by means the most apparently simple, but at the same time the most perfectly successful. The very fact of the earth's approaching nearer to the sun contains in itself the necessary elements of a succeeding removal from that luminary; and the removal in like manner contains in itself the elements of a return. It is the same with all the bodies in the heavens of which we have any knowledge; and therefore it is that the study of the heavens becomes so eminently instructive in the knowledge of God the Creator.

In support of the advantage of the study of the heavens, on the human mind, and in leading man to the knowledge of God, and impressing upon him the necessity of keeping God's law, both as deducible from the study of his works and as revealed in his word, we have the following very striking and exceedingly sublime passage in the first six verses of the nineteenth Psalm:—"The heavens declare the glory of God; and the firmament showeth his handy work. Day unto day uttereth speech, and night unto night showeth knowledge. There is no speech nor language where their voice is not heard. Their line is gone out through all the earth, and their words to the end of the world. In them hath he set a tabernacle for the sun, which is as a bridegroom coming out of his chamber, and rejoiceth as a strong man to run a race. His going forth is from the end of the heaven, and his circuit unto the ends of it; and there is nothing hid from the heat thereof."

This passage (and it is worthy of remark that it is given as an introduction to an enforcement of the wonderful power of the Divine law, and the blessedness of those by whom that law is observed) contains not only a most attractive incitement to the study of the heavens, but also much more of the knowledge discoverable by that study, than many are aware of. First, we have an allusion to the heavens, or the material creation, and to the firmament, or the law which determines the appearances of the material creation, as equally declaring the glory of God. Secondly, we have this declaration at all times,—in the sun by day, and in the moon and stars by night. Thirdly, we have the accessibility of this knowledge to mankind of every race and in every climate. Fourthly, as if to entice us to descend down from those lofty contemplations, and use the light of the sun as an instrument to assist us in acquiring a proper knowledge of our own little spot of creation, the earth, we have the superior grandeur and influence of the sun set forth by the most enlivening figures —a bridegroom coming forth from his chamber, and a strong man preparing to run a race. Fifthly, and to induce us more intimately to connect the knowledge of the usefulness of the earth with that of the glory of the heavens, we have the universality of the sun's action upon the earth specially declared. Lastly, we have something which goes deeper into the philosophy of nature than any expression, in the same number of words, or indeed in any number of words, which is elsewhere to be met with:—"There is nothing hid from the heat thereof."

The most recent of the great discoveries in science—one of the present day, as may be said, and which, though rendered so plain as that it cannot be doubted, is not yet demonstrated, and, perhaps, from the nature of the subject, can never be demonstrated—is that of the identity of all the great agencies by which the natural gravitation or inertia of matter is overcome, and motion, life, and all other species of action, in the material creation, brought about. The grand discovery to which numerous experiments, made by the ablest men, in the most careful manner, in the honest search of truth, and without any view to the establishment of a pre-conceived theory, and so often repeated as to render it impossible that there can be any mistake in them, is, that light, and electricity, and galvanism, and magnetism, and vegetable and animal life, and every means by which any natural motion, in opposition to gravitation or weight, is produced, are all in principle the same, and also the same as the heat of the solar beams; and, that all the differences in their phenomena and effects are explainable by the different degrees of their intensities, and the different natures of the substances in which those phenomena and effects appear. This generalization has already been carried so far as that, with the exception of life, all the others have been made to produce brilliant light, accompanied by heat sufficient to kindle inflammable substances; and the violent action of living animals, and even of plants, is always attended by an increase of temperature, though, of course, the living structure would be destroyed long before the heat arrived at the ordinary point of ignition. From the little that we know of luminous animals, whether of the land or of the sea, we have still enough to show that certain localities of the animal body can produce, if not matter at the temperature of ignition, at least a gas which inflames with light the instant it comes in contact with the air. The details of this subject are, however, foreign to our present purposes, and we merely mention them to show how intimately all the parts and all the phenomena of nature are connected with each other; and we may add, that the analysis of the beams of the sun was the first part of this most important investigation, and paved the way for all the rest.

This inquiry, wonderful as are the results which have already been arrived at, is still only in its infancy; and, indeed, in the grand laws of nature, we may say, with truth, that all that has hitherto been done only lets us see how very much more remains to reward the labours of future inquiries, and how rapid the progress of discovery must be when men shall have learned to enter upon the practice of it, in every department, with a knowledge of those grand general principles of Nature's working which are most boldly and at the same time most briefly, and we may add most simply, set forth in the volume of the heavens. Nor is it the least part of our encouragement in this noble work of improvement, that we have not sanction and encouragement merely, but the most striking hints for our guidance, in the volume of inspiration itself.

But instead of there being anything wonderful or unexpected in those hints, with which the Bible abounds, not only that men should cultivate their minds in the knowledge of nature, as the foundation of arts, and civilization, and temporal enjoyment, but of the nature of the subjects themselves, and the means of inquiring the proper knowledge of them,—the reverse is most strikingly the case: for God has endowed us with the capacity of knowing these things; he has placed our chief happiness in that knowledge, and made our enjoyments, our means of obtaining, and even of knowing the comforts of life, dependant upon this knowledge; so that if we fail in doing so, we bring ourselves into the situation of the unprofitable servant from whom the talent was taken away. Further, we should do well to bear in mind, that in the same condition as man quits this world at death, in respect of mental cultivation, so must man remain to all eternity. This is one mighty moral of the parable of the talents, which is so impressively given by our Saviour himself; and the admonition which it proclaims to every one, into whose hands the sacred volume may come, is, not in words indeed, but in effect, and in emphasis—"if you would not be ignorant and miserable to all eternity, arouse and learn in time."

Nor has the beneficent Author of our being left himself without a witness here, any more than in the other revelations of him, which we have in his word and his works. Matters are so ordered that, even in this world, our knowledge is the measure of our enjoyment. We find many persons who are miserable and discontented, notwithstanding that they are in possession of every means of comfort which the world affords; and, on the other hand, there are many who enjoy the most complete and uninterrupted happiness, notwithstanding that their labour is severe, and their means scanty. But if we carefully examine the condition of these parties, we shall invariably find that, whatever may be the extent of his formal education, the discontented man is always ignorant; and that the happy man is invariably a man of information.

SECTION II.

NECESSITY AND ADVANTAGE OF THE STUDY OF THE HEAVENS.

The necessity which man has for a knowledge of the heavens is very obvious; and the advantages which men have derived from that knowledge are very numerous and very varied: hence, we shall only notice a few of the leading points.

In the first place, time is one of the most important of all considerations to every man, whatever may be his condition in life; and, other than what we derive from the knowledge of the heavens, we have no natural standard of time, and could not, with certainty, keep our appointments, or transact even the most ordinary business with anything like advantage to ourselves or satisfaction to others. It is true that, in the present improved state of the arts, we have mechanical clocks and watches, which keep more uniform time, for short periods, than that which we obtain from observation of the heavenly bodies; but even these are, in a great measure, results of our knowledge of the laws of celestial motion; and we have no standard, except the heavenly bodies, by which to ascertain whether our mechanical time-keepers keep true time or not. For longer periods of time, a knowledge of the motions of the heavenly bodies is absolutely necessary; and it was not till after the science of the heavens had made very considerable progress, that the length of the year, or time of the earth's annual revolution round the sun, and the length of the day, or time of the earth's rotation on its axis, could be accurately compared with each other. The appearances of the moon, during its revolution round the earth, are so varied, and those nights during which the moon shines are so cheering to persons who have occasion to be abroad, as compared with nights on which there is no moonlight, that the moon early attracted the attention of mankind, and there are nations who still keep time by moons. But as the time of the moon's revolution round the earth is not any even part of that of the earth's revolution round the sun, and as this again does not contain an exact number of rotations of the earth upon its axis, those three methods of counting time cannot be made to agree with each other without a very intimate knowledge of the celestial motions.

But, independently altogether of those variations in the positions of the sun and moon, which are the consequences of those three motions, there are appearances on the surface of the earth itself, which are produced, each by one of these motions; and thus, no one of the motions, as a standard of time, will answer for the whole. The day which is occasioned by the rotation of the earth on its axis, is the most striking of all these phenomena; because, throughout the whole earth at some times, and over the greater part of it at all times, one portion of the day is light, and the other portion dark. The month, which, though different in our Calendar, in which the three motions are, as much as possible, adapted to each other, was originally the same as a lunation, or a revolution of the moon round the earth. The tides of the ocean, though they vary, at different seasons and from other causes, yet depend chiefly upon the moon; and, to people inhabiting the shores of the sea and the estuaries of tidal rivers, it is often of great consequence to know the times of high and low water long before they occur. The year is determined by the revolution of the earth round the sun; and to all people, and more especially to people who cultivate the ground, a knowledge of the seasons, or times of the growth, maturity, decay, and death of those plants which are cultivated for the use of man, is of the utmost importance; because the cultivator must provide for the general character of every season before it comes, or else his cultivation will be to little purpose.

Now, in order to adjust the days, months, and years to each other, so that we may be enabled to employ our time to the best advantage, and have from the abundance of the season of growth a sufficient supply for that season at which the earth yields nothing, requires a very intimate knowledge of the motions of the heavenly bodies. No doubt, it is the motions of the earth of which the knowledge is necessary; but those motions are not discoverable, at first hand, any more than people who are below deck in a ship can know the rate at which that ship makes way through the water. They are discoverable only by the apparent motions of the heavenly bodies, which are (in the case of bodies remaining stationary) at the same rate at which the earth moves, but in the opposite direction. If, however, the body, from which the motion is to be determined, has a motion of its own, the rate and direction of that must be known and allowed for, in order to get at the true rate at which the earth moves.

If the body, from which the rate of the earth's motion is to be reckoned, is moving in the same direction with the earth, but at a slower rate, the apparent motion of the earth, as estimated from that body, will be the difference of the two; for example, the moon performs its revolution round the earth in about twenty-nine days and a half, and the earth performs its rotation upon its axis in twenty-four hours, or one day: or, any point on the earth's surface moves twenty-nine and a half times as fast in rotation as the moon does in its revolution round the earth; but they both move in the same direction, that is, from west to east, according to our mode of estimating position, both on the earth's surface and in the heavens. Consequently, the earth will, in its rotation on its axis, appear to move slower as estimated by the moon than as estimated by the sun; and if we divide a day by twenty-nine and a half we shall obtain the difference, which, on the average, is between forty-eight and forty-nine minutes. But, whether we reckon by the sun or the moon, we estimate by the apparent motion of the luminary, and not by the real motion of the earth; and, therefore, while estimating in a rude manner, we say that the sun always arrives at the south point of the sky, at twelve o'clock mid-day; the moon, estimating in the same rude way, will arrive at the south point between forty-eight and forty-nine minutes later every day than on the day preceding. These are but rude averages, and there are many circumstances to be taken into account before we can arrive at the truth, as nearly as that truth can be arrived at; but they serve to show the principle, and also how essential it is to have some considerable knowledge of the system of the heavens, in order to be even nearly accurate in estimating times, tides, and seasons.

It would be inconsistent with our present purpose to enter into any of the niceties or difficulties of this part of the subject; and, therefore, we shall content ourselves with simply mentioning, in addition to what has been already stated, that this question of time, simple as it may appear to those who have not studied it, is, nevertheless, one which requires the most intimate knowledge of the heavens before it can be determined with anything like accuracy; and yet there are few things more essential to mankind than the accurate determination of time. Compared with what we have to do, in providing for this world and preparing for the next, the time of the longest lived of the human race is but short. It is both our duty and our interest to make the most of it; and this we cannot rightly do, unless we know exactly at what rate it passes, and also how to apportion it to our different engagements and pursuits. The system of the heavens properly studied, enables us to do this to a very great degree of accuracy; and, therefore, upon this ground alone, the necessity and the advantage of studying the heavens would be fully proved to any one capable of reflection.

In the second place, it is only by means of a knowledge of the heavens that mankind have arrived at anything like satisfactory knowledge of the earth itself. Before the system of the heavens was properly known, and long after men had observed and were well acquainted with all the apparent motions of the celestial bodies, their notions of the earth were exceedingly limited, and, as it now appears, after the truth has been found out, very absurd. The old notion was, that the earth was a flat surface, longer from east to west than from north to south; and we have evidence of this in the names which were then given, and are still retained for the measures of the earth in those directions. Distance from east to west, when spoken of generally, is still called *longitude*, which means "measure in length;" and distance from north to south is still called *latitude*, which means "measure from side to side," or in breadth, which is always understood to be a shorter dimension than length.

When this was the general belief, even of learned men, the boundaries of the earth became a very perplexing matter: in some instances they were supposed to be seas, in others an indescribable sort of darkness—something which was neither land, nor water, nor air, but merely another name for human ignorance. They found it necessary to say something about the boundaries of this flat earth; and, as they could not possibly give a true account of that which really had no existence, their only resource was that of all men who are placed in like circumstances—they made use of words which had no meaning whatever, and imagined things to exist which could not, by possibility, have any existence.

The consequences of this belief that the earth was a flat surface, were, if possible, still more absurd than the belief itself. The flat earth was regarded as a sort of a partition or, more strictly speaking, a floor in the universe—if universe it could be called, of which the lateral extremities were so perplexing. The habitable side was, of course, the upper one, above which was the region of light, while below the other side was altogether a region of darkness. The former contained, of course, first the atmosphere, then the region of the sun, moon, and stars, and above that the dwellings of the gods of heathen mythology, all this part of it differing according to the fancy of the describer, but all perfectly incompatible with an accurate knowledge, or anything approaching to an accurate knowledge, of the true God; because gods which had a particular local habitation, in one part of the universe rather than another, must have been, not only finite gods, but material gods, and therefore not gods at all,—not creators, but creatures, and creatures not of God's making, but of man's imagining; and yet, however, some of the more intelligent among the people, who held this belief, must have been perplexed with its absurdity, no other conclusion could be drawn from the belief that the earth was a flat surface. Hence we have another argument for the necessity of a knowledge of the true system of the heavens for enabling us, in so far as man can know so awful a subject, to have a proper knowledge of the true God.

All on the under side of the earth, as the place of darkness, was the region of wo, the place of punishment; though according to the then notion that the regions of the gods could be inhabited by the gods only, and by them in proportion to their degrees of god-ship, it was found necessary to assign the shades or spirits (they were not spirits, however, but thin and vapoury bodies) of good men, as well as those of bad men, to the under or dark side of the earth.

To us these speculations of the times of ignorance appear very absurd, and yet the men by whom they were held, show, by many of those memorials they have left, that in matters which they did properly understand, they were our equals, if not our superiors; and if the labour of ages in the search of truth, and above all the destruction of the fancies of heathen mythology by the light of divine revelation, had not enabled us to acquire that knowledge of the system of the heavens, and of the form and magnitude of the earth which we now possess, as clearly as though the former could be set on the table before us, or we could turn over the latter in the hollow of our hand, we should have been, even at this day, in the same state of ignorance and error that they were, if not worse.

This is a portion of the subject so very important, and one which is so rarely and so slightly treated in any book to which the public in general have access, and we may say in any book whatever, that it requires some further exposition; and, fortunately, that exposition is of a kind which requires no learning, but may be understood and appreciated by any one who will but pause and think a little. Since the fact of the earth's being a sphere was deduced from the knowledge of the general system of the heavens, or rather of that particular system of which the earth forms a part, and also proved experimentally (by ships sailing around it) to those who are not able to appreciate the reasoning, many methods have been pointed out by which common observers, on the surface of the earth, and without any reference whatever to the celestial bodies, or to anything else, except the portion of the land or the sea that may happen to be visible at the time, may be able to see and convince themselves that the earth is a sphere. But, after a discovery is made, it is not difficult to point out new ways of making it; for when the end is known, it is very easy to shape the means so as to answer the end. It is, for instance, stated, that people see the tops of steeples, which they are approaching, before they see the bases, and the masts of ships, which are approaching them, before they see the hulls; also, that in receding from a steeple, they lose sight of the base much sooner than they do of the top, and that when a ship sails away from them, they see the masts after the hull is invisible; and, therefore, they say we may conclude, nay we may be sure, that the earth is a sphere and not a plane surface, on which latter the whole steeple from top to base, and the whole ship, from mast to hull, would come into view, or cease to be seen, at exactly the same time. All this is, no doubt, very true; but there were lofty objects on the land, and ships arriving at ports and sailing from them, long before the sphericity of the earth was deduced from celestial observation; and yet, up to the time at which this took place, no one thought of drawing such a conclusion from these occurrences.

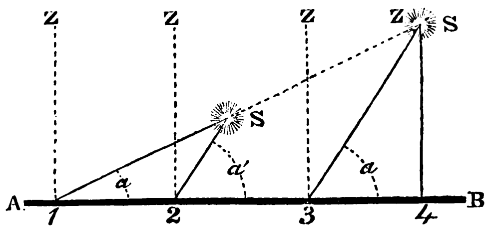
Indeed it is not at all probable, or even possible to suppose, that from common observation on the surface of the earth, and confined to the earth only, the form of the earth could have been inferred. When the ground which the eye of an observer commands is not level, the local inequality of that surface is always so much greater than the curvature arising from the spherical form of the earth, that this local inequality is the only difference of level which is at all perceptible. If the observer is in a situation where there is no local inequality, then his feeling (even in spite of his mental conviction of the spherical figure) is that all the part of the earth's surface within his view is perfectly level, that the heavens above him consists of a dome of a blue colour, resting upon the boundaries of this level earth; and if it happens to be a clear night, so that the stars are visible, his feeling is that they are shining specks all equally distant from him, and differing from each other in magnitude. Nay, if it were possible for a man to walk fairly round the earth upon the bank of a canal, the water in which stood all the way tranquil at the mean level of the earth's surface, then the feeling as arising from his observation of the earth would be that he had taken a long journey on a road which was perfectly level all the way, but that, strange to tell, long as it was, the beginning and end of it were exactly the same. This particular mode of observation is of course impossible, but there is a very near approach to it in circumnavigating the ocean. The people on board the ship have a constant feeling, from the mere observation of the sea, that it is a perfect flat all the way, except the local inequalities arising from the waves; and in addition, they are very apt to be astonished at losing a day if they sail westward, and gaining one if sail eastward, according to the calendar, though they have entered every day which they have spent on the voyage correctly in their log-book.

There is nothing which more completely shows the great superiority of the mind over the body, of philosophical inquiry over the mere exercise of the senses, than the difference between the true system of the heavens, including the earth as part of that system, and those notions which we acquire of it by common observation. The true system is at perfect variance with all that we see; and yet so simple are its principles, so clear is the evidence on which they rest, and so completely satisfactory, so easily understood, yet so sublime is the whole of creation on the great scale, so far as we can know it, that it commands belief without any argument; and there is no portion of knowledge in which the mind feels so secure and so triumphant over the frailties of the body as the study of the heavens.

We shall perhaps render the impossibility of obtaining anything like a rational knowledge of the heavenly bodies, or even of the earth itself, upon the supposition that the earth is a plane surface, more apparent, by calling in the assistance of two simple diagrams, the one representing the earth's surface as a plane, and the other as that of a sphere.

Let the problem in each case be to determine the length of a degree, or any number of degrees, of the earth's surface. As preliminary to this, it will be readily understood that from the known size of any portion of a plane or flat surface we can determine nothing with regard to the unknown parts of it, and consequently nothing with regard to the whole. For instance, if one were to be sent down on the middle of a level plain, the boundaries of which extended everywhere beyond the view, and if one were to measure any portion of surface there, as a square foot, an acre, or any other quantity, there are no means by which, from the quantity so measured, any knowledge whatever could be obtained of how many feet or acres were in the whole plain. But this is precisely the situation of men endeavouring to ascertain the extent of the earth's surface upon the supposition that that surface is a plane; therefore, even in this case, they must have had recourse to some body distant from the earth; and the body to which they had recourse was the sun. In the simplest view of the matter, and without certain corrections which are results of our knowledge that the earth is a sphere, and which of course could not be even thought of before mankind were in possession of that knowledge, the distance, measured along the apparent arch of the heavens, from the horizon or boundary of the level land or sea and the sky, to the *zenith* or point directly overhead, was then, as it is still, reckoned *ninety degrees;* and the number of those degrees intercepted between the horizon and the place of the sun at mid-day, was called, as it still is, the sun's *meridian altitude.* It was observed then, as now, that in going southward the sun's meridian altitude, at the same season of the year, became greater, and that in going northward it became less; and this naturally suggested those variations in the sun's altitude as a means of measuring distances on the surface of the earth. If there were two places, at the one of which this altitude was a degree less on the same day of the year than it was at the other, the natural inference was that the two places were a degree of latitude, that is a degree in the direction of north and south, distant from each other; so that it was only farther requisite to measure the distance of those places as accurately as possible, and the measure thus obtained showed the length of the degree.

Let us inquire what real knowledge would be obtained by this means; and for this purpose we introduce the following diagram:—



Let the line A B represent an indefinite portion of a meridian, or, north and south line on the earth's surface, as a plane; and 1, 2, 3, 4, points on it, at which the dotted lines 1 Z, 2 Z, 3 Z, and the line 4 Z, are respectively the perpendiculars; and the direction Z the zenith of each, the sun (S) being in the zenith at the point 4, and consequently having an altitude of ninety degrees, as seen from that point. Let 3 be another point, at which the altitude of the sun is one degree less, or eighty-nine degrees, (the difference in the diagram is much greater than this, because one degree would not have been perceptible in so small a figure; but the principle is the same for one degree as for any number,) and let the object be to obtain the length of the space 3 4, the supposed degree on the earth's surface. That space, being on the earth's surface, can be measured, and so can the angle formed by the lines 3 4, on the surface, and 3 S, directed to the sun. This angle is measured by the dotted arch *a*.

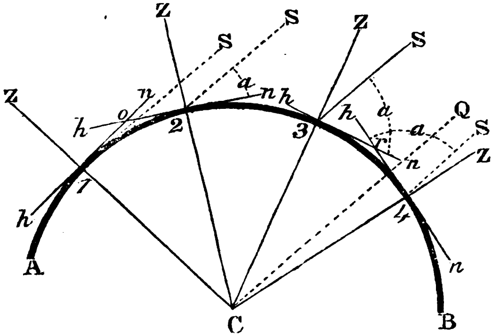
Now upon examining this figure it will be seen that the knowledge of the angle *a* at the point 3, the only datum which can be obtained, except the length of the line 3 4, has no reference whatever to the length of any portion of the line A B, and therefore cannot be the means of obtaining any information respecting that line. But we have already said that the knowledge of any part of a plane of which we know not the boundaries can give us no information as to the rest of that plane, and, in like manner, the length of the part 3 4, however accurately it is determined, can give us no information whatever as to the length of the line A B, or as to the part of it to which 3 4, is equal. Therefore, the obtaining of two points on the earth's surface at which the elevations or altitudes of the sun were one degree different, and the exact mensuration of their distance on the surface, could afford no information whatever regarding the rest of the earth considered as a plane. The result, if worked out, would give a distance of the sun from the earth, which would be the line S 4, from the point 4, and the line S 3, from the point 3. It is easy for any one who has the most elementary knowledge of the doctrine of plane triangles to see to what a strange conclusion this would have led, as to the distance of the sun; for the distance S 4, must have been less than half of what the diameter of the earth has been ascertained to be, that is, less than 4000 miles. But the distance of the sun from the earth, as ascertained in the most satisfactory manner by a knowledge of the system of the heavens, is, on the average, about ninety-five millions of miles; so that the greatest distance obtainable on the supposition of the earth being a plane, would have been little more than a twenty-four thousandth part of the real distance. But this would not have been all, or nearly all the error; for supposing the portion 1, 2, to have been measured equal to 3, 4, and the altitude of the sun to have been taken at the points 1 and 2, the difference of those angles—that is, the angle 1 S 2, at S in the figure—would have been found the same as the angle in the former case, and the distance of the sun from the earth would have appeared to be less than in that case; and if the operation had been continued still further, in a direction receding from the point at which the sun was in zenith, the altitude of the sun—that is, the sun's perpendicular distance from the earth—would have kept constantly diminishing, till. in the extreme north, it would have appeared that the sun altogether touched the surface of the earth, at a very moderate distance to the southward.

In like manner the moon and the stars would have appeared to be exactly at the same distance from the earth when they had the same altitude, but at different distances when they had different altitudes. In no case, however, could any of them have been by possibility calculated to have a greater height above the earth's surface than half the diameter of the earth, or about four thousand miles; and thus, upon the supposition of the earth being a plane, it would have been impossible to have ascertained that the whole visible heavens were more extended in space than what we know to be the magnitude of one hemisphere or half of the earth,—nay, the proof would have been that the magnitude as observed any where would have been less than this, and that it would have changed with every change of place, both in the heavenly bodies and in the observer.

Such, as to the extent of that creation, to which imagination itself can set no bounds, would have been the ignorance of mankind if they had not studied the appearances of the heavenly bodies, and deduced the great laws of nature's working from careful observation of them; and as all nations who have remained in this ignorance have made but little progress in any kind of knowledge, we can hence see the vast advantages that have been derived from this, which may be considered not only as the foundation of all that is grand in natural science, but as absolutely essential to anything like a rational adoration of nature's Almighty Creator.

If the whole of his visible works were reduced below the dimensions of one-half of that which is only as an atom in the system, and which, to the most powerful of our telescopes, would be an invisible atom at less than one millionth part of the distance of even the nearest of those starry gems which display themselves to our unassisted vision every clear night,—if such were the magnitude of the material universe, as ascertained by principles of accurate measurement, as it would be if the earth were really a plane surface, the whole of the glory of nature would be gone, and consequently the glory of the God of nature could not be felt.

Let us now consider the result of the same measurement on the supposition that the earth is a globe or sphere, and in this we shall be assisted by the following diagram :—



Let the curve A B represent a meridian, or north and south line, on the surface of the spherical earth, in the same manner as the straight line A B represented a meridian line on the earth as supposed to be a plane, and let the points 1, 2, 3, 4, be situated at the same relative distances as in the former case; then, upon the supposition that the earth is a perfect sphere—and it differs so little from one that we may in the mean time consider it as such—the perpendiculars at all these four points, indeed at all points of the earth's surface, will meet each other at C, the centre; and the zeniths, or points directly overhead, at 1, 2, 3, 4, will be respectively in the directions of Z, Z, Z, Z, also the lines *h n*, cutting the lines Z, C, in the points 1, 2, 3, and 4, will be the visible horizons at those points, making right angles with the perpendiculars Z C; and the altitude of the sun at any of those points will be a portion of the right angle formed by the horizon and the perpendicular, on the one side or on the other, as it happens. But the quantity of that angle will be determined by the very same means as in a former case, though the angle so determined will be a very different one, having reference to the magnitude of the earth, and not to the distance of the sun.

But as this sperical form of the earth is not a matter of direct observation, but one of inference from other principles, we must allude to some elements afterwards to be explained in order fully to understand it. The chief of these is the vast distance of the sun, and the consequently small magnitude which the earth would appear to have if seen from that luminary. This is a matter of accurate and by no means difficult observation, but we shall in the mean time assume it as a fact. If, then, two spectators were placed on opposite points of the earth, the difference in the angular position of the sun to their observation would be only about seventeen seconds of a degree, of which a right angle contains three hundred and twenty-four thousand. This angle is so small that in two straight lines ten yards in length no deviation of the one from the other on account of it could be observed; and therefore for any moderate distance upon the earth's surface lines directed towards the sun may be regarded as parallel to each other, or as making no angle whatever at the sun. Indeed the angle which they do make there is so very minute that it is not necessary to be taken into account except in the very nicest observations.

With this understanding, let us suppose that the parallel dotted lines 1 S, 2 S, 3 S, and 4 S, are directed to the sun from the points 1, 2, 3, and 4. 1 S falls below *h n*, the horizon at 1, and therefore the sun would not be visible there; but at the points 2, 3, and 4, the angles *n* 2 S, *n* 3 S, and *h* 4 S, (as, in this case, the sun is on the other side of the zenith,) measured by the dotted arches *a*, are the altitudes of the sun at these points.

Now it is obvious that none of these angles furnishes us with any means of ascertaining the angle at the sun, or the distance of that luminary. That which they do give us is the angle which the horizons of the places of observation make with each other: for instance, either of the equal angles, 3 *r h* and 4 *r n*, formed by the horizons of 3 and 4, extended till they cut or cross each other in the point *r*. If we compare either of those angles, which are equal to each other, with the angle 3 C 4, we shall find that it is equal to either of them; for the angles at 3 and 4 are right angles; the angles 3 *r* 4 and 3 *r h*, and also 3 *r* 4 and 3 C 4, are equal to two right angles, consequently 3 *r n* and 3 C 4 are equal to each other. Or we may state generally, that the angle which the horizons of two places make with each other is always equal to the angular distance between the places at the centre of the earth, considered as a perfect globe. When this angle is known, it is easy to find what part it is of 360 degrees, the whole circumference; and then we have only to measure accurately the distance between the places, and multiply that by the number expressing the part which the angle is of 360 degrees, and we have the circumference of the earth expressed in terms of the measure which we applied to the distance of the places. Thus if, in the above figure, the angle 3 C 4 were found to be ten degrees, and the distance of the places 3 and 4 to be 692 miles, the whole circumference would be 24,912 miles, or, in round numbers, 25,000 miles, which is near enough for being remembered for common purposes; and, by the properties of the circle, the diameter answering to this is, in round numbers, 8000 miles, and the radius, or the distance from the surface to the centre, is 4000.

After the sperical form of the earth is ascertained, there are other methods by which its dimensions may be calculated,—such as the distance at which the mean level can be seen from a point at a known height above the level; but this method, and every method in which there is no reference to the celestial bodies, requires much more correction, and, after all, is much more liable to error than that which is derived from celestial observation; and, as has been already remarked, these methods were never thought of until the laws of the celestial motions had been deduced from a careful and long-continued series of celestial observations. Even the invariable fact, that the horizon, upon the level surface of the earth, whether of sea or of land, always appears a circle, and the visible portion of surrounding space always appears a circular dome, with the greatest elevation at the zenith, or directly over the observer's head, at whatever point of the earth's surface the said observer may be, is, of itself, strong evidence of the earth's being a sphere; but this also is evidence found out only after the discovery of the same truth by other means.

But, in whatever way we obtain it, when we are once in possession of the accurate measure of the earth, this measure becomes a standard, by which we can extend our mensuration to every celestial body, whatever may be its distance, with not more chance of error than we have in ascertaining the distance of two places only a few miles from each other. Or, if there be any distance which defies the measurement that this standard affords us, then we have the satisfaction of knowing that the body which thus cannot have its distance measured by the line, sets equally at nought the efforts of the imagination. Thus, from our own little nook of earth, assisted by the simple observation of that sun without whose beams our earth would not be habitable, we are enabled to look upon this mighty system of the universe with something more than an eye of mere wonder. We behold one celestial body, the moon, attendant upon, and revolving round our earth; we find our earth, and many similar bodies, revolving round the great central mass, the sun; we find others, which are more erratic, and to which, from the form that they usually assume, we give the name of comets, coming within the range of measurable distance for a space, and then receding to unknown depths into those regions wherein neither eye nor telescope can discern them. We see all this, and, when it is visible, we can measure all this; and not only so, but in the case of all those bodies which revolve round the sun, whether as primary and having that motion in the revolution only, as is the case with the earth, or secondary and having also a motion around some primary, which they accompany in its revolution round the sun, in like manner as the moon accompanies our earth, we can calculate their times and places. Nor is this the whole; for we can tell the laws of all their motion, with far more ease and far more certainty than we can tell the impulses of our own hearts; and, though some of them are of such magnitude that the earth is, in comparison, truly "a little thing," and all that man contends for on its surface, all that he wrangles for, and too frequently allows to draw him from the contemplation of nature and the reverence and service of nature's God, is less than "the small dust of the balance," we can determine their weights with as much certainty, indeed with much more certainty, than if they were within the reach of our own arm, and we could take them up in the hollow of our hand.

Nay, incomprehensible and incredible as this knowledge, derived from the study of the heavens, may seem to those who are ignorant of it, it is but a small portion of that history of the works of God which the instructed eye (and the instruction is neither difficult nor abstruse) can read in this mighty volume. Those starry specks which "gem the brow of night," and which, to our unreflecting observation, seem to be nothing more than shining spots on the blue and solid concave of the sky, carry us into depths of space where the boldest wing of science is of but small avail; and while an infinitude of extent calls equally for our admiration at every point, we cannot withhold our adoration,—we cannot but feel that this is a "temple made without hands;" and, as in so far as we can follow it, the law to it as matter is *one law*, that that law includes us—that, all insignificant as we seem when we bring our minds to this mighty contemplation, " we also are His offspring;" and under such a feeling, we ought to manifest the most steadfast determination to obey His will with all our minds, and to keep His commandments with all our strength.

It is a law of all nature—of all that creation which God has set before us for contemplation and for use, that whatever is eminently calculated for exercising the understanding, awakening the admiration, and delighting the properly disciplined feelings, is, to the same extent, calculated for our practical use, and to the same extent comes home to us to minister to our temporal enjoyments as rational beings, and become, at once, the stimulus to further degrees of knowledge, and the means by which that knowledge is to be acquired. This is true of everything which is captivating, or striking, or grand in any one department of nature; and it is especially and conspicuously true of the study of the heavens.

It would be rather foreign to the purpose, as well as incompatible with the size of this small work—a work, the object of which is rather to entice the reader to the study of the heavens, than to supply the details of that department of knowledge—to enter into even an enumeration of the practical advantages which have resulted from a knowledge of the true system of the heavens. But we may mention that this has been the means by which civilized man has arrived at a knowledge of all the regions of the globe, and which might have enabled him, and in many cases has enabled him, to extend the blessings of civil knowledge in the arts, and the still greater blessing of Christianity to the people of every zone.

It is this which renders the widest oceans, those which girdle half the circumference of the earth with an unbroken expanse of water, the safest, as well as the swiftest highways by which distant lands may be visited. In early times, and before the system of the universe was understood as it is now, men had found out that the pole star retained its position in the north with little variation; and thus, by the simple observation of that star, they knew the direction of their course, and whether it was northerly or southerly. But, with regard to easting and westing, that star, or any other celestial body taken singly affords no information; because the pole of the heavens, and every other celestial body which apparently revolves round that pole, exhibits exactly the same appearance, round the entire circumference of every parallel of latitude, on what place soever of the earth that parallel may be situated. When, however, the mariner becomes acquainted with the apparent motions of those celestial bodies which change their places in relation to the stars, (and those motions can be known only by the laws that regulate them,) he is in possession of a guide in the heavens which never leaves him; and though tempests may have beaten him for weeks or for months, under clouded skies, and for thousands of miles, no sooner does the cloud depart, and the moon and the stars make their appearance, than he takes those instruments and those tables with which science has furnished him, and, in a few short minutes, his place on the globe is accurately determined, his course set, his vessel trimmed, and he is speeding onward to his destined port. Nor is it unworthy of remark that that compass which gives him direction, when no heavenly body is to be seen, in all probability, owes its polarity, and, consequently, its value, to a modification of the same energy which enlightens and enlivens in the beams of the sun, which impels the earth onward in its career, and which sparkles in the radiance of those stars whose distances are all but infinitude as compared with the most extended measure of which we can have any comprehension.

It were easy to extend our account to the uses of the science of the heavens to many volumes, and still to leave it as unexhausted as ever. There is nothing that we perceive in nature which is not connected with this magnificent system. Not a change of time, of tide, or of season, but which has its cause in the natural influence of the celestial bodies; and how much soever it may be modified by locality on the earth's surface, celestial influence is always the grand element in it; and even when we come to consider local terrestrial modifications, we, in very many instances, find it necessary to refer again to the heavens for their explanation. There is not a drop of rain which descends, a particle of dew which forms on the bud, a fountain which pours forth its living spring, or a river which rolls its torrent to the sea, but which is dependent upon those mighty bodies which the speed of an eagle could not reach in the longest period of human life. Of all those vegetables that the fertile earth produces, for use or for ornament, there is not one which is not called into activity and brought to maturity by the action of the sun, neither is there a streak upon a leaf or a tint upon a flower but what is limned by the pencil of the orb of day. Without this action no creature could come into life;

so that if it were possible for us to conceive our earth to be put without the pale of the system, and deprived of the all-invigorating energies of that sun on which it depends, all in it and on it would be stillness, death, and oblivion. All those mighty influences have also this advantage, that when once we know the law according to which they act, we can calculate the succession for any length of time: and, while at ease in our chamber at one point of the earth's surface, we can say, with certainty, what effect those celestial influences are producing throughout its whole extent; and thus the heavens become, in the strictest sense of the word, the keys to the knowledge of universal nature.

The moral here is so obvious, so striking, and so instructive, that we need hardly pause to point it out; but as the material earth would be abandoned to an unbroken eternity of lifelessness if it were deprived of the genial influence of the material sun,—and even if that sun were to suspend its influence for one day or for one moment, the system of life and of beauty in the earth would be deranged and lost without recovery,—so, in the intellectual world, if He who "set in the heavens a tabernacle for the sun" were to abandon the human mind to itself, that abandonment would be mental or spiritual death of the most fearful description,—were He to hide his face but for a moment, man would be utterly lost; for man can be safe only in the free grace of his bountiful God.

SECTION III.

NATURE OF THE KNOWLEDGE OF THE HEAVENS.

In order that the accomplishment of any object may be at once easy and successful, it is necessary that we should have a clear notion both of the nature of that object and of the means of accomplishing it, before entering on the accomplishment. This becomes the more necessary, the more extensive, the more varied, and the more inaccessible the object is in itself, and also the more limited and liable to error or imperfection the means which we must employ.

The study of the heavens possesses all the qualities now enumerated in the highest degree. The very nearest body to us of the mighty assemblage, the moon, is 240,000 miles distant from any point at which we can view it; there is none of the rest which is not greatly more distant than this, and the majority of the number—millions to one of the whole—are so remote as to defy all possibility of estimate, so that we can only say of them that they are beyond a distance, which is absolutely infinitude to our understanding; but how far even the nearest of them may be beyond this distance, or how many million times over that vast extent may be repeated again and again before we reach the last glimmering speck which, if we could view it from the same distance, is perchance a thousand times more radiant than our sun, and which, standing on the verge of the known creation, as it were, beckons us onward to improve our telescopes, and yet farther explore the wonders of almighty power in the hitherto unfathomable depths of space, it is impossible for us to determine.

All this congregated host of the heavens appear to be (ascertained by observation as far as that has been carried, and rendered probable by analogy to the very depths of material infinitude) in a state of constant and energetic action,—each in itself and all upon each other, so that there is a correspondence and even a unity existing between those parts of creations of which billions of miles could not count the distances; and it may be said with truth, that the bond of this union extends, from the lightest particle of dust which floats buoyant on the still atmosphere to all the masses which career through immeasurable space, so that "not even a sparrow can fall to the ground" without being sympathized with by planets in their revolutions, and by suns and systems in their more mighty career.

Such is the subject to the contemplation of which the student of the heavens is invited; and be his powers and attainments what they may, he stands under no dread of exhausting the inquiry. Indeed, it is so extensive that if it had not been arrived at by slow degrees in the course of thousands of years, its vastness and grandeur, bursting at once on the mind of ignorance, would have been so overwhelming as to put an end to every attempt at knowledge, and we should have stood humbled, in that adoration which every step in the knowledge of this wonderful structure is calculated to inspire. But the very circumstance of the grandeur of this structure limits the means which can be made use of in seeking a knowledge of it, and other than that information respecting it which light brings to the eye, our senses are unable to give us the slightest feeling of its existence. We are thus thrown upon one sense as the inlet of the whole of our original knowledge of the most gigantic subject which can occupy our thoughts; and we get our information at the hands of a most singular but an exceedingly swift messenger, whose march is indeed so amazingly swift that how we can question it by the eye is an especial marvel, and may excite our admiration of the power displayed in the structure of that little organ to as high a pitch as even those majestic heavens of which it is our only informant. That is reckoned a good ear which can accurately feel to a semi-tone in music; and there is certainly no ear which can divide to such a degree of minuteness any sounds which can be made the basis of speculative knowledge. What then shall we think of the power of that organ which receives all its intelligence from a messenger posting along at the rate of 192,000 miles in one second of time!

But such, as has been ascertained by means afterwards to be noticed, and in which there can be but little error, is the rate at which the light of the solar beams comes to the human eye; and it is not merely possible—it is highly probable—that there are other lights more fleet than this. We have evidence upon the earth, where the most powerful actions that take place are not even elementary atoms compared with those that go on in the heavens. When a feeble taper is lighted out of doors in a dark night, we can see the light of it making its way through the atmosphere; and it is a perceptible, though a very short, time, before the light of a candle diffuses itself through an apartment of even moderate dimensions; but the flash of vivid lightning is so rapid that we can instantly see it, whether out of doors or in the house, and whether our face be turned to it or not. It is, as we may say, a light which "finds out the eye," instead of being found out by it. The case is very different with the flash of a musket, or even with the most brilliant of those lights which are used as signals.

We cannot calculate those differences so as to state them in numbers, because they are modified by many causes connected with the state of the atmosphere which we cannot analyze or separate so as to know their effects; but still we can feel enough to convince us that the rate of the motion of light is in proportion to its intensity, and even to render it highly probable that the intensity and rapidity are identical—that light is motion, and that it appears brilliant and produces a strong impression on the eye just in proportion as it comes swiftly to that organ; and farther, that the intensity of the light is exactly in proportion to the energy of action in the body from which it proceeds, or to that of resistance in the body through which it passes, or that by which its progress is arrested.

According to the most careful and judicious experiments which have been made on a subject of such nicety, it is rendered highly probable that the light of very many of those bodies to which we give the name of stars, and which are so remote from us that they appear to have no disc or sensible magnitude, even in those telescopes which magnify so much, that a square mile of the surface of the moon, which is less than the

1,400,000th part of the whole disc of that luminary, is distinctly visible and can be measured;—according to these experiments, it is highly probable that many of those remote stars are not only bodies far exceeding our sun in magnitude, but sending forth light which is in the same quantity, that is, as proceeding from the same extent of luminous surface, far more intense; and therefore, whatever may be the kind of action which gives origin to this luminous impulse, we may be sure that it is always great in proportion to the brightness of the light and the speed with which it shoots onward through the region of space. This is a portion of the subject, however, which extends far beyond the bounds of any that can yet be called science; but it shows us, that though light is the only medium by which we can acquire a knowledge of the heavens, yet that this medium is every way as unbounded and as wonderful as that grand assemblage of worlds and systems of worlds in the revealment of which it is our only agent. And though the eye, wonderful as is its structure, fails us when we have reached only a little way,—when we have, as it were, felt along the radiant beam to a small portion of the stars,—yet we may say, and say with truth, that this same light has become the tutor of the eye, and extended the range of its vision, and with that the boundaries of the empire of knowledge, many thousand fold. Yes, it was the knowledge of the properties of light which gave us the telescope, or, which is the same thing, pointed out to us the principles upon which that instrument is constructed; and the telescope has extended our view to the remote heavens, and not only so, but to a very great extent it has given the clearness and force of mathematical demonstration to our knowledge of the less remote parts; which, but for it, must have remained at best only rational conjectures, if they had even amounted to as much. It is the same instrument which has enabled us to carry the line and the balance as far into celestial space as a disc discernible by the highest magnifying power that can be seen, and enabled us to measure the magnitudes and distances of bodies to which the whole earth is but a fragment in comparison, and to weigh their masses with as much certainty, and scarcely less deviation from the truth, than we can measure and weigh the common commodities of merchandize with the best adjusted standards and the nicest balances. There are, indeed, so many small modifying circumstances affecting these latter instruments, in the moisture, the thermomentric or sensible heat, and in the electric or generally imperceptible heat of the atmosphere, that our weighing and measuring on the small scale is liable to as many sources of error as that in which millions of miles form the beam of the balance, and suns and planets the weights.

Such is the subject which presents itself to the student of the heavens, such is the medium, and such (briefly hinted at) the organ of his knowledge; and when we consider the stupendous magnitude of the subject, the perfect simplicity of the medium (which is, probably, not a medium at all, but merely a manifestation), and the solitary sense, which we can bring to it as an inlet of the whole foundation of our knowledge, it may well seem passing wonderful that this science of universal nature, so to express it—this knowledge of creation, on the grand scale, should be far more simple, far more perfect, and, we may add, far more demonstratively established, than the science of the very simplest matter connected with the ground. Such, however, is the case: we not only know more of the principles which sustain worlds than we do of those which bring together the elements of the minutest grain of sand, or particle of dust, but we know them through countless ages, and we can determine, with great accuracy, the places which they occupied thousands of years ago, or those which they shall occupy thousands of years hence; so that our investigation of the heavens is bounded only by infinitude of duration, as well as by infinitude of extent. It is not so with the simplest particle of dust; for aught we can tell of its history, it may have formed part of the palace or even the person of a monarch, at no very distant period; and a short time only may elapse before it shall be turned into the most noxious weed that grows, or the most loathsome reptile that crawls the earth.

Nay, even in those sciences which may be said, in a great measure, of our own contrivance—the abstract sciences of number, and magnitude, and quantity—there are perplexities which set our ingenuity at defiance; numbers are incommensurable; elements, in our attempts to determine space, are ambiguous; and problems, in our investigation of quantity, are insoluble, or liable to have the results affected by indeterminate elements, which no refinement of analysis can eliminate; and thus, in what we feel, and not unjustly, proud of, as the most lofty efforts of thought, we are reminded of the imperfection and failure of ourselves as the contrivers of those modes of research. In proportion, too, as we depart from the abstract inquiries, and proceed to the experimental consideration of that terrestrial matter which is within our reach, and where we can not only bring all the senses to the assistance of each other, in as far as they can be so brought, but employ both substance and mode of action in artificial and experimental inquiries after truth, we are still more liable to error; and though the practical results which we derive from those inquiries are of great and indescribable benefit to us, the science of such matters has hitherto been in perpetual fluctuation; for, though every new discovery has heightened the value of the practical application, every such discovery has, in general, so shaken the previous theories as to call for a modification of them rather than become a means of their establishment. This has not invariably been the case, and it is different in different branches of the science of terrestrial nature; but if we take a considerable portion of the history of those sciences, it has been the rule rather than the exception.

In the science of the heavens, ever since that deserved the name, that is, since it rested upon sound principles—principles not involving palpable absurdity in the very statement of them—the case has been very different; for every discovery, in whatever quarter it has been made, and however subversive it has, at first sight, appeared to be of the general principles of the system, has, when fairly worked out, proved to be in every instance a clear demonstration of their truth. If it has been a new motion, or a new variation or disturbance of motion, in any one body to which the general principles of the system can be applied, then it has invariably shown itself to be a necessary result of those general laws, indispensable to the permanence of the system,—new only to our observation; but in itself of such a nature as that we can neither tell its origin nor predict its end, except by a direct and immediate reference to Him who made the universe, and who alone can alter or modify its general laws.

The science of the heavens is, therefore, a science very different from that of any portion of matter on the earth's surface upon which we can produce any mechanical or chemical change. It is not the science of the matter of which the celestial bodies are composed, either in its formation or in its changes; because of the minor acts which are going on in those bodies we never can obtain any knowledge. We can know them only as parts of the great system; and there is no celestial action which can come within the scope of science, save the action of body upon body, as apart from each other, and self-balanced in free space. It is true that the sun and the moon, which are the nearest to us, exert influences, and most important influences, upon the earth which we inhabit, and the surrounding atmosphere, and that they (the sun especially) are the chief agents in all natural action on its surface; but as this kind of action is displayed only in the earth and the atmosphere, which may be considered as the elements upon which the celestial bodies operate, it forms no part of the science of the heavens strictly so called. Leaving this, therefore, out of the question, the knowledge of the heavens becomes not so properly a knowledge of the heavenly bodies as of the laws by which they are regulated; and thus the name Astronomy, or "the *law* of the *stars*," is a very appropriate one, far better than *Astrology*, "the *voice*, *reason*, or *interpretation* of the *stars*," even though that name had not been so long degraded to the purposes of a somewhat knavish superstition (all superstitions partake more or less of this character), as to be unworthy a place in the catalogue of rational and useful sciences.

As our object is to excite a desire for the knowledge of the heavens, by presenting a broad, general, and simple view, rather than to enter into any of the minute details, from which our limits as well as our intention preclude us, we may here shortly hint at the reason why this, the most extensive of all sciences, and the one which lies most distant from us, should yet be the most perfect and satisfactory of the whole; and when we reflect only a very little, we can readily see why such should be the case. It is a science of pure observation; one of which, so to speak, we can make no part our own, by hastening or retarding any one result. Where we can do this, we are always in some danger of attaching a superior importance to that portion, however small, in the bringing about of which we have been employed; which thus becomes a sort of possession of conquest to us; and thus, according to a very strong and, within proper limits, very useful tendency of our nature, we are apt to prize it above its just value. Now though, in the ordinary conduct of life, this tendency, when rightly used, is of much value, and is, in fact, the bond which links us to our country and our kind, and enters largely into the composition of all the social virtues, it is by no means so advantageous in the prosecution of science.

There, it is not what we know, but what we do not know, which should be the attraction; because, what we know already is for practical use, either as the instrument of more knowledge, or as the means of that enjoyment to which knowledge leads; whereas it is the unknown part to which our energies should be directed, and which should stand most conspicuously and invitingly before us as the object of our ambition. And when all that we can know is the result of observation, we are necessarily placed in the most favourable position for the acquiring of additional knowledge. That which we have already observed becomes as a "twice-told tale" even to our minds in the repetition; and this very circumstance forces us on to future observation, with an earnestness of desire always increasing in proportion to the increase of that which is already known. Thus, the very nature of the science of astrology is, of itself, calculated to carry forward with increasing rapidity and success every one who enters heartily upon the pursuit of it.

We have ample proofs of this in the history of this science as compared with other sciences; and those proofs are continued to the present time, in that portion of the people of all nations who, unseduced by artificial modes of learning or habits of life, are allowed to spend much of their time abroad under the canopy of heaven. It is usually understood that the shepherds of Chaldea were the earliest astronomers—the fathers of this, and, through this, of all the other sciences; and shepherds and peasants, who still continue to count their hours by the sun, and who have to regulate their operations by the succession of the seasons, however limited may be their astronomical knowledge, have a fondness for the sun, the moon, and the stars, which is not possessed by persons to whom the elements of the science are familiar in the usual technical form. They may not know the laws which regulate those luminaries, but they learn the times of their appearance by experience, and, whether by day or by night, can apply them to the regulation of time. Even little children, before we are in the habit of giving them credit for the possession of reasoning (though in this we are probably much in error), are always very strongly and very delightfully excited at the sight of the moon or of bright stars. In such cases, children are not the worst of monitors to their superiors in years.

SECTION IV.

APPARENT DIURNAL MOTION OF THE HEAVENS.

In conformity with the division which was pointed out in a preceding section, of the object, the medium, and the organ of astronomical knowledge, it becomes necessary, first of all, to cast a rapid glance at the appearance of celestial space to a spectator on the earth; because this is not merely the alphabet of our book, but our book itself, in which we can read all the larger lines by the unassisted eye, and in which, though there is much left for the telescope, there is enough apparent to the naked eye, not only to satisfy, but greatly, usefully, and delightfully to instruct the great body of mankind.

Before we can so analyze the apparent heavens as to see the necessity, or even the propriety of the laws afterwards to be noticed, it is necessary to know the imperfections, or sources of error, that may exist in light as the medium of our knowledge, or in the eye as our organ of perception; but as the simple appearance to our senses, without any reference to errors of observation, or to laws which are, in reality, the results of observation, and not primary guides to it, is the natural beginning,—the foundation, without which there can be no structure other than an "air-built castle," which exists only in the book of artificial instruction, and which, though it may not be positively denied, or even strongly doubted, never can carry the felt force of that truth which rests upon direct observation,—we must first take some notice of it, and then we shall be better able to point out the few errors, or, more strictly speaking, modifications of the truth, to which our direct observation is subject.

Of the appearance which the heavens present to a spectator situated on the earth, we shall offer no pictorial representation; and, indeed, though *maps*, representing the heavens directly as seen from the earth, and *celestial globes*, representing them in reverse, are of much use in the study of the details, they are of no use, or even worse than useless, in conveying that general notion of this system which can be obtained only from nature itself, and which, as it is not exactly the same at any two places, or during any two moments of measurable time in which it *can* be successively observed, any representation would not answer half so well as that which we have in nature, free and open to all.

Now, upon what part soever of the earth a spectator is situated, that which appears to him as being "the framework" of the heavens always seems of the same form, and, under the same circumstances of the cloudless atmosphere, of the same magnitude. It always appears a portion, nearly but not quite the half, of a hollow sphere or globe, of a blue colour more or less intense according to the state of the atmosphere. The point directly over head, or that to which a pole or other tall object, which does not lean to any side, points, always appears the highest in the canopy or dome. Even if it is obscured by clouds, the general shape is not much altered, nor is the apparent size so much lessened as, from the real difference in the length of the view, we might be induced to believe. There is, however, a felt difference in this respect, not only between the clear sky and the cloudy, but between different states of each. The blue sky of day never appears so ample as the raven-black sky of night; the night sky, illuminated by the full moon, never appears so ample as the moonless sky does; and in cloudy skies, those in which the clouds are thick and dark never look so distant as those in which the clouds are pale. These differences in the appearance of the sky have some information to give us, if we would think and receive it. The blue sky of day receives its colour from light acting on the earth's atmosphere; and the moon-light sky, though, as the light is less intense, and not quite the same in its composition, it is differently coloured, yet receives its tint from the light acting on the same atmosphere; and this light, produced by the action of the luminaries on the atmosphere, is the reason why the stars are not seen at all when the sun shines, and why they are faint and apparently few in the clear moon-light. There are other circumstances which, when we come to reflect upon them, show us that the apparent magnitude, and also the colour, of the apparent sky, depend upon the nature and distance of the substance which acts upon the light, or rather, perhaps, on which the light acts. When the upper part of the air is what is called "gummy," and there is a ring of reflected light round the moon, or pencils of bearded light round the brighter stars, the heavens always appear of smaller dimensions than when the air is clear. So, also when the sun or the moon is seen through a fog, which takes off the brilliance of the lustre but allows the form of the disc to be seen, the luminary always appears at a much smaller distance than when it is seen in the clear sky. So, also, even when there is no visible vapour, except what may be inferred from the colour of the sky in the thick air of a rich valley, if one ascends from that to a lofty mountain, around whose summit the air is dry and pure, the sky expands and deepens in its tint; and the view on the surface of the ground, not only widens with the elevation, but becomes clear in the bringing out of distant objects.

This following of our change of position on the earth by the apparent dome of the sky, and these variations in apparent size arising from different states of the atmosphere, clearly show that the apparently spherical form of the space by which the earth is surrounded is nothing but what is usually termed an "optical deception," that is, a mere appearance to the eye, owing to the incapacity of that organ for judging of distances so remote as those at which even the nearest of the celestial bodies appear, and therefore confounding them all in one apparently nearly equal distance from the point at which it is situated, considered as a centre.

It will further appear, on a very little consideration, that we have different notions of the magnitude of the hollow sphere of which we thus apparently see part, arising not only from different states of the atmosphere, as already noticed, but from the extent of the earth's surface which is visible to us, or forms what is termed our *sensible* or rather *sensal horizon*. It is hardly necessary to mention that the word "horizon" is Greek, and signifies "that which terminates." In the case under consideration, it is the boundary which separates all that portion, both of the heavens and the earth, which is visible, from that portion which is not. For reasons which will be explained afterwards, the portion of the heavens thus seen, in all cases where higher ground than that on which the observer is situated does not interfere, amounts to a full half of the space by which the earth is surrounded, and generally speaking, to rather more than half; but this does prevent the portion of the earth's surface which we see from forming an element in our estimate of its apparent magnitude to the eye. If the earth's surface within our sensal horizon is level, the boundary of it appears equally distant from us in all directions, and the straight line extending from the eye to that boundary, or, as we term it, "the *radius* of our terrestrial horizon," becomes, generally speaking, the measure of the apparent distance of the eye from the whole concave surface of the apparent celestial hemisphere. From differences in the state of the atmosphere, our feeling of the average celestial distance does not exactly agree with this terrestrial measure, but the apparent deviation from it is not very great; although this terrestrial measure is so very small in proportion to the celestial distance, that though we stood on the highest mountain in the world, or even could ascend to the height of a thousand miles above the earth's surface, the terrestrial measure would not amount to a fraction of the celestial distance which any refinement of arithmetic could express. Still, however, this optical error as to the distance does not, in itself, affect the relative distances of the heavenly bodies, that is, their lateral or angular distances, as they appear to the eye, any more than though the eye had possessed a sufficiently penetrating power of telling the real and absolute distances of each, without any other process to assist it.

Such, then, is the relation between the visible part of the heavens and our perception of it; and with this understood, as well as with the understanding that the positions of the celestial bodies always shift with regard to our horizon, though not always with regard to each other, as we shift our horizon by changing our place, or as they are shifted by the apparent diurnal, or daily, motion of the apparent sphere, we are prepared for making, with the proper advantages, the first and simplest observation in popular astronomy.

If our observation is made during the day, the dome of the sky will appear to remain altogether at rest, and the sun merely to cross it from east to west, in a longer or shorter time, and at a greater or less elevation above the horizon, according to the situation of the place at which we observe, and the time of the year at which our observation is made. These differences are matters of observation, and as such observations have been made at almost all accessible points of the earth's surface, it is not necessary particularly to allude to them, as they belong to the description of the earth rather than the heavens. We may mention, however, that in the northern parts of the earth the sun appears always to cross the diurnal sky in a curve, sloping less or more to the southward, according as the place is situated less or more northerly; and that the highest point of this apparent daily curve of the sun's motion, with some exceedingly slight seasonal variations, marks the south from the position of the observer; and if the observer imagines a straight line to be drawn on the surface of the earth through this south point and the point at which he stands, such a line will be to him the terrestrial *meridian*, or mid-day line; so, also, if he imagines an arch drawn across the dome of the heavens through this south point and the *zenith*, or point directly over his head, and continues till it meets the horizon, this arch, which on the average will be almost an apparent semicircle, will be his celestial meridian, any objects in the extreme horizon, on the surface, or even within it, will serve to fix this line; so that he can refer to it as a first standard of position, and he can cross it by an east and west line and arch, dividing the eastern and western halves equally into four quarters or quadrants, and from these cardinal lines it is easy for him to find, by subdivision, the positions of all the points of the compass, or even more minute bearings, as he may see cause; and by the very simple process of holding up a thread, to the end of which a weighty plummet is suspended, so that the thread may hang across the centre of any celestial body, and also be seen against the mark in the horizon, he would easily be enabled to tell its bearing. These are rude methods compared with those actually used by astronomers in the determining of positions, but the great principle is the same; and, in the meantime, the reader will be pleased to consider, for the sake of those readers who actually are so, that he is neither acquainted with the principles and practice of astronomy, nor in possession of any instrument save his own eyes, or any apparatus except the earth and the heavens, as they appear to the most unlettered of the human race.

With this understanding, let the observer suppose himself to remain in his position until the sun has gone down; and, supposing that the sky is still cloudless, and that there is no moon to obscure the lustre of the stars, then,—as twilight begins to fade, and the russet chases the brighter colours westward after the sun, and is in its turn chased by the raven gray of night, which deepens in tint as it extends more completely over the visible heavens,—he will find star after star make its appearance, all in the order of their apparent brightness, until the glory of the night will far exceed the radiance of the day.

The light, though varying a little in colour in different stars, will be found more exquisitely white and beautiful than that of the sun; and, if the observer has not habituated himself to the sight frequently before, he will find delightful occupation for several hours in contemplating this dome of deepened but softened sapphire, glittering at all points with diamonds of the most splendid lustre, all scattered over it with an irregularity which is, however, far more pleasing to the eye than if these beautiful specks were arranged into symmetrical figures.

In the calm sublimity of this night view, all will appear to be in a state of rest with regard to each other; and, as under such circumstances there is little to attract the attention towards the earth, and no very ready means of comparing the relative positions of even the dimly seen objects upon it, unless they are lofty and near at hand, the impression will be that he is looking upon that "pillared firmament"—that unchangeable investment of the earth and the air,—to which such frequent allusion is made by the poets.

But if he will remain his two hours, or even one hour, without taking note of the stars nearest the horizon, and more especially those near the southern part of it, and will then examine them in those parts, he will find that this apparent heavenly dome, all silent, still, and stable as it seems, has yet shifted so much as that many of the stars which he first noticed in the southwest have now disappeared; many new ones have made their appearance in the south-east, and all those in the intermediate parts, without shifting their relative distances from each other, are moved westward.

If he now turns to the north, he will find that those stars which were directly in that quarter, and near the horizon at the commencement of his observation, will have climbed obliquely upward in the north-east, that others will have occupied their former place in the extreme north, and that others again will have descended in a slanting direction in the north-west.

If his observation is made at a season when the nights are long, so that he can observe at intervals, from six o'clock in the evening till about the same hour in the morning, and if at the first of these times he observes a conspicuous star just on the verge of the horizon, in the exact north, or where his celestial and terrestrial meridians meet; then, if he watch this star, from time to time, he will find (if he takes careful note of it, so as not to mistake it for any other,) that it mounts upward in the east, marking out a very regular semicircle in the eastern part of the heavens, until near the zenith, but on the south or the north of it, according to circumstances, it will be found again in the meridian at nearly six o'clock in the morning. If, while it is there, he divide the arch of the meridian between its northern and southern positions as accurately as he can, and make a mark (as on an upright post for instance,) to let him know the point, he will find, by subsequent observation, that this point is very closely connected with the motion of the stars; that all which circulate round without setting—and they will do so, of course, if they do not set in the extreme north—circulate round this point as a centre; and that even those which do rise in the east, and disappear in the west, performing a revolution in a part of a circle only, still have this point as a centre.

This point is thus a very important one in this apparent revolution of the heavens. It is called the POLE; and, as we have referred to the northern part of the earth, it is called the North Pole; but an observer similarly situated in the southern part of the earth, would have found out a similar pole in the south, round which all the stars visible to him would appear to revolve exactly in the same manner, and also from east to west, only the slope of the circles or arcs of their revolution would have sloped northward, where they crossed the celestial meridian between the zenith and the north. The slope of their paths would thus have been the reverse, and many of the stars themselves would have been different; but the time of their revolution would have been so exactly the same, and that portion of the stars seen by both would have corresponded so exactly, that, upon comparing notes, it would have been impossible for them not to see that they have both been examining the same starry sphere which comprehended the whole of surrounding space visible from the earth, and also that this sphere revolved from east to west on the two poles, as fixed centres, in the course of very nearly but not exactly the length of twenty-four hours, as measured by the sun-dial, or any other instrument by which solar time, or time according to the sun, could be pointed out.

It must be borne in mind that these poles are not fixed points; and that, in so far as the stars are concerned, there are not any peculiarities connected with them, any more than with any other points in that boundless space through which the stars are distributed, at distances from each other, which, when we attempt to measure them, are found to be perfect infinitudes both to our measure and our comprehension. It is true that, in the present state of matters, there is a star within only a short distance of the point which we call the North Pole of the heavens; but this star has nothing to do with the place of what we call the pole; for, while to our observation the star has maintained its relative position among the other stars ever since the first notice of it, the pole itself is in a state of continual change, being affected by two periodic motions, a longer one performed in the long period of 25,868 years, and a very small one performed in 19 years, the result of which is a very complicated revolution of the pole among the stars in the course of the longer period; but these two motions have reference to the earth only, and neither affect the stars nor are affected by them in the slightest degree. These motions, slow as is the one, and small as is the other, would still of themselves furnish abundant proof that these celestial poles, as we call them, are occasioned by the earth, and not by the stars. This irregular figure in which the apparent pole moves so slowly, extends over more than an eighth part of the entire circumference of the heavens; and thus there must be many pole-stars after long periods of time. The present pole-star is about 1° 24′ distance from the pole, which is less than one-eighth of the distance which it had since stars began to be observed with some accuracy; and as it is at no great distance from the apparent pole, and is also a conspicuous star, it is of considerable advantage, in pretty nearly determining the north by simple inspection. It is a star of the third magnitude (*Cynosura* or *Ruccabah*, in the Little Bear); there are no stars nearly so bright within some distance of it, and it is easily known by two of the stars in the four-sided figure formed by the very remarkable constellation of the Great Bear, always pointing to it, in whichever part of the heavens they may be in the course of their revolution. On the frontispiece to this volume, there will be found a slight sketch of this pole-star in the upper part, and of the principal stars in the Great Bear much lower down, by comparing which with the heavens, the pointers and pole-star may be very readily found.

In as far as the appearances of the stars during one of these apparent daily revolutions, or even a very considerable number of them, are concerned, it would be of no consequence whether the apparent motion were a real one of the stars, or the counterpart of a real rotation of the earth in the contrary direction; but when we come to consider the motion among the stars of the apparent pole of the starry sphere, or that the stars do not obey it, by accommodating themselves to its changes of place, we are compelled, from observation alone, and without any reference to the possibility of such a sphere having stability, to reject the idea of these poles being the poles of the heavens; when we find that the motions of none of these bodies which change their positions in regard to the stars, have any reference to it in these changes, with the exception of the moon, which, though evidently very slow in its apparent motion, appears to have a very intimate connexion with those disturbances of the poles; and when, farther, we find that the earth, under every circumstance, remains true to it, by having the same point constantly, and without the slightest variation, directed towards it;—when we consider these facts, all of which rest upon the direct evidence of observations made in the most careful manner, and through a long succession, not of years only, but of ages, we cannot possibly resist the conclusion, that the earth must be the only body in the universe to which the places of the poles can be indications of centres of motion: though, as the moon obeys these changes, but only in a disturbed and irregular manner, yet always returning to the same obedience after the lapse of about nineteen years, it may, indeed must, have some sort of motion of which they are, within certain limits, the continually varying centres. Farther, as these poles are, by actual observation, of the accuracy of which there cannot possibly be the smallest doubt, ascertained to be, in all their changes with regard to the stars which remain fixed in respect of each other, and also to all the bodies which change their places, with the exception of the earth only, directly opposite to parallels on the surface of the earth, which have never changed their positions with regard to the rest of that surface, it is altogether impossible to resist the conclusion, that these poles point out in space the real poles of an axis round which the earth has a rotation in exactly the same time in which the apparent diurnal revolution of the heavens is performed. It follows as clearly, that no one body of all the countless number that appear in the heavens can, by any possibility revolve round the earth or the earth's axis as a centre, either in a longer period of time or in a shorter one, with the single exception of the moon. In the case of the moon, the motion which has reference to the axis of the earth, even under the disturbing circumstances which produce the irregularities, and which compensate themselves at the end of about nineteen years, cannot be the apparent daily motion of the moon round the earth, because that is, according to the observed difference of the moon's apparent diameter, sometimes wholly performed when the moon is at a greater distance from the earth, and sometimes when it is at a less. Besides, when the motion of rotation in the earth, upon an axis pointing to the celestial poles, performed from west to east or in a contrary direction to the apparent motion of the stars, has been once established, every apparent diurnal motion of any luminary whatever it may be, which is performed in the same direction as the apparent motion of the stars, must be occasioned by the real rotation of the earth upon its axis; and if it is performed in a different time whether longer or shorter, there must be a motion of the body itself, or some second motion of the earth, by which the difference in time is produced. Of such compensating motions, there can be only one referable to the earth, because, though a body may have a rotatory motion round its own centre, and a progressive one in space at the same time, it cannot possibly at the same time have either two rotatory motions or two progressive ones.

If a body has a rotatory motion round its own axis, (for it must revolve upon an imaginary line passing right through it,) and also a progressive motion in space, these two motions, though in the case of a body revolving in free space they may be in different planes, yet they must be either in the same direction, or in opposite directions.

This, perhaps, may be rendered more clear to those who are not accustomed to such speculations if we state the facts as observed in the apparent motions of the starry heavens, of the sun, and of the moon. Now, if a star is observed on the meridian, at any hour by our common reckoning on any night, it will be found on the meridian again four minutes earlier on the following night; and if, in like manner, we observe the moon on the meridian at any hour on any night, the moon will be about fifty minutes later in coming to the meridian on the next night.

The time which any celestial body requires to make the circuit of the heavens, is called a *day*, as regards that body; if a star, it is a *siderial day*; if the sun, it is a *solar day*; and if the moon, it is a *lunar day*. The lengths of these are matters of observation, not of inference; and any one may verify them by an ordinary clock or watch, so as to be convinced of their general truth. From what has been said, it will be seen that the average length of the siderial day is twenty-three hours, fifty-six minutes, or four minutes shorter than that of the solar day; but that the lunar day is about twenty-four hours fifty minutes, or nearly fifty minutes longer than the solar day.

Now, it is of the first of these apparent motions only that the pole, as formerly explained, appears to be constantly the centre; and, as already hinted, there is a very slow deviation of the stars from this pole, but which is not accompanied by any change of their relative situations with regard to each other; this slow motion is so limited in the course of any moderate period of years, and it is confined to so small a portion of the apparent surface of the heavens, that it cannot rationally be regarded as a progressive motion of the whole mass of the stars through space. As little can this slow motion, which is not completed in less than the vast period of 25,868 years, and the daily motion, which is performed in twenty-three hours, fifty-six minutes, be both rotatory motions of the starry heavens, not only because it is impossible for any body, whether large or small, to have two rotatory motions going on at the same time, but because the daily motion is apparently performed round the earth, and the slow motion apparently round the circumference of a small circle in the heavens. And when, in addition to these two, we find the sun apparently moving round the earth four minutes slower every revolution than the stars, and the moon fifty-four minutes slower, it becomes quite impossible to refer all these four motions either to the starry heavens, or to the two celestial luminaries, without some motion of the earth.

Such is the result at which mankind arrived by careful observation of the apparent diurnal motions of the sun, moon, and stars, before they began to consider by what means these bodies could be sustained in their places, and at the same time perform their motions. It would be foreign to our purpose to notice the various speculations into which they entered in their attempts to solve this problem; neither shall we refer to any of the other celestial bodies, which, star-like in appearance, yet change their relative places among the stars in a manner so irregular, sometimes shifting one way, sometimes another, and sometimes again apparently remaining fixed, that it is impossible to refer any of their motions to a revolution round the earth as a centre, or to assign any two of them the same rate and period in their apparent celestial marches. We may just remark in passing, that it was found necessary to imagine the existence of a certain number of spheres or rings, invisible in all parts, save those which contain the luminaries, and to imagine that these have motions so different, that no common rule would apply to them; and thus, while it was observed that everything on earth was perfectly obedient to laws, the whole heavens appeared to be lawless, or, at least, to depend upon laws which could not be referred to any general principle, so as to show that the whole universe was the workmanship of one Creator. It was this ignorance of the law which rendered the knowledge of the heavens of so little value to mankind at that period; and as men are not naturally different now, it becomes necessary shortly to consider the great principles of the law before we enter into the results of observation for any longer period than a day, or as applied to any other bodies than the sun, the moon, and the stars—including, under the last name, every celestial body, except the first and second. We shall do this, even before we speak of magnitudes and distances; because by simple observation, without a knowledge of the grand law according to which the heavens are sustained, and all the host thereof perform their motions, neither magnitude nor distance can be known. Of this law we shall attempt to give as clear a view as is compatible with the nature of the subject, with the short space to which we are restricted, and with the avoidal of that technical language and symbolical expression which are inconsistent with our plan, and which, therefore, would tend to defeat our object.

SECTION V.

STABILITY OF THE HEAVENS.

This is the most stupendous question, of a merely physical nature, to which the attention of the human mind can be directed; and when we attempt to generalize it so as to have some conception of it as a whole, the judgment is absolutely overpowered, and the imagination turns giddy. The application of the law has taught us, upon evidence that cannot be controverted, and by reasonings the accuracy of which cannot be doubted, that of the works of God there is literally no end, but that in proportion as observation has been rendered more accurate, and the telescope has carried it in every direction to many times the range of the unassisted eye, sun after sun (for in these wonderful depths of space worlds or planets are too insignificant for entering into the account)—sun after sun attracts our attention, till we are more completely lost in the mighty multitude than we would be should we set about literally to count one by one the grains of sand on the shore, or the drops of water in the ocean. Indeed, from a comparison of the distances beyond which those bodies must be situated, and the light which they send athwart the immeasurable gulf, rendering our nocturnal sky so brilliant, they may be the centres of systems of a higher order, to which our sun,—with all his attendants in our system, discovered or yet to be discovered, regular in their forms and their periods and solid in the greater part of their masses, as in the case with the planets and their attendant moons, or filmy and unsubstantial as appear to be the trains, and possibly the whole volumes of, at least many of the comets,—it is probable that, in comparison with those starry gems, the system of our sun may be less than our earth is in comparison with the whole of that system, or than a thistle-down floating on the breeze is in comparison with the solid rotundity of the earth.

Such is the matter which presents itself to our contemplation; and this matter is everywhere self-sustained: displaying all its phenomena, performing all its operations, and accomplishing all its purposes, in so far as those purposes are known to us, without the slightest control by anything material; and, at the same time, so wondrously made that, while everything is performed, nothing is injured. More than this,—wide as the different portions of matter, cognizable by our senses or our instruments, are apart from each other, and totally unconnected as they are by anything which, in common language, we can call material ties, so perfectly, so constantly, and so readily are they obedient to the law, that the whole work n concert; and it is impossible not to feel that all this immensity is not only the workmanship of one Author, but the effect of a single creative fiat—that though in the lapse of years and ages, of which we have no memorial, and of which consequently we can take no account, those mightier creatures of the same Creator, whether as single world, as system, or as sun, may have the period of their usefulness numbered, and may be withdrawn from their individual existence,—just as those smaller creatures which remain for a few hours or years upon the surface of this earth, active and performing their parts in its economy, after which death passes upon them, so that, as the same identical beings, they return no more, but that as while the general economy of nature requires it those tenants of *this nether* world are self-continued, race after race, in numbers continually fluctuating, now increasing, now diminishing, and now stationary, just as the perfect working of that beautiful design and purpose which runs so conspicuously through the whole may render necessary,—even so, in the immeasurable regions of space, as sun and system fades away, new heavens and new earths may be produced; so that while an old globe, like an aged animal, a dry tree, or a thirsty desert, has ceased to be able to perform its functions in terms of the law, death passes upon it, and its dust is dispersed through the universe to form the nourishment of other globes, which shall arrive at maturity, perform their appointed functions, and ultimately perish, in terms of the same law.

Thus, when we think of this mighty system, we find that it comes exactly within the observation of that general succession of death and of birth, of decay and of renovation, which we see everywhere taken place in the world around us, and to which we, the observers, in as far as we are material, are as subject as the rest of the matter which we observe.

At this stage of the contemplation, and before entering on a short exposition of the law of which this mighty system of nature everywhere furnishes proofs, there are some collateral matters of which a passing glance may be taken, were it only to show how wonderfully all the parts of true knowledge are connected with each other, and how directly they all point to, and combine themselves with, that knowledge which is most exalting to the hopes and essential to the welfare of man.

In the first place, the revealed Word of God has been the grand instrument by which we have arrived at an accurate knowledge of the laws of the works of God, so as to be enabled to make those laws the means of extending our knowledge. It was not till the sacred volume had taught mankind to look upon all the productions of nature, wherever situated, as formed by the power, and governed by the wisdom of one God, that people thought of applying to the distant parts of creation those principles which they had observed in the near and familiar bodies,—it was till the Reformation, by which event the Bible ceased to be a proscribed, and therefore a sealed book to the people, that sound opinions in the philosophy of nature began to be entertained; and although the same mental enlightenment to which the Reformation was owing had occasionally displayed itself before that most important epoch in the history of man and of science, yet it displayed itself in peril and persecution.

The truth here stated is undeniable and undoubted; and it tends to place the sacred volume, and that religion which it unfolds and inculcates, in the most valuable and the most endearing light, by showing us that God is our only sure guide to all truth, and that his religion is not a mere ceremonial for occasional display, but a living principle bearing upon all that we know and all that we do; that, in the largest and most literal sense of the words, "In Him we live, and move, and have our being."

In the second place, and it is a natural deduction from the former, this feeling that the heavens are the workmanship of the same Being who made us and all things upon the earth around us, gives us both scope and confidence in the acquiring of knowledge, which without this feeling we could never have obtained; and how much soever we may be in the habit of boasting of great men and great discoveries, this is the real source of all the improvements of modern times. Nor is it difficult to see how this must be the fact. There are many cases in which we can trace no visible connexion between even subjects which exist at the same time, and near to each other in space; and, when we consider the heavenly bodies, with the exception of the sun and the moon, we cannot primarily find any connexion between one and another, or between all or any of them and the earth. But the consideration, or feeling, that they are all works of the same Author, is in itself an established connexion, the necessary result of which is, that fundamental principle of all philosophy, that "in like circumstances a like event will take place." Our belief in this principle is, whether we think so or not, an inference from the feeling of the being of God; and this is the principle which has carried us to all our useful knowledge of matter on the earth, and of the mightier masses which compose the heavens. No doubt this has been the foundation of human action from the time of man's creation, though it was not till a comparatively recent period that men knew of its existence. We must not wonder at this, for there are many parallel cases; and, among the rest, the human body has been nourished and kept in health by the circulation of the blood ever since man existed; yet this, the most important of all the functions of the living body, was not known till about the year 1628, a little more than two centuries ago; and the professionally learned opposed it with the same obstinacy as, down to a recent period, they did the various steps in the discovery of the law of the heavenly bodies.

Those steps it is not our purpose to trace, further than by stating that they were a series of references from the earth to the heavens, and from the heavens back again to the earth, founded on observation of facts so carefully and so often observed that there could be no mistake, and conducted upon the principle above-stated, which may be more briefly expressed by saying, that "like *causes* produce like effects." This subject of "cause and effect" requires a little explanation; not that it is difficult in itself, but because many attempts have been made to render it both a difficulty and an error; and also because it is essential to a ready and clear understanding of the grand question of the stability of the heavens.

Speaking of nature, we call the first of two consecutive events the cause, and the second the effect; but there is something more meant than this; we never see the word cause but when there is *action* in the case; and our true notion of "cause" is, "that which can act;" which is sometimes a matter of observation, and sometimes one of inference or of belief, in either of which cases it is liable to all the errors of imperfect judgment. This cause we, in all cases, feel to be something more than meets the senses; and we are never satisfied with it, as being original and primary, in any body or event, though for the sake of brevity, we sometimes call them causes. But begin with what we may, when we attempt to trace it backward in time, it goes on before us as involved at every additional step as at the first; and though there are steps of knowledge, they do not satisfy the mind till we arrive at the great First Cause; and here we have the same overwhelming feeling of immensity as when we attempt to follow matter through the regions of space: we feel to what the succession tends; but there is "a gulph fixed," beyond which mortal eye cannot see; and how far soever we may carry our knowledge, it must, if we have carried it aright, at last merge in adoration.

It is further worthy of being borne in mind that the original word "cause," as expressive of the *action* of natural causes, meant "heat," or "burning," of which lightning was the type; and though this has sometimes been used, not very philosophically, as an argument against the principle of causation, it is very remarkable that our most modern discoveries point to *heat*, under one or other of its modifications, as the nearest approximation that we can make to the principle of all natural action, the immediate cause so to speak of all that takes place on the material creation, whether on the great scale or on the small. Nor is it less remarkable that this same heat, under the general name, "fire," or the particular and peculiarly expressive one "lightning," is the symbol used to shadow forth to human perception the power of God himself. When it is said that "the elements shall melt with fervent heat," or that "the earth shall be burnt with fire," we have not only the most forcible expressions that can be addressed to the understanding of man, but we have those terrific effects ascribed to the very agents which, upon known principles, are capable of producing them.

In this heat, or fire, or light, or whatever other name we may give to some of the modifications of it, we have one of the elements of *stability*,—and stability which admits of action both on the earth and in the heavens—throughout the whole of material nature, indeed; and whether the sensible effect of it be motion, or light, or growth, or animal life, or any other appearance, these are so linked together that we cannot separate them. In so far as both experience and observation go, we can set no limit to the power of this element; and as it is light, and light only, which reveals to us the whole of the creation which is beyond the very limited range of the ear, we must admit that it is a power diffused through universal nature. In all that we know of it, it is a power of expansion and separation,—an active power, even producing or tending to produce changes in the state or the place of every piece and every particle of matter.

Now, we want only an antagonist power to this—a power of rest, coherence, and resistance of motion, as another element, in order to render the stability of the whole system complete. It is a general, and we may say a self-evident, principle, that if we have two antagonist powers or forces, exactly equal to each other, and acting directly opposite, that we must have stability, whatever they may be acting upon, or whatever effect either of them might produce singly, or acting with more energy than the other; also, if those two forces are so adapted to each other as that they shall both change exactly at the same rate, then the body on which they act may be held stable, while it passes through any number of changes, both of place and of state.

The *gravitation* of matter, that tendency which every piece of matter that we can observe on the surface of the earth has to press downward, which we call its *weight*, and which not only always tends to press downward, but actually does press, and, when not resisted, produces motion downward, is exactly such an antagonist to motion as is calculated to produce the kind of stability respecting which we are inquiring. Therefore, it is necessary that we should be well acquainted with this gravitation.

We cannot call it a property or quality of matter; because such properties or qualities belong to individual portions, and are the means by which we distinguish different kinds of matter, whereas this gravitation is common to all matter, and is the test by which we know its quantity, and even its existence; and so constantly are we in the habit of associating the notion of gravitation, or weight, with the notion of matter, that it is quite impossible for us to think of the one without at the same time thinking of the other.

We find that, whatever may be the state of bodies, whether what we call solid, or liquid, or in the state of air or gas, they display this phenomenon of gravitation, in the exact proportion to the quantity of matter that we suppose there is in equal bulks of them; as, for instance, all solids that are sufficiently large for being visible to the naked eye, and also all liquids that are in drops which are individually visible, fall, or gravitate, to the earth, if they are not supported by something, which, like themselves, is apparent to the senses. These are instances of gravitation acting when there is nothing to resist it but the air. In the case of liquids again, of which water is the most familiar instance, we find some substances which gravitate to the bottom, and others which are forced to the surface, even when we push them below it, by the superior gravity, or gravitation, or weight, of an equal bulk of water.

In all cases, it is invariably towards the earth that detached pieces of matter gravitate, and never in any other direction, unless they are pushed by stronger gravitation in some other portion of matter; and in such cases, where there is nothing to prevent their motion, we find that the heaviest body descends towards the earth, and the lighter one ascends from it—just in the same manner as the scale of a balance which has a great weight in it descends, and makes the scale with a smaller weight kick the beam.

In so far has been observed on the surface of the earth, there is no exception to this mode of gravitating; and we know of nothing by which it can be hindered but the exertion of what may be called an opposing force. Sometimes, indeed, what we consider as a simple resistance prevents the action of gravitation; as, for instance, a leaden weight may be supported on ice, or suspended by a string; and the roofs of buildings, the arches of bridges, the branches of trees, and an endless variety of things, are apparently supported hanging in the air, in opposition to that gravitation which would bring them to the earth. But, in all these cases there is a power of resistance; and any one could imagine the piece of lead to be increased in size till it broke the ice, the building or the arch to be so much too heavy for its support that it would tumble down, or the branch of the tree so long and heavy that it would break by its own weight; and any one who has been familiar with orchards must have often observed trees loaded with such a weight of fruit as that the branches required to be propped up, to prevent them from breaking.

If we consider this gravitation of substances on the earth's surface toward the earth itself a little more attentively, we shall find that it is the cause of the stability of all things. If we place in water a substance exactly equal in weight to its own bulk of water, we find that it has no stability; and there is very little stability in a thistledown, or a spider's thread, when it floats freely in the still atmosphere. The reason is, that things in those situations have their gravity exactly balanced by the liquid and the air in which they float; and thus, whatever might be the weight of the one if taken out of the water, or of the other if the air were removed, while they remain in those fluids the least force moves them in any direction; and if the body, which were just the weight of its bulk of water and floating freely in that element, were a hollow ball of the hardest steel, if one were to touch it blindfolded, it would feel just as soft and liquid to the fingers as water, and it would be impossible for a blindfolded person to find out that there was anything at all in the water.

Now, is it not easy to perceive that if there were no gravitation all bodies would be as imperceptible to the touch as this hollow sphere of steel in the water? Therefore, gravitation is really the only means by which we have a sensal perception of the existence of matter; for the eye sees nothing but colours, and the ear hears nothing but sounds, neither of which are matter; and, consequently, if it did not resist our touch, and make us feel sensible of that resistance, we could have no notion whatever that matter existed.

Again, it is easy to perceive that if there were no gravitation, nothing could keep its place on the surface of the earth, and nothing could be done. Every one knows how unstable a thing a balloon is, and yet it is supported by gravitation; but if there were none, the largest mass of rock, the greatest mountain, nay, even the earth itself, might be pushed aside by a touch of the finger; so that, even granting that under such circumstances man were endowed with the same powers of action as at present, those powers could be of no manner of use to him, because everything would move off from an imperceptible touch, and he could make no impression whatever upon it. But man himself could not move, could not so much as open an eye-lid, or point a finger: for there is no motion even of the body of an animal unless it is supported by some point of rest, and be that point of rest what it may, it is always ultimately resolvable into gravitation. It may appear, to those who have not thought on the subject, that the strength of cohesion in that which forms the immediate point from which the motion starts would be sufficient to sustain the motion. But such is not the case; for if we were to return to the case of a hollow ball of steel floating in water, and weighing exactly as much as its own bulk, and attempt to hammer a piece of lead upon it, we should find that we made no more impression than if the water alone were our anvil: and yet there is very considerable gravitation in this case, for a column of water, about thirty-three feet high, and one inch thick, presses on the bottom with a weight of nearly fifteen pounds.

Even in the case of a bird taking wing and mounting in the atmosphere, though the muscles or organs of motion with which the bird is furnished enable it to move contrary to the course which it would take if gravitation alone acted upon it, yet the bird absolutely ascends in consequence of the resistance of gravitation, and if two points were taken in the expanded wings, so that half the stretch were between them, and one quarter on each side, and the half exactly equal in gravitation or weight to the two quarters, the bird, let it exert it itself as it might, would swing upwards and downwards on those two points; and, if we were to suppose that it had no weight as itself, or, which would amount to the same thing, that it were exactly of the same weight as the air in which it were exerting itself, it would continue to swing there for ever, without moving a hair breadth in any one direction.

This case of the bird brings us very near to that of gravitation, in giving stability to the great system of the heavens; but it is so essential to have a proper understanding of the vast importance of this phenomenon, in the whole range of material nature, whether on the smaller scale or on the greatest, that we shall mention one or two cases more.

As we can have no knowledge of matter unaffected by gravitation, it is impossible for us to determine to what extent solidity may, in all cases, be owing to it, and our present purpose does not require this description of knowledge. But, different as are the cohesions of substances, it is highly probable that gravitation is the basis of them all; and that the whole of the modes of union among the particles, or immeasurably small portions of matter, to which those detached masses with which we are familiar are owing, may be nothing more than different modifications of this attraction or principle of union; just in the same manner as all the modes of motion and action which we observe in nature, and which are as it were the active energies of nature, while gravitation is the fixed fulcrum which supports them, are most likely modifications of one principle of separation. We know well, that however strong the natural cohesion of a substance may be, if it is broken, and ever so thin a film of air admitted into the fracture, it adheres no more; and all the unions of particles, whether they take place in crystallization, in the growth of animals, of vegetables, or in any other way, may take place simply in consequence of air and all other substances being removed, in a manner which we cannot explain, and the natural attraction enabled to act.

There is frequently far more of sound philosophy in a single expression of the Bible than in a whole volume of human composition; and when we reflect on the declaration, "He hangeth the earth upon *nothing*," and bear in mind that it was the want of an ultimate support which so long perplexed men in their endeavours to understand the system of the world, we may well feel astonished, and cannot help feeling delighted, at finding the very essence of this doctrine of the stability of the system declared in this sentence, as expressly and as explicitly as words can declare it. "He hangeth the earth upon nothing:" it is balanced, and every part of the system, from the widest heavens to the minutest thing, is balanced upon the two principles which we have mentioned. The principle of attraction or union, and the principle of repulsion or separation; and if we are to suppose that any one portion of matter is equally under the influence of these two principles, it is impossible not to suppose that this portion of matter must be stable, whatever be its peculiar qualities, its magnitude, or its quantity. Also, if we can suppose, and the supposition is an easy and an obvious one, that those two principles, which, for the sake of brevity, we may call opposing or balancing powers, can change according to some law, so as to retain the same relative intensity, then it is evident that any body influenced by them may pass through any extent of change, and yet remain equally stable throughout the whole of it.

Let us take a very simple case, that of a stone thrown obliquely up into the air. If the stone had been let slip from the hand, it would have fallen to the ground, and, therefore, we may say that it gravitates towards the earth with a certain force; and, without the projectile force communicated to it by the hand, it would have done nothing else but have obeyed this law. But the force of projection is greater, and the stone ascends, though at a diminishing rate, till it gains a certain point, higher or lower, according to circumstances, and then it descends in a curve nearly similar to that in which it rose when projected. Any one would readily perceive that, when it ascends, the projectile force must be greater of the two, but that the gravitation must be greater during the descent; and that there is a middle point at which the two forces must be exactly equal, and the tendency of the stone neither to ascend nor to descend. If it were possible to keep up exactly the projectile force which it has at this point, it is evident that the stone might, by this means, be kept revolving round and round the earth for ever, without any tendency either to approach nearer to the earth or to remove to a greater distance, but that it is altogether impossible that it could support itself, except the force with which it moved were exactly equal to the tendency which it had to gravitate.

We can observe that, in so far as the earth and the projected stone are concerned, there is nothing but the two opposing forces. The air, no doubt, resists in proportion to its density or gravitation, and if the air is in motion, that will blow the stone aside, less or more, according to circumstances; more, of course, the lighter the projected stone is in proportion to its bulk, and the greater that the motion of the air is in proportion to that of the stone; for if the projected body were a feather or a thistle-down instead of a stone, all our power would not be able to project it to any distance against the resistance even of the still air; and if there were even a very moderate wind, that wind would carry it out of the direction, if blowing across, and turn it in the opposite direction, if contrary. But these are proofs of the universality of the principle, not contradictions; they show that every motion which takes place in a direction different from that in which gravitation acts, opposes gravitation to the exact amount of its intensity; while gravitation, to the full amount of its intensity, counteracts every motion which is not in the direction of gravity.

In the case of the light body, the impulse given to it by the wind acts in opposition to gravitation, as well as the projectile force given by the hand to the stone; and, therefore, it is of no consequence whether the motion by which gravitation is counteracted is produced by one force or by any number, so that the joint effect of the number is an exact counteraction of gravitation. A piece of matter can move but one way, whatever may be the number of forces that impel it. These will affect its direction only: if they are uniform, the direction will be always the same, and if they are variable, it will change in the exact proportion of the variation; but still it will, under all possible variations, be but one motion.

It is farther evident that gravitation in one direction may be balanced by an equal gravitation in the opposite direction, and that if the stone were so placed between the earth and any other body—the moon, for instance—as that the gravitation toward each were exactly equal, the stone would remain as perfectly balanced as if the gravitation toward either of them were exactly balanced by a motion; only the balance would not, in this case, be stable against even the slightest contingency; for the bringing it a single hair-breadth nearer to the one than to the other would destroy the equilibrium, never again to be restored; and if we were to suppose the two bodies, between which the stone were situated, balanced on the same principle, how large soever they were, and how small soever the stone, the descent of that stone to one of them would destroy their equilibrium, and the stone would draw after it the body which it had left. The mass thus united would again destroy the equilibrium of everything around, so that whatever number there might be of the celestial bodies, if they were sustained by gravitation alone, the movement of a little pebble, aye, of a single atom over a single hair-breadth, would speedily accumulate the whole into one mighty ruin.

Thus, though it is possible to imagine a stability of the system of the heavens (including, of course, the earth), by means of gravitation alone, yet that would be a dismal stability—cold, dark, motionless, dead,—so being, and so remaining, from its creation to its final catastrophe. For heat is motion, light is motion, and life is motion; and any one of these, exerted to the smallest extent at any one point of a system, stable only by means, of gravity, would destroy the balance, and bring the whole to speedy and final ruin.

Herein we see the indescribable beauty of the two antagonist or balancing powers, the adaptation of which to each other is the grand law of the material creation; and herein we see a display of wisdom of design, and power of execution, which proclaim, in language that cannot be mistaken, and dare not be resisted, the omniscience and the omnipotence of Him at whose bidding this law, and all the mighty system which it regulates, came into existence.

In order more clearly to see how admirably the two principles are made and fitted for each other, and for filling the universe with beauty and enjoyment, let us just consider what would be the effect of one single mass of matter—the earth which we inhabit, for instance—if it were wholly given up to gravitation. In such a state of things, it is evident that there could be no alternation of day and night, and no succession of seasons, but that all would be dark and invisible; for those delightful changes are produced, not by gravitation, not by the earth itself, but by the warming and illuminating influence of the sun; and these are not the gravitation of the earth, but opponents to it. We need not add, that in such a state of things, there could be no growth and no life, for these are sustained by opposing gravitation; and when the plant or the animal dies, that is, when its opposing powers ceases, it falls prone to the earth, never again to arise in its own strength.

A world without growth, without life, and involved in utter darkness and extreme cold, would be a world dismal enough to our comprehension; but let us just cast a single thought on what would be its structure as a mass of matter,—dead, dark, and cold. Under such circumstances, could there be any distinction of mineral from mineral, or of even land from sea?—there could be none. All the differences which we observe, whether in the growing and living productions on the surface of the earth, in the countless variety of minerals which make up its solid mass, or in the distinctions of land and water, or, in short, of any one material thing from another, are the results of powers acting in opposition to gravitation. Gravitation is indeed, so to speak, the anvil in Nature's workshop, the resistance which enables the working powers in nature, the countless modifications of motion, to elaborate and manufacture all that we see: but still it is only the anvil; and in nature, as in the arts, if there were nothing but an anvil there could be no work done.

As we already said, and as every one must feel, it is impossible to imagine matter to exist without gravitation; and as there is no limit to the division, at least to the imaginable division, of matter, and, indeed, none to the real division, except in the imperfection of our senses and our instruments, it follows of necessity that all matter must be conceived as reducible to, and therefore composed of, ultimate atoms or particles, all so extremely small, that the quantity of matter in each, and the gravitation of each, which is at once the sign and the measure of the quantity of matter, must be exactly the same. If we could even imagine a difference, we should not have arrived at the limit; because we could still reduce the larger one to the quantity and weight of the smaller. It would be of no consequence how different were the qualities of the portions of matter which we subjected to this virtual analysis, for those different qualities do not depend upon gravitation; and though gold, and lead, and cork, and the common air of the atmosphere were the four which we selected, we could, in this analysis, imagine the smallest possible particle or portion of the lightest one, air, and then imagine each of the others to be divided down to a quantity of exactly the same weight or gravitation.

Hence it follows, that in one world or body of matter, subject to gravitation, and to no other law, there could be no difference of parts. It would be dark and dead; it would be uniformly so throughout its mass; and it would remain so for ever, that is, for the whole period of its existence,—actionless, useless, void. We have only to imagine the number of such masses of matter to be multiplied beyond the power of our arithmetic, and suppose them to be all under the same law, and no other, in order to perceive what the universe would be under the government of this one power; that is, if the Almighty Creator had given it no law but the single one of gravitation.

But when we look around us, we find that all is in a state of constant activity,—that all is in motion, and that much is in growth and in life,—and that these phenomena are as much associated with what we actually observe, as the phenomena of gravitation is with our notion of the very existence of matter: it is impossible for us even to think that matter can exist any where throughout the universe without being under the one part of the law as well as the other.

Such is the law, or principle of stability, by means of which any number of bodies might be sustained, and might perform any number of motions or other actions, upon the simple supposition that the two balancing portions of this law should be always adapted to each other, so that they might be equal to each other throughout all their changes. After this, we have only to apply to the heavenly bodies that which we find to be, at all places, and under all circumstance, invariably true upon earth; and if so, then we are prepared to study the appearances of the heavens with understanding and to advantage.

There is, however, one other little element, not of the law itself, but of the mode of its action, which it is necessary for us to take along with us, both in the investigation and the application of the principle. It is this: no change, no motion, can be produced by the operation of two opposing forces which are exactly equal to each other; for the result of such an opposition would be perfect rest. That which gains the victory must be the stronger of the two: how much will depend on circumstances, but it must be stronger. For instance, a man can stand with a weight on his shoulders which he cannot lift and place there; and in every case that we can observe, less exertion is necessary to keep any one moving thing in motion than to start it into motion at the first; and, in like manner, that by which any motion or action whatever is in any way changed, must, at the first, be stronger than that which it changes. This is called resistance to change of state, and it holds equally with changing the place of an entire body, or with changing the condition of the whole, or of any part of it; and we shall afterwards see that this resistance is an important element in giving stability to the system of the universe amid all its apparent changes. It forms, as it were, an elastic spring, which admits a certain play to the system without an injury to the parts; and in the case of two balancing forces, we shall afterwards see that it has the reacting elasticity of a spring, as well as the yielding one.

Every one who has noticed the bending of a stem or a twig to the passing gale, or the beautiful waving of a hay or corn-field when the summer breezes play over its surface, must have perceived the protection which these little and tender things have in their elasticity; and as in these, so is there in those mighty volumes of matter which career through the regions of space, a means of yielding and returning to their mutual action upon each other; a stability and motion, in short, which could not be obtained in a state of rest—so true is it that life involves in itself the means of living; and when we come calmly and seriously to the contemplation, we find that in God's working, to create is to preserve, and that to whatever it is his pleasure to give being, he at the same time gives the means of preserving that being until it has accomplished the purpose of his Almighty will.

It is this which renders the contemplation of the works of God, whether we study them in the heavens or on the earth, so pleasant and so profitable. There is not a world, there is not an atom, without his keeping; in his sight, change is stability, misery is enjoyment, and death is life, in so far as material nature is concerned; and when we apply this analogy to that which is immortal, that which cannot be subject to physical dissolution, we cannot but be impressed with the feeling, that in him, in the knowledge of him, and in the keeping of his laws, there is all our happiness, and should be all our desire.

We have seen in a former section how the simple fact of the earth's being a globe enables us to measure its size. We have only to find the angular distance of two places, and this gives us the part of the whole circumference of the earth which is between them; and then, if we measure the length of this part, we can, by simple multiplication, find the whole circumference. From this, the diameter, or any other line connected with the globe, can be found, and thus we have a standard of about 8000 miles to use in the measurement of the heavens. This is our line, and the earth also furnishes us with our balance in the phenomena of gravitation, whenever we have examined that phenomenon so far as to see how it is affected by the distances of bodies from each other and their quantities of matter. The outline of this examination will form the subject of our next section.

SECTION VI.

GRAVITATION AND MOTION.

In the preceding section, we have attempted to present to the reader the most general, simple, and elementary view of the material creation, conceiving this to be the point at which we should commence our observations and reflections, in order to understand what we observe, and to be accurate in every conclusion at which we arrive. In this view we put all the differences of matter, whether as to place in the universe, appearance to our observation, or action of one portion upon another, entirely out of the question,—taking only the two great principles of *gravitation* as the general expression for the *existence* of matter, and *motion* as the general expression for the *action* of matter.

Simpler or farther than this we cannot carry our analysis. We are here upon the same mysterious and shadowy boundary at which we invariably arrive when we push our analysis to the extreme point. We contemplate space—in every direction it extends onward to infinitude, and eludes our farther comprehension; if we trace backward any organized thing,—the giant oak, for instance, which records the succession of ten generations of our kind,—we come ultimately to the embryo acorn, on the very verge of nothingness. It is even so with every subject which we can by possibility study; and therefore we need not wonder that such should be the case with those grand elements of that whole, of which the varieties of individuals that it presents show us only the minor modifications.

In all those cases when we come to the bourne of our knowledge, and trench upon infinitude, in which way soever that infinitude may lie—in the vast, or in the viewlessly small, in the extreme of resistance or of action—there is but one foundation upon which the mind can rest—one ark in the deluge of doubt upon which the dove can with safety close its weary wing;—we have approached, as nearly as human weakness in the contemplation of material nature can approach, the throne of the Almighty Creator, before which, adoration is our most solemn duty, and should be our most delightful enjoyment; and as we find the same determination in every subject which can engage our thoughts, the conviction is irresistible, that all things are under His government.

This is the conclusion at which the unsophisticated mind would of itself arrive upon reaching this ultimate goal of human study; but the way is long, and there have not been wanting attempts to make it crooked; for some of those who have arrived at the perception that gravitation and motion are the primary causes of every appearance of matter, have most strongly turned round and asserted that these principles were to be sought as principles, and not as the action or evidence of principles, of those very effects of which they are the causes. Upon such false reasonings they have spoken about the "cause" of gravitation and the "cause" of motion, as if these belonged to matter,—that is, proceeded from matter as their primary origin. Now, though it be true that the displays of the action both of gravitation and motion, in particular pieces of matter, have a relation to the qualities of those pieces; yet when we come to generalize either the one or the other, we find that there is no origin for either which will satisfy the candid mind, or be consistent with sound reasoning and true philosophy, but the creative power of Almighty God.

When we lay the corner stone of our elementary knowledge upon this sure foundation, we can then turn to all the productions and all the phenomena of nature, trace all their relations, all their successions, and all the modifications and workings of those great principles with equal safety and delight; for as the Rock on which we are founded is everywhere present and everywhere the same, the same safety, the same certainty, and the same success must attend our contemplations, whithersoever in the wide and varied extent of perceptible or imaginable creation they are turned.

Having made these few preliminary, but not, we trust, inappropriate remarks, we shall now proceed to mention, as briefly, and with as little technicality of expression as possible, the outlines of the mode of action in those two great principles, as we have experience of them on the earth, and as we apply them to the phenomena of the heavens, by analogy from this experience; and, first, as to gravitation.

It has already been said, that gravitation, in any portion of matter, is equal to the quantity of matter in that portion, and the only measure we have of that quantity. In the whole range of our experience upon the earth's surface, we find that every body which is not supported by means which we can understand falls to the earth, in consequence of this gravitation; and therefore we infer that any two pieces of matter, or indeed any number of pieces whatever, would fall towards each other, if some opposing force did not keep them asunder. Suppose two bodies, containing exactly equal quantities of matter, to meet each other by the action of gravitation, it is evident that they would meet exactly midway between their original places, because, if the forces are exactly equal, and nothing to affect either of them, the effects which they produce must be exactly equal. On the other hand, if they were unequal, it is evident that the smaller body would move over the greater distance, because gravitation is a *drawing* force—a force which brings portions of matter together—and the greater body must draw more strongly than the smaller, in proportion as it is greater; for instance, if the one were double the other, the two would meet at one-third of the distance from that one, and two-thirds from the other, and so in all other proportions.

Upon this principle, all bodies near the earth, which we can by possibility observe, must fall to the earth by gravitation, without any sensible motion of the earth towards them. For, as we have already stated, the earth is about eight thousand miles in diameter, and we very seldom have an opportunity of observing the fall of a single body more than a few feet in dimensions. Farther (and the means by which this is determined will be noticed afterwards), the earth, taken altogether, is about four-and-a-half times the weight of the same bulk of water, or one-fourth of that of the same bulk of gold, as dug native from the mine; that is, every solid foot of it, taking one kind of substance with another, weighs 281 lbs. 4 oz., or, in round numbers, 2½ cwt. This is about double the weight of the most compact granite, which is our most heavy and durable building stone; and when we consider what an immense, and, to us, incomprehensible number of square feet there are in a globe eight thousand miles in diameter, and that each of those weigh 2½ cwt., we can form at least some notion of the force of gravitation in the earth, as compared with that of any moveable portion of matter near its surface.

It is found by observation, however, that when a plummet is hung by a slender thread near a large mountain, the side of which is steep or abrupt, the plummet is attracted, or the direction of the thread inclines a little towards the mountain. Now, the largest mountain on earth is much less in comparison with the earth itself, than a grain of sand in comparison with the mountain; and, therefore, if gravitation were effected by quantity of matter only, no such deflection of the plumb-line could take place. There must, therefore, be another element in the action of gravitation: let us inquire what that element is.

The original discovery of this element was a matter of no small difficulty; but in science, as in life, the labour in making the road is intended to render the passage of the traveller quick and easy; and so we shall pass lightly over it. We must consider every mass of matter as made up of a countless number of those elementary particles to which we alluded in the last section, and that these

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particles all mutually tend to each other by their gravitation. There must, therefore, be some point within the mass to which they all have an average tendency; and if we could suppose the mass to be divided by a plane section, or perfectly straight cut, through this point, the quantity of matter would be divided into equal parts, in whatever direction the cut were made. This point is called the *centre of gravity.* In a perfect globe it is the centre of the globe, and, as all parts of the globe are equally distant from the centre, gravitation is equal at all points of the surface of the globe, unless affected by some external cause. In bodies of different forms, gravitation is not equal at all parts of the surface, though the differences may be calculated by a process which is difficult in proportion as the body is irregular in its figure. We have nothing to do with this difficulty however, as the earth is so nearly a globe, that, in general reasonings, it may be regarded as exactly one. And we may consider the centre of the earth as the point at which the whole of its gravitation is concentrated; and this will hold, whether we regard the effect of the earth on a small body near its surface, or on a large one distant in the heavens. Let us now consider the mountain. This also must have a centre of gravity; and though we are not called upon to ascertain in what part of it the centre of gravity is situated, as we are not speaking of a particular mountain, we can easily see that any small body, such as the plummet, near the mountain, and free to move, will be attracted toward the centre of gravity of the mountain, in proportion to the quantity of matter raised above the mean level of the earth's surface which the mountain contains. The plummet is thus acted upon by two forces which tend to pull or stretch the string by which it is suspended; the gravitation of the earth, by much the greater of the two, stretches the string downwards, and the attraction of the mountain, acting in the cross direction, but much more feebly, draws it a very little to one side. The string is the resisting force acting against both these; and among those forces the plummet obeys the stronger—hangs if the string is strong enough, but falls to the earth if it is not.

Now we have said, that in respect of the quantities of the matter, this attraction of the mountain would not be at all perceptible, but yet it has been perceived. What other circumstance is there that could give the mountain an advantage? Even if it were solid gold, and, fifty times the size of any mountain upon the face of the earth, it would still be too small for any comparison with the earth; and from what has been said of the weight of granite, we cannot conceive that any mountain can, taken altogether, weigh as much as an equal bulk of the whole matter of the earth. The only other circumstance is the different distances of the two centres of gravity. If we suppose the plummet at the mean level of the earth's surface, it is about four thousand miles from the earth's centre of gravity, and only a mile or, at most, a few miles from that of the mountain, according to circumstances; and there is no way in which we can conceive that the mountain obtains the advantage which observation shows that it does obtain, unless by its centre of gravity being nearer; and therefore we must come to this conclusion—"gravitation is inversely as the distance of gravitating bodies;" that is, as the distance is increased, the gravitation is diminished, and as the distance is diminished, the gravitation is increased; the quantities of matter in the gravitating bodies being considered the same all the time. At what rate does this variation take place? Is it the same with the change of distance, or is it different? Let us inquire.

The answer to this inquiry may be obtained by the solution of a *dynamical problem*, that is, a solution or answer to a question in the doctrine of forces, the data for obtaining which are partly theoretical and partly founded upon direct observation. This, however, is a technical matter, and, as such, it does not come within our limits. But there is a more popular view, which is scarcely less convincing. We mentioned that the whole attraction which any body exerts may be conceived as concentrated into the average point, or centre of gravity; and it is evident that the gravitation of the body, or the force with which it attracts any other body, may be expressed by straight lines all meeting in this point, and diverging farther and farther from each other as they are continued from it,—that, in fact, they may be represented by radii of the body itself considered as a sphere or globe, or as radii of any real or imaginary globe, of which the body exerting the gravitating influence may be conceived as being the centre. The surfaces of globes are to each other as the squares of the radii, in the same manner as any other similar surfaces are to one another as the squares of the corresponding sides; and this holds with regard to any portion of the surface, however small, as well as to the whole of it.

But the body on which the gravitating influence is exerted presents a surface towards the exerting body exactly equal to its own section; as, for instance, the circular disc which the full moon presents to the earth is of exactly the same apparent magnitude as the flat surface which the moon would present if the half next the earth were cut away. Now, if we suppose an imaginary sphere to surround the earth at the distance of the moon, the moon's disc will occupy a portion of the surface of that sphere, and the gravitating influence which the earth exerts upon it will be correctly represented by all the straight lines, or radii of the earth, which, extended as far as the moon, would fall on the disc; and their number, whatever it may be, will be the measure of the attraction of gravitation which the earth exerts upon the moon.

This being understood, let us imagine the moon to be brought to exactly half the distance from the earth's centre, its magnitude remaining the same as before, and let us suppose its disc, in this state, to form a portion of the surface of a sphere of half the former radius, it is evident that a greater number of radii drawn from the earth's centre would now fall upon it, or, in other words, it would be more powerfully attracted. But the whole surfaces of the two spheres are to one another as the squares of their radii; and as the larger one has a radius double that of the former, the surface of the larger sphere will be to that of the smaller sphere as the square of 2 is to the square of 1, that is, as 4 to 1. But the disc or section of the moon is the same in both cases, and therefore whatever part it may happen to be of the surface of the larger sphere, it must be four times as great a part of the surface of the smaller sphere, as the whole of that is only one-fourth of the surface of the greater. Now, the surface of both spheres equally represent the whole attractive power of the earth; and as the earth remains the same, the attractive power at the surface of each sphere must be the same, and over an equal portion of the sphere it must be smaller in proportion as the sphere is more extended; that is, at double the distance it will be one-fourth, at three times the distance it will be one-ninth, at four times the distance it will be one-sixteenth, and so on for all other distances, the measure for any two distances, being always inversely as their squares, expressed in the same measure. It is to be understood that these measures begin at the centre of the earth and not at its surface, and that, consequently, if distances above the surface of the earth be reckoned, four thousand miles must be added to each of them; and that the intensity of gravitation at any two heights above the surface will be inversely as the squares of the two sums. Thus, gravitation at the height of a mile will be to gravitation at the mean surface, as the square of 401 to the square of 4001, which will make a difference of about one pound two ounces in the gravitation or weight of a ton, if weighed against any power which is not affected by gravitation, but no difference whatever if weight were weighed against weight.

The highest mountain in the British islands does not rise nearly a mile above the mean level; but we shall not err much if we say that if difference of gravitation has no effect on the strength of the human body, a man could lift more in the rate of about one pound to the ton, on the top of that mountain, than at the mean level of the earth. If we could suppose a man removed to the height of about four thousand miles from the surface, his strength, as exerted against gravitation to the earth, would lift four times as much as at the surface; at the height of eight thousand miles he would lift nine times; and the height is not *very* great at which, if the man himself could be supported by any means, he would be able to carry St. Paul's cathedral on his back, as lightly as a soldier carries his knapsack.

The law of gravitation of which we have attempted to give a popular view—first, in respect to quantity of matter, and secondly, in respect to distance, is usually generalized by saying, "the intensity or force of gravitation is directly as the quantity of matter and inversely as the square of the distance."

The fact (for what we call laws in nature are nothing else but clearly established general facts,) of the intensity diminishing as the square of the distance, is a most important one in the study of various departments of nature; for it is evident that the same reasoning which applies to gravitation will apply to every other description of power or energy which can be considered as referable to a centre, and acting equally in all directions round that centre. Such analogy, be its effect what it may, will invariably diffuse itself through a sphere of which the point whence the energy emanates is the centre, and, consequently, the action upon an equal quantity of matter will always be inversely as the square of the radius of the sphere, or distance from the centre. This is the case with heat, with light, with the power of distinct vision in the human eye, and probably with every species of what may be called primary action—that is, action which we cannot ascertain to be the result of any previous motion, which motion being in itself a result of action, makes the action that follows it secondary.

It is easy to see that this rapid diminution in proportion to the increase of distânce must soon render a small original energy quite imperceptible. Thus, the attraction of a mountain will not be perceptible beyond the distance of a few miles, the heat of a moderate fire in the open air is not felt beyond the distance of a few yards, and the light of a small taper, even in a dark night, disappears when we remove to but a moderate distance from it.

This law of the diminution of intensity is easily convertible into a means of ascertaining the original intensity if we know the distance, or the distance, if we know the original intensity; and it is one of considerable importance in the study of the heavens.

The light of the sun, for instance, conceals that of even large fires in the open air, if at a small distance; and yet the average distance of the sun is 95,000,000 miles. Now, if we suppose the terrestrial fire which is just obscured by the solar light to be at the distance of a mile, the law of diminution, inversely as the squares of the distance is, will give the original intensity of solar light at the body of the sun as being 9,025,000,000,000,000 times greater than that of the terrestrial fire; and this is a number all but infinite to our comprehension. But still this indescribable splendour—a splendour which no human eye could dare to approach within the distance of many thousand miles—appears to be nothing in comparison with the glory of some of the radiant bodies in the more remote heavens. It has been ascertained, by the late Dr. Wollaston, that the light of the Dog Star (Sirius), the brightest in our heavens, but probably the brightest only because it is the nearest to us, cannot be less at the star than double what that of the sun is at the sun; and that it may be, and most probably is, many times greater.

Our perception of light is immediate, while that of heat or of gravitation is secondary, and discovered only in the sensible effect which it produces on the state of some substance which we can observe; and therefore our discernment of these cannot be carried to the same degree of nicety as our discernment of light. But as they follow the same law, there can be no doubt that they do extend to immeasurable distances; and that the gravitation of every body throughout the universe extends to and influences every other one, though our means of observing the results are confined to a very limited portion.

From this alone, and without any straining of analogy, it follows that we are perfectly correct in applying the epithet "universal" to the principle of gravitation, because, though the decrease is rapid in proportion to the increase of distance, the one must accompany the other the utmost limit to which we can carry them; and thus the very nature of the law of gravitation makes that law a necessary part of the whole system of material nature. Such being the case, we have only to ascertain the distance of any two bodies from each other, and the quantity of matter in each, in order to determine with perfect certainty, and as much accuracy as is attainable in inquiries of such magnitude, the influence which the gravitation of each exercises upon the other. In addition to this we have only to investigate the opposing or counteracting principle—motion; and if we can as clearly establish its laws, we shall be in possession of all the elements of the phenomena of the heavens; so that, to as great a distance as we can, by true analogies from well ascertained standards, measure distance and determine quantity of matter, we can tell what has been, is, or will be, the place of any one celestial body at any one moment of time, and also what influence its being there will have upon the place of every other body within the range of our mensuration.

Let us therefore, secondly, examine what are the principal laws of motion.

This branch of the subject is, however, attended with difficulties which we do not meet with in the other. We do not know all the immediate causes by which motion may be originated, or changed, or destroyed; and though, when a body containing a known quantity of matter is moving at a known rate, and in a known direction, we can tell the quantity of its motion, and also the extent to which it can resist or counteract gravitation, yet we cannot consider motion as an inseparable adjunct of matter, and therefore as being in any way connected with or measurable by quantity of matter. Thus gravitation and motion have, so to express it, no common measure, which we can apply to them under all circumstances, and thereby determine the relation or proportion which they bear to each other. We can, however, compare them in particular cases, and, fortunately for us, in the study of the heavens, the motions of all the bodies whose distances we can measure, and whose weights we can ascertain, come within the manageable part of the general problem; and, though we would at first sight not expect it, the puzzles are found nearer home—immediately within our reach, as it were—in the differences of structure and action which we perceive among the productions of nature on the surface of our own globe, or as far as we can dig into its substance, or ascend or examine into its atmosphere.

Our idea of motion in itself is abundantly simple: we cannot imagine a body to move without its being put in motion by some force, or combination of forces, and whether the force be one or many, the progressive motion of any body can be only one, and in one direction: the direction of the impelling force, if there be only one, and the direction of the *resultant*, or combined action of the whole, if there be several. In the study of the heavens, we do not require to perplex ourselves about the forces which originally produced the motions that we find there, because we can know no more of the mode in which the motions originated than we can know of the mode in which the bodies themselves were called into existence. If a body is put in motion by one force which merely sets it going, we cannot imagine it to proceed in any other than a straight line, or either to increase or decrease in the rate, or velocity, of its motion, without the action of some new force competent to the production of the change; for to imagine otherwise would be endowing the material body with creative power, inasmuch as all the action of matter, whether motion simply or anything more complicated, is a work of creation as much as matter itself. But if any new force acts, there must be a change in the direction of the motion proportionate to the energy of this new force; and if we suppose a body to have been put in motion by an original impulse, which would have sent it onward in a straight line, but that it is acted on continually by another permanent force, then that other force will continually deflect, or turn it away from the straight line, and it will move in a curve, the form of which will depend upon the relation of the two forces, and whether they are constant or variable in their intensity. If they are exactly equal to each other, and both invariable, the body will move in a circle, having the direction of one of its forces for its centre; and if they are equal to each other, but variable, the body will not move in a circle, because each force, alternately, will have a tendency to exceed the other. The kind of curve will vary according to circumstances; but it was demonstrated by Sir Isaac Newton that, in every case where one of the forces is *central*, the body must always move in one or other of those curves called conic sections; and as gravitation is in all cases a central force, and as it is always one of the forces in determining the motion of every celestial body, it follows that the path of every celestial body, move how it may and where it may, must be at all times a conic section, though not necessarily always of the same form or magnitude.

Different degrees of density or quantity of matter in the same bulk, and of rate of motion or velocity, will cause the path of the body upon which the central force is exerted to move in different curves; but if the moving body upon which a central force, or force pulling or drawing towards a centre, such as gravitation is, is exerted, be one of considerable density and retain the same form, the path will be an ellipse or oval, of which the body exerting the central force is in one of the *foci* or centres. This will be more particularly explained in a future section.

The quantity of motion, when spoken of generally, is, like that of gravitation, made up of two elements,—the quantity of matter in the moving body, and the rate at which the body moves. The rate is estimated by the space passed over in a given time, and in our common ideas of motion this is all that we mean, for we do not take the quantity of matter into the account. Thus, where we speak of the rate or velocity at which a bird flies, a horse runs, or any other motion is performed, we always speak of the time required to pass over a given distance, or of the distance passed over in a given time. Different velocities are thus compared with each other, by stating that they are inversely as the times, and directly as the distances; in other words, the longer time that is required the motion is the slower, but the longer distance that is passed over the motion is the quicker. Hence we get a simple numerical comparison by multiplying each distance by the time of the other. For instance, if one coach passes over thirty miles in four hours, and another passes over twenty miles in three hours, the rate of the first will be to that of the second as three times thirty to four times twenty, which is ninety to eighty, or nine to eight, so that the first coach goes nine miles in the same time that the second goes eight.

Motion, considered merely with reference to the body which moves, can never be regarded as proceeding from a centre, and therefore no element, varying either directly or inversely as the square of distance, can enter into the estimate of the rate of motion considered as a power opposed to gravitation in the moving body. The only elements of that power are those already stated—the quantity of matter, and the velocity—and the expression for the motion as a power in the sense alluded to is their product, and it is always a simple product, arising from one multiplication of two factors, consequently the expression for it in numbers is of the same kind as that by which we express a surface or *area*—a square, for instance—the product of the length and breadth. Simple as it appears, this is an important consideration, and must be borne in mind by every one who wishes to understand the laws of the planetary motions.

Bearing it in mind, therefore, let us revert to the elements of which the force of gravitation is made up, and see of what kind of product that force is composed. Like the force of motion it consists of two elements, the quantity of matter and the square of the distance; and we have already seen that in estimating the relative force of gravitation in two cases, we take the quantities of matter directly and the *squares* of the distances inversely, and the product of these elements are simple expressions for the force of gravitation in the two cases. But the square is a product—the product of a quantity by itself,—and as such it expresses a surface or area, and this surface or area has again to be multiplied by the quantity of matter in order to get the expression for the force of gravitation. Now, when we multiply a surface by any factor the result is an expression for a solid,—that is, whenever three numbers are multiplied together, we may consider them as length, breadth, and thickness, and their product as a solid, in the same manner that we consider two factors as length and breadth, and their product as a surface.

Any surface may be expressed in terms of a square; and, in fact, whenever we speak of the contents of surfaces, as of the number of yards in a carpet, or the number of acres in a field, we always mean *squares;* so also, when we speak of the quantity of solids, as of the feet in a wall, or the yards in a mound of earth, we always mean *cubes*, that is, solids which have six faces all exactly square. But our expression for motion is a product of two factors, and our expression for gravitation is a product for three factors: hence we arrive at the law of variation in motion and in gravitation, so that, under every possibility of change in each, they may still remain equal to each other; and this is the grand law of the celestial motions:—MOTION VARIES AS THE SQUARE; GRAVITATION VARIES AS THE CUBE.

This is the substance of what is called "Kepler's *third law* of planetary motion;" and though, now that we are in possession of the elements of the force of gravitation, its principle is not difficult to be understood; yet, when we consider that the illustrious astronomer whose name it bears arrived at this law by reasoning founded on observation of the celestial bodies only, and without any element to guide him, save the doctrine of forces as then known, and when we also consider that this and the other laws deduced by Kepler from observations (chiefly those of Tycho Brahe) were the means by which Newton connected the action of gravitation, as observed on the earth, with the system of the heavens,—the deduction of this law may be regarded as one of the noblest efforts of human genius.

In order rightly to understand the operation of this law, we must consider which of the elements of each force are capable of variation, in the cases of the same bodies. We cannot imagine any change in the quantity of matter, either of the central body which attracts the moving one by the force of gravitation, or in the moving one which just balances this attraction by the force of its motion. As already remarked, the quantity of matter, as measured by gravitation, has nothing to do with its qualities as apparent to our senses or to any other test.

An ounce of water is the same identical ounce, whether it be flowing in the fountain, dashing in the cascade, rolling in the river, tumbling in the ocean, rising in vapour, descending in rain, drifting in snow, congealed in ice, or even if its elements (its oxygen and its hydrogen) are separated from each other, and every single elementary particle of each of them has gone separately to the formation of a new and different compound. The law which God has given to it and to all nature is a perfect law—and it is one; and though this same ounce of water should pass through a million of changes a million times over, not one atom of it would or could perish, except at the bidding of Him who called it into being.

The earth which we inhabit *may* have been a waste of waters; it may have been rank with aquatic plants, and peopled with those giant aquatic reptiles whose bones are now monumental in the earth; trees of thick foliage may have overshadowed it, and the elephant may have lopped their twigs in those regions where there is now no native quadruped larger than a mouse: cultivation may cover it with every flower which pleases the eye, and every herb and fruit which can support life; industry may bustle, science may beam, and religion may bless; and anon, all its beauty and its glory may pass away, and it may be resigned to the shifting sand or the overwhelming flood;—but still, "He who of old hath laid the foundations thereof" is its preserver amid all changes, and He alone can pronounce the doom of nothingness upon even its smallest atom. The microscopic mite and the mighty globe are the same in His sight, and His providence upholds the one as well as the other.

It follows from this, that the only elements of the two opposing forces that can vary, are velocity, or *time* the measure of velocity in the case of motion, and *distance* in the case of gravitation; and this brings us exactly to the enunciation of

Kepler's third law: "The squares of the periodic times of different bodies revolving round a central one, and retained in their paths or orbits by gravitation, have the same proportion to each other as the cubes of their mean distances from the centre of that body round which they revolve."

As a consequence of this it follows that, in order to preserve the balance of the two forces, and thus retain the revolving body in its orbit, every approach nearer to the centre must be accompanied by an increase or acceleration of the motion of the revolving body; and that every increase of distance from the central body must be attended with a diminution or retardation of motion, so that at every point of the orbit and every moment of time the two forces may exactly balance each other.

If the motion were performed in a circle, it would be perfectly uniform throughout the whole circumference passing over equal portions of that in equal times; and if we were to imagine a line drawn from the centre of revolution to that of the revolving body, this line,—which is technically called the *radius vector*, or "carrying ray," because, while one end of it remains at the centre, the other end, as it were, carries the revolving body round the circumference or orbit,—would sweep over equal angles, while the body passed over equal parts of the circumference. As the motion in this case would be uniform, and as the radius vector sweeps over, or as it is technically called "describes," the whole surface contained within the orbit in the course of a revolution, this radius vector would pass over or describe equal surfaces or areas in equal times, and also while the revolving body passed along equal parts of its orbit.

Thus, if we call the time of an entire revolution a year, and suppose that year to be divided into twelve months all exactly of equal length, the body, revolving in a circle, would pass over a twelfth part of its orbit each month, the radius vector would describe exactly a twelfth part of the angular space round the centre—exactly a twelfth part of the area of the orbit, and remain constantly of the same length.

This is the simplest case of orbital motion,—or motion of one body round another, sustained on the one hand by gravitation towards the central body, and on the other by the force of its own motion constantly tending to drive it away from the centre,—that we can imagine. We may mention that the central force, that which draws or attracts the body towards the centre, is called *centripetal force*, or force *to* the centre; and that the opposing force arising from the motion of the body is called *centrifugal force*, or force *from* the centre.

But though this circular motion is the simplest to our comprehension, it is one which could not be maintained in the system of the heavens unless the whole system consisted of only two bodies,—a central one, and one revolving round it. Because, as we have already said, notwithstanding the rapid rate at which the force of gravitation diminishes with increase of distance, we can imagine no distance at which it altogether ceases. From every mass of matter, how small soever, and wherever situated, gravitation feels its way through the whole universe, acting upon and disturbing the motions of every other body in proportion to its intensity, and consequently affecting them differently according as they are greater or smaller, and also as they are nearer or more remote. It is these interferences of body with body, or rather the disturbances which they occasion, that constitute the difficulties and niceties in understanding the moving and mechanism of the heavens; and some of them, though exceedingly small, and requiring long periods of time before they accumulate to an observable amount, are among the most abstruse subjects in the whole science of the heavens, or indeed in any one department of knowledge, of which the principles are simple and clearly and readily understood.

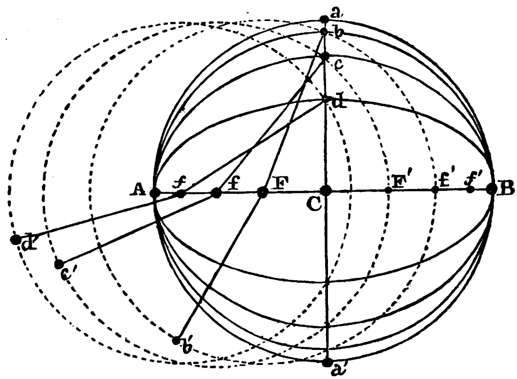
It will be perceived that in a perfectly circular motion, in which these centripetal and centrifugal forces were invariable, there would be no provision for any contingency; and no body but the one could revolve, without being nearer at some times than at others, and thus either pulling it outside the circle or inside, according as it came on the same side of the centre with the revolving body, or on the opposite one. In whatever way this disturbing force acted, it would destroy the circle, and there would be no means of return,—for a circle is of one invariable form, and if that form is once departed from there are no means by which it can be regained. The circle has but one centre, and the distance of the circumference from that centre must be always the same.

An ellipsis or oval is a much more accommodating figure. It has two centres, called the *foci*, situated in the longest diameter, one on each side of the middle point of that diameter, and both at equal distances from that point, which distance, or half the distance of the foci, is the *eccentricity* of the ellipse. The sum of the distances of the circumferences from the two foci is the same at every point, and always equal to the longest diameter; so that the eccentricity may vary ever so much and the shape of the curve change along with it, while the longest diameter, and consequently the average or mean distance of all the points of the curve from each focus remains permanently the same.

If, therefore, we are to suppose that a revolving body moves in an ellipse, in either of the foci of which the attracting body by which the revolving one is retained in the ellipse is situated, it is evident that the mean distance of the two bodies will remain the same under every change in the eccentricity; and that, consequently, the mean rate of motion and mean force of gravitation will be exactly the same as if the body revolved in a circle having the mean distance for its radius.

This may, perhaps, be rendered more clear by referring to the following diagram.

In this diagram, the circle A a B a′, and the three ellipses A b B, A c B, and A d B, have all the same diameter, namely the line A B, passing through C, the common centre of the whole, and of course divided into two equal parts by that point. C A, or C B, is the radius of the circle, and of course equal to C a, C a′, or any other straight line drawn from the centre C to the circumference. All diameters of the circle, in what direction soever they are drawn, are equal to each other, equally divided at the centre, and equally dividing the circumference; and therefore it is not necessary to give any one a particular name.



But, upon looking at the ellipses, it will be seen, that though the diameter A B is common to them all, the cross diameters of which b C, c C, and d C are respectively the halves in the three ellipses, are all shorter than A B, and all different from each other.

It may assist those who are not conversant with geometry, for whom only these remarks are of course intended, to mention how these figures were drawn, for that involves the principle of their differences from each other, and from the circle.

Well, with the exception of a ruler for drawing the straight lines, the only instruments used were two pins,—a bit of thread, and a pencil; the ends of the thread were tied together so as to form a loop exactly twice the length of A B. Then, first, to make the circle, a pin was stuck in the point C, and the loop of the thread put over it doubled, in which state it was, of course, as long as C A or C D. Putting the point of the pencil into the other end of the double loop, stretching it to A, and moving round by a, B, and a′, to A again, the circle was described.

Next, for the ellipse A b B, nearest the circle, two pins were stuck in the points F, F′, taken in A B at exactly equal distances from C. Then the ends of the same loop of thread single (which was, of course, equal to the whole length of A B), were put over the two pins, and both folds taken upon the point of the pencil, reached the point A, and swept round by b to B; the pencil was then shifted to the under side, and the other half of the ellipse described in the same way.

For the ellipse A c B, the pins were stuck in the points f f′, and for A d B, in the points *f f′*, the same loop of thread being used in the same manner as in describing the first ellipse A b B, care being taken that the two pins were, in each case, equally distant from the centre C.

From the manner in which these ellipses were described, it will readily be seen that, by using the same bit of thread; that is to say, a loop or double exactly twice the length of A B, an infinite (that is, an unlimited or countless) number of ellipses might be described, all having A B for their principal diameter, but all different from each other in the cross measure. A B is not any determinate line, that is to say, it is not a line that we are obliged to use, nor is it at all necessary to measure its length. It is any line taken at random; and therefore whatever is true of a circle, and ellipses having A B for their common diameter will be true in the case of those having any other line whatever, whether an inch long, a million of miles, or an indeterminate length beyond what we can measure.

If a a′ is drawn through C at right angles to A B it will divide the circle and also each of the ellipses into four equal parts, that is, into quarters or quadrants. The portions b C, c C, and d C, intercepted between the circumferences of the ellipses and the centre, are halves of the conjugate diameter of each, and the other halves of the same diameters are intercepted by the circumferences on the same line below the points C. These conjugate diameters differ in all the ellipses. They are called conjugate because they are as it were "yoked with" the transverse or principal diameter A B.

F, and F′ f, and f′, and *f* and *f*′ are respectively the two foci of each ellipse: and the distance of any of those points from the centre C, which is half the distance between the corresponding points themselves, is the eccentricity of the ellipse; and it will be seen that in proportion as the eccentricity increases, the conjugate diameter diminishes.

The law of this diminishing is easily seen: join one focus of each ellipse with the extremity of its conjugate diameter; that is, draw the lines F b, f c, and *f* d; and these three lines are of the same length, because, by the construction they are halves of the loop of thread, or each equal to the radius of the circle. As they are equal their squares must be equal, and the square of each of them is, by the well known property of right-angled triangles, equal to the sum of the squares of the semi-conjugate diameter and the eccentricity of the ellipse. From this it follows that an ellipse having A B for its transverse or principal diameter may have every variety of form between the circle and the straight line, it being a circle when there is no eccentricity, and a straight line when the eccentricity is equal to half the transverse diameter.

But if we suppose a central body to be placed in the focus, and another body to revolve round it by the balanced forces of motion and gravitation, these balancing forces will be exactly the same in intensity at the mean distance in every ellipse having the same transverse diameter, whether the eccentricity of that ellipse and its consequent deviation from the circle be greater or less. The whole revolution of the body will also be performed in exactly the same time, but in the circle it will be uniform; while in any of the ellipses it will be unequal at different times, in proportion as the eccentricity is greater.

Thus let the central body be situated at the point C, and let A be the body revolving in a circle, it will pass over each of the four quadrants A a, a B, B a′, and a′ A in exactly one-fourth of its entire revolution, and will move with the same velocity, at the four points which join those quadrants and at all others.

Again, let the central body be removed to F, the focus of that ellipse nearest the circle, and let the body revolve in that ellipse. At A it will be nearer the central body than the mean distance, by the eccentricity F C; while at B, the opposite extremity of the conjugate diameter, it will be farther from the central body F than from the centre C by the eccentricity F C; and that at the point b, the end of the quadrant, or extremity of the conjugate, it will be at exactly the same distance from the central body E as if that body had been in the centre C, and the revolving body in the circumference of the circle at a. In the lower half of the ellipse it will of course be the same, because the halves of the ellipse are exactly similar to each other.

Circumstances in the other two ellipses, A c B and A d B, will be so exactly the same,—with the exception that as the eccentricity increases and the ellipse becomes flattened, the different rates of motion at different points will be more variable,—that it is unnecessary to go over them in detail.

In these three, and in all possible ellipses having the same transverse diameter, the mean distance of the revolving body from the central one, that is, its distance on the extremity of the conjugate diameter, would be exactly the same, and the forces sustaining it exactly the same as would balance it in the primary circle. Thus, with the centre at F, the body would be so balanced as that the forces it had at the point b would carry it round the circumference of the circle b b′, of which F is the centre, if f were the centre, the body at c would have force equal to what would carry it round the circle c c′: if the *f* were the centre the body at d would have the same force as would carry it round the circle d d′; and it would be the same in the case of every other ellipse upon A B, where it cuts the line a a.

Notwithstanding this, it is very evident that if the revolving body should deviate ever so little from the circumference of the original circle, or the central body ever so little from the centre of that circle, the motion and the force of gravitation would at that instant become unequal. If we look back to the figure, and take the lowest ellipse, as being most distinctly seen, we have four points, A, d, B, and that where the ellipse cuts C a′, which mark out the four quarters of the ellipse, of which *f* is one of the foci, the one in which the central body is situated, and which, in the case of one body revolving round another, is called the upper focus, to distinguish it from the other or lower focus *f′*.

It will be recollected that the proportion of the squares of the periodic times, or rates of motion, is also that of the cubes of the distances. Now, *f* A is the distance of the revolving body when in the point A, *f* d is its distance when in the point d, and *f* B its distance when in the point B: the first point being the nearest distance, the second the mean, and the third the greatest. And according to the law the squares of the rates of motion will be inversely as the cubes of these distances. In the ellipse under consideration, these lines vary much in length, and they vary in all cases much more than the ellipse apparently varies from the circle, because the longest and shortest distances are always twice the eccentricity different from each other, and the one of them once the eccentricity greater than the mean distance, and the other once the eccentricity less.

We have gone into the explanation of this motion in an elliptic orbit with much more of detail, and at the same time with far less of the expression of science than is usually done; and we have done this, even at the risk of being thought tedious, for two reasons, which appear abundantly strong to support us even under the accusation of dulness. In the first place, it is altogether impossible for those who do not understand geometry thoroughly, at least as far as the conic sections, (and, indeed, who have not felt their way a good deal farther,) to form any accurate notion of this kind of revolution, without a good deal of explanation; and unless they understand this, the volume of the heavens is really a sealed book to them, or rather, perhaps, a book, the words of which they can pronounce, but of the meaning of which they are ignorant. Secondly, we have observed, in many instances, that those who had at least some general knowledge of the principles in the book, as it were, and could bring the force of their *calculus* to bear upon it, so as to work out correctly, in a technical manner, problems of no ordinary difficulty, yet had the possession and the use of this most beautiful and most efficient instrument as a piece of mere scholarship which they were incapable of applying to the real heavens as they appear, and which, therefore, was in truth nothing more than a mental toy, and the exercise of it only so much intellectual idleness. Now, for the great body of mankind there is wanted a species of knowledge upon all scientific subjects, which has not yet got an appropriate name in the vocabulary—it stands, as one may say, somewhere midway between ignorance and formal school learning, possessing a great deal of the power of the latter, but disencumbered of its formality; if the expression may be allowed, it is neither a courtly nor a canonic robe, which stiffens a man up, but an every-day dress, which allows him to work, and keeps him comfortable while he is working. This is sometimes called treating subjects popularly, though no description of knowledge, or mode of treating it, can be strictly called popular until the people are in possession of it; but that it is the best possession they can have in this world is a truth which does not require to be established by argument.

It is one of the peculiar advantages of the present day, that Scientific Knowledge has come forth of the closet and the cloister, to dwell among the people as their daily instructor and guide; but it is somewhat to be regretted that she still continues to have a foreign accent, and that the people do not understand her language, neither does she understand theirs. In consequence of this, people use scientific terms, and state scientific truths, of which they do not understand the meaning, and of which consequently they cannot make those daily practical applications in which the real value of science consists.

The knowledge which does not point directly to the doing of something which could not be so well done without it, is *useless* knowledge,—it being understood that *useful*, as contrasted with *useless*, means everything that can make mankind either wiser or better. Now, it will often be found that those who can quote the words or even the maxims of science with abundant readiness, are yet not able to put their hand better to a single thing than if they were ignorant of the words, and therefore their science necessarily falls under the denomination of useless; and this defect appears in so many instances that the translation of the scientific meanings into the every-day language of life, though a humble task compared with the original extending of science, is yet, in a popular point of view, by far the more valuable of the two.

SECTION VII.

PARTICULARS OF AN ELLIPTIC ORBIT.

Hitherto we have spoken of motion sustained by the opposed action of motion and gravitation, or centrifugal and centripetal force, in a general sense only, and without reference to any one particular body; we have done this in order that we might consider the general principle in the simplest view which can be taken of it, and thus not have the perplexing and unsatisfactory labour of doing two things at once.

We shall now, however, as the first step toward the application of the general doctrine to the system of the heavenly bodies, call the central body, the attraction of which retains the revolving one in its elliptic orbit a *sun*, and the revolving body a *planet*.

And, when we come to real bodies, actually performing those motions of which we have spoken generally, it is essential to bear in mind that the one does not revolve round the other, as if that other were a fixed point, stable independently of the laws which regulate the revolving one. The central body, whatever may be its magnitude, and weight or quantity of matter, as compared with those that revolve round it, is still under the same law, and sustained by exactly the same powers which sustain them. Were this not the case, the application of the principles which we have attempted to explain would merely change the place of the difficulty, and not remove it,—would merely shift the point of ignorance, but, in reality, leave us as ignorant as ever: this would be an exemplification of the old story of "the earth supported by the mountain, the mountain by the elephant, the elephant by the tortoise, and the tortoise by—no one knows what."

The simplest view which we can take of the matter is, that of two bodies, the one central, and the other revolving; but as, even in this simple case, both bodies are subject to and sustained by the very law, that of the balance produced by the equal and opposing forces of motion and gravitation—the one what we may term an *active* force, and the other which we may term a *passive* force, there are no means of sustaining the one which do not equally apply to the other, and if one of the bodies revolve round the other one, it must do so just because it contains a smaller portion of matter. The two must, in fact, revolve round their common centre of gravity, and the situation of that centre of gravity must depend upon the relative quantities of matter in the two bodies. Of the original impulse we know, and we can know, nothing; and whatever this original impulse may have been, it is not a necessary element in the motions as we find them. When any impulse ceases to act, the motion which it produces becomes a function, or phenomenon, of the body acted upon. For instance, it is to the explosion of gunpowder, or rather the expansive force of the rapidly-produced and heated gases which are the results of the ignition, that the cannon ball owes its initial motion; but when it has once began to move, the motion becomes, as we may say, *its own*, and would remain with it for ever, if some counteracting cause did not remove it. It fractures a stone wall, strikes and rebounds from the earth, wastes itself upon the yielding substance of a rampart of turf, is finally subdued by the force of gravitation toward the earth, or has its motion destroyed by some opposition or other, and so at last comes to a state of rest; but it would never come to this state if there were not some opposition capable of destroying its motion. We cannot call the motion a quality or property of the moving body, but it is a power which that body possesses while it is in motion; and, as matter has not in itself any capacity of producing and originating motion, so any piece or portion of matter, whether large or small, has no power of destroying, or putting an end to, or even changing, either in direction or in velocity, any motion that may be communicated to it.

Therefore, if the superior gravitation of a central body—that is, its greater quantity of matter—is sufficient to cause another body to revolve round it, that other body cannot passively revolve round this centre while the body round which it revolves remains at rest. Difference of mass will alter the circumstances, but both will remain true to the law, and their motion will be really about their common centre of gravity, as if the two were one continuous body, having a motion of rotation round its own centre of gravity. Whatever, indeed, may be the distance of the body which we say revolves from that which it revolves round, the difference between the two and one body is one of degree rather than of kind. It is probable that the ultimate or primary particles of no body are in absolute contact, and we are acquainted with many forms of matter where there are spaces between the visible pieces, which admit of peculiar motions of the individual parts, at the same time that the whole not only gravitate toward the earth, but at the same time partake equally of all its motions. If it were not for this, we should be unable to perform any operation in the arts, or even to move any part of our bodies. Now, the same law which, acting in the case of a little separation, enables all the operations which we see on the earth's surface and in its atmosphere to go on, while the whole are all in perfect obedience to the general laws, and partaking of the general motions of the earth itself. The same law, acting in the case of greater separations, enables each planet and other body in the heavens to perform its peculiar actions, while the grand operations of the whole system are going on. Also, as the general tendency of all bodies on or near the earth to gravitate towards the earth's centre is the bond of union by which they are all held together, instead of being strewn over the regions of space; so that general action of gravitation, which, as we have said, feels its way to unmeasurable distances is the band of systems—the bond of the whole universe.

But if, from the very nature of gravitation, two bodies must revolve, not the one round the other as fixed, but the two round their common centre of gravity, so must three, or four, or any number; and though when we attempt to follow the succession we are in this as in all cases lost in the immensity of the subject, we can imagine no stability for any one mass in the universe, by what name soever it may be called, other than revolution round some centre of gravity, in terms of that very same law of which we have exemplifications in everything that goes on upon the surface of the earth.

Magnitude and distance do not in the least affect the principle of the law, though they determine the quantity of its effect. Directly as the masses, and inversely as the squares of the distances, is a law far more immutable than those of the Medes and Persians; for it has emanated from a Law-giver who knows no change; and it is just as impossible to conceive that any system of bodies revolving in free space can revolve in any other way than round their common centre of gravity as it is to conceive that a smaller weight shall outweigh a greater in the scale of a just balance.

We can make perfectly satisfactory experiments upon this centre of revolution with bodies near the surface of the earth, notwithstanding their common gravitation to the earth itself. Indeed, as this gravitation to the earth affects them all in the exact proportion of their quantities of matter, it does not affect our experiment any more than if it had no existence; for it is only repeating a truism to say that that which affects all equally cannot make the least difference to any. Difference of distance from the centre of the earth would, no doubt, make a difference; but then, any difference in this respect between piece and piece of the matter upon which we can make an experiment, is so small that we need not, and indeed cannot, take it into the account.

Now, if we do not restrain their natural motions by absolute force, we find it impossible in any experiment that we can perform to make a heavier body revolve round a lighter one. If we have a common playing bowl turned to a perfect sphere, and load one end of it with a piece of lead, launch it with what force we may, it will turn round upon the bias which the lead gives it, and if it is sufficiently loaded it will wheel into a complete loup let the green along which it is rolled be ever so true. Connect a ball of lead and a ball of cork, or any two bodies, the one of which is either bulk for bulk or absolutely heavier than the other, by a bit of string, tie another string to the middle of the connecting one, so that the two bodies may hang side by side, then twirl the string round, and the lighter body will invariably revolve round the heavier one, and the heavier one will remain more and more without revolving motion, in proportion as its weight exceeds that of the other. Take two bodies of equal size and weight (equality in both respects is necessary in order to counteract the resistance of the air,) and upon twirling the string it will be found that they separate equally and revolve in opposite parts of the circumference of the same circle. If they are unequal, but not greatly so, each will appear to revolve in the circumference of a different circle, the lighter in a larger circle, and the heavier in a smaller one. Now, whatever we find to be the case in those pieces of matter which are equally under the influence of terrestrial gravitation, in proportion to their quantities of matter, we may be sure must also be the case with those larger masses which revolve in free space. The general conclusion therefore is, that all bodies which revolve, or, in fact, which are sustained in free space, revolve round the centre of gravity of that system to which they belong, whether the system be primary or secondary, that is, whether it revolves round a centre of which we do not, or do, know the sustaining motions. When we come to apply these principles to the actual appearance of the heavens we find an example of one primary system of bodies, of the centre of which we do not know the motions; and also several secondary systems, the motions of whose centres are known; but in both cases, or indeed to any extent that we can follow the combination of subordinate systems to higher and higher causes even in imagination, we can, by no possibility, even think of a mechanical law supporting any system, or its centre, other than that of the opposing power of motion and gravitation.

There remain other two particulars, of which at least a slight knowledge is necessary, in order fully to understand the motion of a planet round a sun, or centre of the system, in an elliptic orbit. These are the *momentum* or acquired tendency to motion, or perhaps we may say *power* of motion in a moving body, and the *composition* of motion, that is, the *resulting* direction of one compound motion, which, though one in its direction, is yet produced by two forces, the directions of which make an angle with each other.

The first of these is a very simple matter, for as we can suppose no effect to take place without a cause adequate to the producing of it, and as an effect in action implies an active cause, we cannot even imagine any motion to be produced or modified without a cause adequate to the production or the modification. Therefore, with whatever force, or velocity which is the measure of force, any revolving body may move in any part of its orbit, we must suppose, and, indeed, cannot help supposing, that, if the attractive force which deflects it toward the centre round which it revolves were to be, in any way, instantly destroyed, the body would move on in a tangent to the curve in which it then was, whatever might be the form of the rest of that curve; that is to say, it would move on in a straight line, in the same direction, and with the same velocity which it had at the instant that the central force were destroyed, and, if the attraction of no other body should affect it, it would continue to move in that direction, uniformly and for ever.

On the other hand, if the motive force were to be stopped at any point of the orbit, the revolving body would move toward the centre of gravity of the system in a straight line, commencing with a velocity exactly equal to the gravitation at this point, but constantly increasing in the proportion of the squares of the times, and at last impinge upon the central body with a final force, equal to the square of the distance.

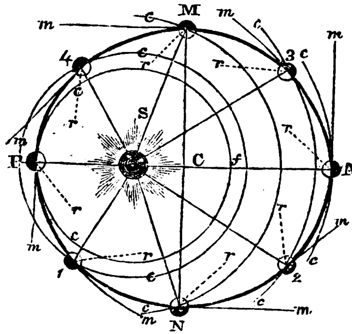
The other preliminary matter which we have to consider is the composition of these two forces, or the *resulting* direction which is the consequence of these two forces acting jointly. Now, when two forces act at an angle, each of which would carry the body on which they act along a straight line, if acting singly, it is proved, partly by reasoning, and partly by experiment, that their joint action will carry the body along the diameter of a parallelogram, of which the two forces express two sides containing the angle from which the body starts, the other two sides being exactly equal and parallel to these. In the case of equal forces this parallelogram will have all its four sides equal; and its shape, and the length of its diameter, which expresses the velocity of the resulting motion, will be longer or shorter according to the magnitude of the angle formed by the two forces. If this be a right angle, the parallelogram will be a square; if less than a right angle, it will be an elongated rhombus, having its diameter longer than that of a square of equal sides; and if it be greater than a right angle, the parallelogram will be a flattened rhombus, having its diameter shorter than that of a square of equal sides; therefore, generally speaking, the smaller the angle made by the two forces, the resulting motion will be the more rapid, and conversely, the greater the angle the resulting motion will be the slower.

The demonstration of one-half of this truth is a matter of common geometry; but the other half, though it is easy to see that it is true, falls upon an indeterminate case of triangles, and therefore it cannot be established in a manner perfectly satisfactory by geometry alone. It is, however, a matter of observation; and in all cases where we can observe it, it is equally true both as to the velocity and the distance.

The principle is, however, abundantly plain, so much so, as to be one to which every one assents, the moment that it is clearly stated; and this assent is all that is required for popular purposes. If two equal forces acted on any body in the same direction, the motion would obviously lie in the common direction, and it would be exactly double of that produced by either force acting singly. Two horses drawing a carriage afford an instance, though not a perfect one, as they cannot in practice be made to draw constantly with the same pull. On the other hand, if two equal forces act upon any body in directions exactly opposite to each other, the body can obviously have no motion arising from their action. These are the limits; and between them there may be all varieties of angles, and all quantities of motion, from one equal to the joint effect of the two forces down to nothing. But if the forces are equal, it is easy, upon the principle of what is called "the sufficient reason," and which, though not rigid demonstration, is all that we can get in many mixed problems, that whatever the angle may be, the resulting motion will exactly bisect the angle, or divide it in halves; because, the forces being exactly equal, the motion must be equally affected by each of them. [See the introductory proposition to the *Méchanique Céleste* of La Place.]

One of the most familiar illustrations which we have of this upon a large scale, is that of a ship affected both by wind and tide, the one of which acts upon the sails, and the other upon the level. If these are equal, and together, the ship makes double way; if they are opposite the ship will not move at all; and if they are at an angle the ship will make way in the mean direction, and more rapidly in proportion to the smallness of the angle, that is, in proportion as the wind and tide set more nearly to the same point.

Besides these simple principles, we have only to bear in mind, that every body, whether at rest or in motion, possesses an inertia or resists any change of its state, and then we shall be in a condition to obtain, at least, a popular idea of the motion of a planet in an elliptic orbit, having a sun or central body in one of the foci. To shorten the verbal description, we introduce the following diagram.



Let P N A M represent an elliptic orbit, of which P A is the transverse or greater axis, M N, the conjugate, C the centre, the centre of gravity, or sun in S the upper focus, and *f* the lower focus. Also, let the smaller body A, at 1, at N, &c., represent a planet in eight different points of the orbit, the motion being from A, round by N, A and M, back again to P, when an entire revolution will be completed.

The point P is the *perihelion* (round the sun), or point nearest to the sun; the point A the *aphelion* (from the sun), or point most distant from the sun; and the line P A is called the line of the *apsides* (without deviation or deception), because, as we saw in a former section, this line remains of the same length, though the eccentricity and form of the orbit may be changed. The perihelion

(P) is called the *upper apsis*, and the aphelion (A) the lower apsis.

This line of the apsides, or greater or major axis, is an element of the greatest importance in the orbit: when it is determined, the mean distance and the periodic time are also determined; and in the same orbit it remains unchangeable in length. The eccentricity may alter so that the ellipse may expand toward a circle on the one hand, or flatten towards a straight line on the other; and the ellipse may swing round upon it, so as to be in different planes at different times, or the line itself may move either entirely round some point as a centre, or it may vibrate and return; but under all these changes of the form and position of the orbit, and whether they be permanent or temporary—that is, whether they affect the orbit in whole or in part—the length of the line of the apsides knows no change; amid all the perturbations and disturbances of the planets, which arise from their mutual approaches to and recessions from each other, which, altering the relative gravitation, necessarily affect both their directions and their rates and motion, this line remains constant; and while all else is plastic and yielding as the water of the ocean, this line is the rock which rears its head unshaken amid all the sweeping of the tempest and turmoil of the waves.

And when we come to reflect upon it, we find that we might expect it to be even so; for this is the part of the subject at which bounds are set to our farther investigation, and we are compelled to refer at once and directly to creative power. It is the masses of matter and the original impulses given to them (for the last of which, the mean velocity, which is constant as the line of the apsides itself, is the average expression) which determine the length of the principal axis; and, as we have already said, we can refer nowhere for the origin of the mass or of the motion but to the immediate act of the Creator, in whose powerful hand suns and their surrounding planets are infinitely small compared to what the motes in the sunbeam are to us.

The points M and N represent the mean distances from the central body S; 1 and 4 are two points on each side of P, the perihelion, equi-distant from it, and also from the points of the mean distance M and N; and 2 and 3 are two points on opposite sides of the aphelion, A, equi-distant from it and from the mean distances.

The straight lines drawn from these eight points to the centre of gravity of the body S, and meeting each other there, are the *radii vectores* of these points; and if we follow the body from P round by N till we come to P back again, we may observe that the radius vector keeps constantly increasing from P to A, and diminishing from A back again to P. Now, as the square of the rate of motion is inversely as the cube of the distance, the motion from P to A must be continually diminishing, and on the return from A to P constantly increasing.

The radius vector at each of the points we have marked, and at every possible point, is always the direction of the gravitating force at that point; and this force, and the motive force, are always so balanced at the instant the planet is in the point, as that they would, if they remained unchanged, carry the planet round in a circle having the same radius. Arcs of those circles answering to the eight points marked in the figure are drawn with the letters *c c* at their terminations; and it will be easily seen that the circle answering to the perihelion is the smallest, and that answering to the aphelion the greatest; also that at points equally distant either from the perihelion or the aphelion (and if they are equally distant from the one they must be equally distant from the other) fall on the same circle; thus the same arc passes through 1 and 4, the same through M and N, and also the same through 2 and 3.

The straight lines marked *m* at their extremities, are tangents to the orbit at each of the eight points; and they are of course the directions of the motive force at those points, and consequently the directions in which the planet would move off in a straight line if the force of gravitation was destroyed or suspended.

The dotted lines having *r* at their extremities, are the directions of the resulting force at the several points, or those in which the body, if we could suppose its motion to remain, and its momentum from *inertia* to be destroyed, would move, were it possible for the central body to be kept at the same distance from the line of the moving body, which could only be done on the supposition that the central body also moved at an equal rate along another straight line parallel to the line *r*.

Now, if we examine the tangents to the curve at these points, that is the lines *m*, or the lines *r*, or both, we shall see that they have very different directions as compared with the circles marked *c c*, which, as we have said, represent the circles of uniform motion at the different points.

At P and A, the radii vectores, which are the two unequal parts into which the line of the apsides is divided, are perpendicular to the circumference both of the ellipse and of the circle of uniform motion at those points, consequently the lines P *m* and A *m* are tangents both to the ellipse and the circle at those points; also the direction *r*, at each of them divides the right angle S P *m*, or S A *m*, into two equal parts, or at these points the momentary tendency of the body is just as much inclined to the centre as to the perpendicular, or tangents, P *m* or A *m*.

At the point 1 the tangent *m* is not at right angles to the radius vector 1 S, but forms a larger angle with it on the side towards N than on the side towards P; therefore the direction of the motive force 1 *m* falls without the tangent to the circle of uniform motion at that point; and the resulting direction 1 *r* tends more towards the tangent than towards the centre S. Upon examining the position of the other two points on this lower half of the orbit, it will be seen that the lines of direction *m* at these also fall without the tangents to the circles of uniform motion; and that, consequently, at both of them the resulting direction *r* is more inclined to the tangent of the circle than to the centre, or, which is the same thing, to the radius vector.

Now, when we say that the moving body is more inclined to the tangent than to the radius, we are saying in effect that the body in motion is more inclined to move from the centre than towards it, and this again is only another mode of saying that it is actually moving farther from the centre.

If we examine what the situations of the lines of direction are at these four points, we shall find that towards the commencement of this half of the orbit, the departure from the circle is slow, compared to what it is as the body advances, and that it diminishes again towards the point A. The difference through all the parts of it may be easily judged of by inspection of the space intercepted between the smallest of the circles, that is, the circle of uniform motion at P, and the half of the ellipse from P to A, from which it will be seen that the rate of deviation is greatest at the middle, while at P and A the motions are coincident, that is, they coincide at P and A, as an indefinitely small portion of the ellipse at each is parallel to a correspondingly small portion of the circle where it cuts the line of the apsides near both of the foci F and *f*.

At the point A the direction r of the resulting motion is exactly parallel to its direction at P, only it is reserved. At 3 the line of the motive force *m* falls within the circle of uniform motion *c c*, (of which only an arc is represented,) and consequently it must fall within the tangent; and the direction *r* must be more inclined to the radius vector 3 S than to the tangent, in other words the body or planet must tend more to the centre than away from it. At the points M and 4 the direction of the motive force also falls within the circle, and consequently within the tangent, and at them also the planet has more inclination to the centre than from it.

If indeed we compare the two halves of the orbit as divided by the line of the apsides, we find that from A to P is an exact reversal of what takes place from P to A.

Therefore, we can easily perceive that the planet is constantly receding from P to A, and that its motion and the force thence produced must diminish in the ratio at which it recedes; but that from A back again to P the planet is constantly approaching the sun or central body, and that while it is doing so, its motion must be increasing in the same rate as it approaches. It is to be understood that the rate of motion and the distance vary according to the law, that is, that the squares of the periodic times are always in proportion to the cubes of the distances. There is only one other matter to take into consideration in order fully to understand, at least in a rude and general way, the motion of a planet in its orbit, and that it is the change from approach to recession which takes place at the perihelion P, and the change from recession to approach which takes place at the aphelion A. Now, in order to understand this we must keep in mind what has been said about the momentum of inertia of a body in motion, by means of which it has a tendency to continue the particular motion which it has at any one instant. Now, the tendency is not to keep up the mere rate of motion at the same velocity which it has at that instant, it is to keep up the whole motion, the rate itself, and any variation which may have become an attribute of the rate.

Bearing this in mind, and bearing in mind also that the resulting force is always the weaker, and the resulting motion the slower, the larger that the angle is which the two forces make with each other. At P and A the forces are at right angles; from P to A, they make angles greater than right angles; and from A back to P they make angles less than right angles: therefore at any point between P and A, the resulting force or motion of the body is less in respect both of the motive force and the force of gravitation than it is in the points P and A, while on the other hand, at any point back again between A and P the resulting force is greater in respect to either the motive or the gravitating force than it is in A and P. But the motive force is in itself the result of the motion, and must vary with the only variable element of the motion, the velocity. Therefore, if we begin at the aphelion A, where the motive force is least, we have this force increasing, or as we may say, the momentum of the planet accumulating in the accelerated motion, all the way up to P, the perihelion; and for the opposite reason we have the motive force diminishing all the way from P down again to A. Thus, at the aphelion the motion and motive force change from retarding or diminishing to accelerating or increasing, and at the perihelion the change is exactly the opposite. The changes in the rate of motion which take place at these points are the greatest difficulties which beginners feel in understanding the motion of a planet in an elliptic orbit; and therefore we shall endeavour to explain their causes as simply, and in as few words as possible.

To understand this, we must bear in mind that the points A and P are the only ones at which the elliptic orbit coincides with the circle whose radius is the distance of the revolving body from the centre of gravity, S A when the body is at the aphelion A, and S P when it is at the perihelion P. At these points the planet must therefore have all the instability which we have formerly stated to belong to a circular motion, —that is to say, if the force of gravitation and the momentum, or force of motion, are exactly equal to each other, and at the same time both perfectly uniform, the planet will revolve in a circle; but that it cannot so revolve if there is the least deviation from uniformity in either of them. From its very nature, gravitation is perfectly uniform, though it varies according to the law of the squares of the distances; but at the same distance it cannot be said to have any tendency either to increase or to decrease, so that at every point of the orbit, whatever may be the form of that orbit, the force of gravitation is always exactly what would sustain the body in a circle at precisely the same distance from the centre of gravity.

But it is very different with the motive force: this force brings along with it the character or quality which it has previously acquired, and in consequence of the inertia which would continue the motion, for some time at least, even though the cause of that motion ceased to act, if the planet has had a retarded motion in arriving at the apsis, its momentum there will be a retarding momentum, and if it has had an accelerated motion in arriving at the apsis, its momentum there will be an accelerating momentum. But the planet has a retarded motion along all the half of its orbit from P to A, and an accelerated motion through all the half from A to P; therefore, the momentum which it has at A is a diminishing one, and that at P an increasing one, while at both points the opposing or counter-balancing force of gravitation, though different at each according to the law, is perfectly uniform in its intensity, or has no tendency either to increase or to diminish at either.

Consequently, at those two points, the forces which are to carry the planet along are differently circumstanced in respect to each other; and as the gravitation is uniform or constant at both, the planet must obey the force which is variable, or it must yield to the stronger of the two, to a degree proportional to their differences. At A, the aphelion, the momentum is diminishing and the gravitation gains upon it, and so brings the planet within the circle; while at P, the perihelion, the momentum is an increasing one, and it gains upon the gravitation, and so carries the planet without the circle. All the way from P to A, where the direction of gravity from the planet to the centre S, and the line of direction *m*, form an angle greater than a right angle, and the resulting motion is less than the diameter of a parallelogram, of which these two forces are the sides, the force of gravitation acts as a retarding force upon the motion of the planet; but all the way from A through M to P back again, where the angle is less than a right angle, and the resulting force greater than the diameter of the parallelogram, the force of gravitation acts as an accelerating force upon the motion.

We have thus, in the two halves of the orbit, as divided by the line of the apsides, an alternate play of the two forces by which the revolving planet is sustained. At the perihelion we have the planet getting without the circle, in consequence of the assistance which gravitation has given it in increasing the rapidity of its motion, in its arrival to that point; but no sooner does it deviate ever so little outward from the circle, than the force of gravitation becomes in so far a retarding force—a drag, as it were—upon the speed of the planet; and this accumulates upon it till, at the point of aphelion, a momentary equality is produced, and the path, for an immeasurably short distance, is a circle. But the diminishing momentum produces its effect here, or, in other words, the gravitation, which has been gradually gaining upon the motion all the way from the perihelion, overcomes it at the aphelion, and the planet is brought within the circle. But the moment that it is so brought, the force of gravitation becomes an accelerating force upon the motion, and this acceleration accumulates till both forces are equal at the perihelion, and where the momentum of acceleration carries the planet without the circle, and again subjects it to gravitation as a retarding force by which it is ultimately brought back.

From what has been stated, it will readily be seen that the deviation of the planet from the circle involves in it the means of return; and that the return involves in it the means of a fresh deviation; so that if the planet, in any way, or by any means shall once get either outside or inside the circle, it can never more have any circular motion. It, in fact, must alternate between two circles, which have for their common centre the centre of gravity round which the planet revolves, the smaller one having the perihelion distance for its radius, and the larger having the aphelion distance. These circles are the limits within which the motion of the planet must be performed, as they are the only points of the orbit at which the two forces act at right angles to each other, and therefore the only ones at which gravitation does not act, either as an accelerating or a retarding force upon the motion.

Half the sum of the greatest and least distances is always equal to the mean distance; and as, at the same distance the same velocity is always required to sustain the same body, the mean motion must always be the same when the major axis, or double the mean distance, is the same, whatever may be the eccentricity. But, as the *squares* of the times of moving over equal spaces vary as the *cubes* of the distances from the centre, it follows that the more unequal the distances from the centre at different parts of the orbit are, the whole circumference or absolute space, will be the less, though passed over in exactly the same time.

The mere motion, or velocity in space, is not affected by the *square* of the distance from the centre; and therefore it must be, in all parts of the orbit, inversely as the length of the radius vector,—if that is double the length, the space passed over in one equal time must be only one half, and so on for all other cases,—in other words, the radius vector will pass over equal areas in equal times, the arch shortening as the radius lengthens, and lengthening as it shortens.

If this motion be not affected by any other circumstance, the orbit will all lie in one plane, and it will move on in absolute space, according to whatever progressive motion the centre of gravity may have; and though we are not acquainted with the actual motions of the centres of gravity of any of the heavenly bodies, except those to which we give the names of *satellites, secondary planets*, or *moons;* yet still, we cannot suppose any central body to maintain its place, unless it also has motion as well as gravitation.

From the explanation which has been given of the manner in which the two balancing forces of gravitation and motion alternately take the revolving planet under their control, so to speak, and how the force of gravitation, which being a *passive* force—a force of resistance, not of action—acts alternately as the bridle and the spur to the motion, and the necessity of the two forces to sustain every free or detached body in the universe will be readily understood.

The existence of any force besides these is not only unnecessary to the stability of the system, but would be subversive of it; and though these two may pass through a great number of variations, the principle of their acting is the same in every case. There may be many elements in the composition of them, that is to say, the gravitation of many bodies may act on a single body, and that body may receive motion from many impulses; but in each case all of these elements produce but one result, which has precisely the same effect as if there were but one attracting body and one impulse to motion, having the resulting direction and intensity of each. Thus, any one globe or detached piece of matter in the universe may be as stable among millions as if it were alone, and while performing the most apparently complicated motion as though they were all perfectly at rest. Our observation, even with all the assistance which instruments can give it, extends to but a small portion of the system—a mere corner as it were; but still we find in this limited portion enough to show us the simplicity, the efficiency, and consequently the beauty, of those laws which sustain the whole.

It was mentioned formerly that it is not necessary that the path of the revolving body shall be an ellipse. The limits of it lie between a perfect circle, of which we have shown the permanent existence to be impossible, and a straight line, in which the one body would descend to and be united with the other. But between these limits there may be an ellipse of any eccentricity, or there may be a parabola or hyperbola. The ellipse will always give a returning or periodical motion; and though the eccentricity may vary, the periodic time will be nearly the same; but in the other two figures there is no provision for the return of the revolving body to its former place. If we were to speculate upon a part of the subject, of which we can have no direct evidence, we would naturally say that those bodies which revolve in ellipses must belong to permanent systems having a common centre of gravity; but that those which move in other curves will pass far and wide through space, appearing sometimes as if they formed part of one system, and, at other times, as if they formed part of another. But we are not called upon to enter into the investigation of these purely theoretical matters, though the mention of them is necessary, insomuch that no one can contemplate the known portion of the heavens without feeling some desire to speculate about those which are unknown, and thus it is desirable to feel that as they are the workmanship of the same Author, they are governed by the same laws.

There is, however, one point which we may mention, before we close this section and proceed to another branch of the subject, and that is, the disturbances which the motions of any revolving body, and consequently the form of the orbit in which it revolves, may meet with from changes of its distance from other bodies than the central one around which it is understood to revolve. We must bear in mind that, in so far as gravitation is concerned, the quantity of matter and the distance are the only elements which enter into the estimate. The earth, and various other bodies which we shall afterwards notice, revolve round the sun in orbits similar to that of which we have given some account; and we have reason to believe that the sun illuminates and warms all those bodies, as well as retains them in their elliptic orbits. But we must not suppose that there is any power capable of affecting the rate or direction of motion of the revolving bodies, either in the fact of being central, or in the illuminating and warming; quantity of matter—and quantity of matter alone—determines this; and any particular motion which the central body may have, whether round its own centre, or in some more mighty orbit than any of its attendants, does not at all enter into the account. Hence, as in the several motions of the different planets and other celestial bodies, they must be constantly altering their distances with regard to each other, so they must also alter their gravitating influences. The law, with regard to the whole, is the same; the squares of the periodic times in proportion to the cubes of the mean distances. They all revolve in ellipses, having different eccentricities, as well as different diameters, and lying in different planes. They not only all move at different rates from each other, but each of them moves at different rates in different parts of its orbit. They are also all different in magnitude. But they all feel the gravitation of each other,—directly as the quantity of matter, and inversely as the square of the distance.

Now, all these variations must produce innumerable varieties of situation with regard to each other, and the effect of their mutual gravitation must be, to draw any one of them, in a great variety of ways, out of the path it would have if revolving alone. All these ways may, however, be reduced to two general cases:—first, to accelerate or retard the motion of the body; and secondly, to draw it upward or downward from the plane of its orbit. Any accelerating motion must increase the effect of the body's own accelerating motion, and diminish that of its retarding motion; and any retarding motion must have exactly the opposite effect. It will be remembered, that it is the momentum of acceleration which causes the planet to come without the circle at the perihelion, and the momentum of retardation which brings it within the circle at the aphelion; and if we suppose any other force, such as the attraction of another planet, to act, it will hasten this turning point, if it acts in the same way as the variation of motion whose momentum causes the turn, and retard the turning point if it acts in the contrary direction.

For instance, if we refer back to the figure on page 153, and suppose another planet situated without the orbit, in the direction P, toward your left hand, the attraction of that planet will be an accelerating force on the planet in the orbit from A all the way to P, and a retarding force all the way from P back again to A. In this situation, therefore, it will augment the acceleration by the momentum with which the planet turns round the perihelion P, and also the retardation by which it turns round the aphelion A. Now A and P have no virtue in themselves, they are merely the points at which the acceleration brings the motion up to what it would be in the smaller limiting circle and the retardation reduces it to what it would be in the greater. But the acceleration from A to P, increased by the disturbing force of the other planet, must bring the motion up to this rate before the planet in the orbit arrives at P; and so also must the same disturbance, acting in concert with the diminishing force from P to A, reduce that force to the rate of circular motion, before the planet in the orbit arrives at A. The consequence of this will be a change of the position of the major axis, the perihelion apsis of which will be situated above P, and the aphelion apsis below A. The extent of this motion of the line of the apsides will depend upon the proportion which the disturbing force bears to the force of the planet in its orbit; but it would be impossible for one planet to be so situated with regard to another without producing some effect of this kind.

On the other hand, if the disturbing planet were situate without the extremity A of the axis, it would act as a retarding force upon the accelerating motion of the planet from A to P, and as an accelerating force on the retarding motion from P to A; and thus, by counteracting the forces, the momenta of which turn the planet round both apsides, it would retard the turning, and bring the perihelion below P, and the aphelion above A, or turn the line of the apsides in the contrary direction, to a greater or less distance in proportion to the disturbing force.

If the disturbing planet were in the same plane with the orbit of the revolving one, that is, if the centres of both planets, and the sun, or centre of gravity, were in the same straight line, the plane of the orbit would not be disturbed: but if the disturbing planet were not in the plane of the other one's orbit, the plane of that orbit would be disturbed.

When we think of the number and variety of those disturbing bodies, in respect of mass, situation, and distance, we can easily see that the exact determination of them for any one instant of time must be a matter of great nicety. It is a matter upon which, for obvious reasons, we cannot enter; but the instances of simple cases which we have given will serve to explain the principle, which is simple, though the practical application is difficult. We may also mention one or two of the circumstances upon which the variations of those disturbing forces depend.

In the first place, the smaller any body is, it is the more easily disturbed itself and the less able to disturb others. In the next place, the nearer that any body is, its disturbing power is the greater; and in the third place, the more directly that a body at the same distance either opposes or acts in concert with the motion of the body which it disturbs, the greater is the change of motion in the disturbed body.

But it must be borne in mind that when we speak of disturbance, we speak merely of the relative change of place or velocity which the one body causes in the other; for speaking absolutely, the two bodies are equally disturbed, or rather there is no disturbance at all. They address each other from the common centre of gravity, and each occasions in the other an equal movement toward that centre, only the smaller body moves over the greater distance.

It happens in some cases that the shape of a large body suffices to disturb the motions of a small one in its near vicinity, upon the very same principle that the vicinity of a great mountain deflects the plumb line from the perpendicular. The earth and the moon furnish us with the nearest and most familiar example of this kind of disturbance, and indeed of orbital disturbance altogether; and there are very weighty practical reasons why the effects of those disturbances should be known before hand, with the utmost precision to which observation and science can determine them. The apparent distance of the moon from certain readily observed stars, is the grand means of determining the longitude at sea: a problem, on the accurate solution of which more property and more human life are dependant than upon that of any other in the whole compass of science. Indeed it may be said that this is the grand problem of international welfare, the one which brings as it were the ends of the earth together, and links all the tribes of the human race into one brotherhood, so that they may enjoy the same comforts, study the same sciences, practice the same arts, worship the same God, and have their hopes of never ending happiness through the same Redeemer.

It is by means of this problem that the trackless ocean has become a more ready, a more convenient, and a more expeditious thoroughfare than any highway that ever was made, or that ever can be made upon the land. The sea path of itself carries the burthen; and the winds which sport free on its surface, as that air of heaven of whose motions they are the effects, furnish the motive power; so that man has only to exert a little skill and a little industry in order to be carried at his ease round the globe, with the heavenly bodies as his sure and unerring guides.

These disturbed or compound motions of the moon will, however, be more advantageously explained in a future section, when we have noticed the corrections which it is necessary to make upon the observed appearances of the heavens, in order to bring them to an exact correspondence with the real appearances; and in order to do this we must very briefly examine what there may be, either in the light itself which reveals objects to us, or in our position with regard to those objects, which may require some explanation in principle, and constant bearing in mind in practice. To this we shall devote the next section.

SECTION VIII.

APPARENT PLACE, MAGNITUDE, DISTANCE, AND MOTION.

In order to obtain a clear understanding of how far what we observe in the heavens agrees or differs from what really goes on there, it is necessary that we should, in the first place, consider the point from which our observation is taken. The slightest attention to what we observe on the surface of the earth, and in our immediate vicinity, will show the necessity of this; for if we look at a building, a tree, or any object whatever, it presents a different appearance to us whenever we view it from a different point. If we walk round it, it will present the same succession of appearances as if it were carried round us in the opposite direction, and show all its different aspects in the course of the carrying round; and if we have not some other means of knowing that we are in motion—which when we walk is of course immediately communicated to us by the feeling of muscular exertion—we would be very apt to impute our own motion to the object round which we moved. In like manner, if we were to turn round and notice the objects around us in the course of the turning, the appearance would be exactly the same as though we were standing still, and the surrounding objects turning round in the opposite direction, upon the point at which we stood as a centre. So remarkable is the deception of the eye in this case, that, if we turn rapidly, we begin to have an impression of the instability of everything around us, in consequence of which we turn giddy, lose our balance, and fall to the ground. There is even a more singular deception than this, in which the eye and the judgment are at complete variance with each other. Sometimes after we have been walking for some time over a trackless common in a fog, and the sun at last breaks out, we are astonished to find the morning sun in the west, the mid-day sun in the north, or the evening sun in the east, as it may happen. Nor is a fog absolutely necessary for occasioning this difference between the sensation of present sight and the judgment of past experience: for if any one who from living near a straight portion of a river has a confirmed notion that the river flows in a particular direction, shall follow the flexures of that river, where their windings are concealed by woods or any other means, he will fancy that he moves in a straight line all the time, and that the sun shifts sometimes to the right hand and sometimes to the left. Many other instances must occur to every one who is in the habit of making use of his eyes when moving in the open air, but those which have been stated are sufficient to convince us that we must not trust implicitly to what we see, either with regard to situation or to motion, unless we at the same time perfectly understand the situation of the point from which we take our view, and whether we ourselves are at rest or in motion.

Our observation of the heavenly bodies is always made from the surface of the earth, a few feet or yards higher or lower according to circumstances, but still on the average about four thousand miles from the centre of the earth, and the various heights from which we can observe are so trifling in comparison to this, that, in a general view of the matter, they are not worth taking into the account. The earth, from the surface of which we take our view, notwithstanding we are four thousand miles from the centre of it, is a mere nothing in comparison with the range of the heavens which even our unassisted vision commands; and besides being thus as it were only a point in the system, it is not a fixed point. It has two motions, a daily rotation round its axis, and an annual revolution in an orbit round the sun at a mean distance of about ninety-five millions of miles from the point in the body of that luminary which forms the centre of gravity of the two. These motions are both performed in the same direction; namely, from west to east, as we reckon position on the earth—the axis of its rotation being the foundation of this reckoning, but they are performed in different planes; and while the rotation must be considered as uniform, or nearly so, the motion in the orbit is constantly varying according to the law of variation in an ellipse. Neither the one nor the other of those motions changes the relative situation of fixed objects on the earth any more than spinning an orange round on the table or rolling it on the lawn changes the relative situation of any spots that may be on its surface; but both these motions change the relative situation of the earth among the other bodies which make up the great system of nature, and therefore we must take them into account, in order to correct the apparent places of the heavenly bodies, so as to make them agree with the real ones.

When we speak of suns and planets, the masses are very small as compared with the distances at which they are from each other, and therefore the most convenient as well as the most accurate mode of considering them is to regard the centre of each body as its situation, and the point from which observation is made. When we speak of the positions or places of the heavenly bodies as they would appear if viewed from the centre of the earth, we call them their *geocentric* places; and when we speak of them as it would appear if viewed from the centre of the sun, we call their places *heliocentric*. As the centres of the earth and sun are upon the average ninety-five millions of miles asunder, it is evident that no body can have the same geocentric and heliocentric place, unless the centres of the earth, the sun, and that body are all in the straight line.

The change of apparent place in objects, arising from real change of place in the observer, is called *parallax*, which means departure from the *axis* or straight line supposed to be drawn from the object to the point of observation that has been departed from. The departure which occasions parallactic change of place in objects is always lateral departure from the object, for when we advance upon an object, or recede from one, in a straight line, there is no change in the apparent place of the object, and therefore no parallax. The *maximum* or greatest parallatic change, arising from the same shifting of place in the observer, will obviously take place when the whole departure is directly from the axis,—that is, at right angles to it; and between this and the former case, in which the change is merely going nearer the object or removing farther from it in the axis itself, there may be every possible variety of parallactic change arising from the same shift of the point of observation in absolute distance, it being greater as the shift is made more nearly at right angles, and less as it is more nearly in the direction of the axis. Quantities which have their 0, *zero*, or beginning, at an axis, and their maximum at right angles to that axis, are said to vary as the *sines* of the angles which their directions make with the axis, and this of course holds in the case of parallax.

Every change of place in the observer occasions a parallax in all bodies observed, unless the change is made in the direction of the axis; and consequently the name parallax has many meanings. Some of these will be explained in course, but we are now considering only the one which is most simple and of most frequent occurrence in observing the heavenly bodies,—namely, the difference of apparent place in the body, arising from its being viewed from the surface of the earth instead of the centre. This is called the *geocentric parallax*. When the observed body is in the zenith this parallax is evidently 0, because the centre of the earth, the observer, and the object are in the same straight line. If the object is exactly in the horizon the parallax will be the greatest possible, because the observer is then perpendicularly distant from the axis, or line joining the centre of the earth and the body, by the whole radius of the earth, or four thousand miles, and between those extremes the quantity of parallax will vary as the sines of the angles of altitude in the body, the effect of the parallax always being to lower the apparent place. The lineal measure of the parallax is the perpendicular distance between the one point of view, and the axis joining the centre of the observed body and the other point.

The absolute quantity of this parallax depends on the distance of the body observed being greater as the distance is less, and less as the distance is greater. It is the angle which the earth's radius makes, as if seen from the centre of the body, and it is one of the elements in finding the distance of the celestial bodies; but we shall perhaps render this subject more clear by previously considering the connexion which there is between distance and apparent magnitude.

When we observe any object, be it celestial body or anything else, as a whole, the eye is always so turned as that the centre of it is exactly opposite to the centre of the observed object. In common we do this with both eyes, and as these are a short distance apart from each other they produce a small parallax. Beyond a very limited distance—eight or ten miles in unfaded eyes—this parallax produces no effect, but when we bring an object too near, or when the eyes begin to fail, the parallax produces a double perception of small objects, the one part of which confuses the other. The same effect happens in various diseases, and also when the sentient system of the body is stupified by the action of any narcotic poison. In distant observation, we do not need to attend to this parallax of the eyes; it affects nothing which is not near enough for our touching it: we shall therefore speak of the eye as *one*.

A line from the centre of the eye to that of the object is the axis of the eye, or the *axis of vision;* and the light coming from all parts of the object and entering the eye at this axis produces what we call sight or vision. In the mean time we have nothing to do with the manner in which this most excursive and most delightful of all our sensations is produced; and although we had, we should leave it as much a wonder as ever. We might explain the parts and structure of the eye, but after all that we could say and speculate upon, the question, "Why does the eye see?" would remain as unanswered as ever.

The apparent magnitude of any object depends on the angle which the rays of light from its extremities make at the eye, and this of course varies in the same object when seen at different distances, as well as in objects of different sizes seen at the same distance. The law of the variation with distance is easily understood, and the foundation of it may be seen in a very simple experiment:—hold up your finger, at a little distance before the eye, and it appears longer than a pane of glass in the window; that pane seems taller than a tree in a distant part of the garden; the tree taller than the church steeple at the distance of a mile; and the steeple taller than the mountain which is twenty miles off. Now, all these things gradually increase in real height, from the finger onward to the mountain, and yet in apparent height they all diminish; and were it not that we know by other means that they are at different distances from us, we should actually believe that their heights are just what they appear to the eye. If objects are all at so great distances, as that we have no means of distinguishing the difference of them by any test upon the information the eye gives us, their apparent magnitudes will thus not give us any correct estimate of their real ones. If they subtend the same visual angles, we will consider their magnitudes the same; and if they subtend different angles, we will consider their magnitudes as different.

If the magnitude is the length of a line in the same position, it will apparently diminish in the exact proportion that its distance from the eye is increased; for instance, if at the distance of a yard it has the apparent length of what we call an inch, at two yards it will be apparently half an inch, at three yards one-third of an inch, and so on for other distances. If it be a surface, both length and breadth, and all lines which can be drawn across it, in any way whatever, will diminish each in proportion to the distance; and, therefore, the surface will diminish in proportion to the squares of the distances,—that is to say, a square bit of paper, which we call equal to four square inches, at the distance of one yard, will appear only one square inch at the distance of two yards, and so in other cases.

Light from objects, and the feeling which it communicates to the eye of their apparent magnitudes, thus follow the same law as that of all forces or energies which we can suppose to emanate from a centre, and proceed from that centre in all directions in straight lines; and, though the light which is the medium of vision—the means of communication between the object and the eye —does not, in the case of observation from a fixed point, radiate from that object as from a centre, yet light does proceed from bodies in every direction, if their nature is such as that they can afford light; and although, in the case of observation from the eye as a fixed point the light converges to the eye as to a centre, yet the power of vision in the eye may be said to begin at the centre of the eye as a point, and to radiate to every portion of the visible object.

We need hardly mention that the eye sees nothing but surfaces, though, from experience, we judge of the shapes of solid bodies much in the same manner as we judge of the real magnitudes of those which are at different distances from us. In all cases, colour, as we call it, is the chief, and, perhaps, originally the only subject of vision, though experience enables us to connect it with magnitude. It is upon these principles that paintings upon flat surfaces give us such faithful representations of objects very differently situated with regard to each other, that they almost charm us into a belief that the originals are before our eyes, and we feel inclined to take a chair and join the company, or step into the landscape and enjoy the fresh air, according as the subject of the picture is an in-door scene or an out.

There is a great deal of instruction with regard to the knowledge of visible nature in this same picture, if we had time to bring it out; and, as it is, we may mention that the painter makes use of exactly the two elements which enable us to judge of magnitude and distance in that original from which his picture is taken: his lines are diminished in length in the exact proportion of the distances at which he intends they shall appear, and his surfaces as the squares of the same. This is called *linear perspective*. Then, in addition to this, he endeavours to imitate exactly the tones of colour which the distances give to the several parts; and this is called *aërial perspective.* In the latter, all objects at very great distances are blended together in one soft grayish or purplish blue, according to circumstances; and, as this takes place in every extensive view we can have on the surface of the earth, we can easily suppose that all ordinary distinctions of colour must be lost, long before the distance of the celestial bodies is arrived at. It is this vanishing of our perception of difference in distance which rounds the dome of the heavens over our heads; and it is the lingering of light among the particles of our atmosphere which clothes this dome in its azure mantle.

How we come originally to associate equal visual angles with equal perceptions of magnitude, is not, perhaps, easily explained, though it is probable that we measure the breadth of an object by the eye much in the same manner as we measure the length of a road by pacing over it, and that the one judgment of magnitude is founded on the sum of a succession of experiences as well as the other. But, in both cases, the time and the exertion which it costs us enter into the estimate; and, besides, the very standard of our measure depends in so far upon the state of the feelings. This is rendered propable from the fact, that we can fix our attention upon any part of an object without having any perception of the rest. Thus, in a page of a book we can examine any single letter, or part of a letter; as, for instance, we can see whether there is a dot or an *i*, and if so, whether that dot is or is not exactly round; and we can do this without noticing the rest of the page, so as to have any conception or recollection of what it is like. Such are some of the more simple of those general principles of the action of the eye, which it is essential that every one who is to employ that organ profitably, either in the heavens or on the earth, should be well acquainted with.

The fact—for though it is at variance with some of the theories, we may consider it as a fact—that the axis of the eye takes measure of lineal dimensions, by passing successively over the whole length of the line, leads us very naturally to a correct understanding of the visible perception of apparent motion, which is another matter necessary to be well known before we can ascertain whether our observation is or is not correct. We know that, besides fixing upon any one point, to the exclusion of the rest, the eye can regard not only any entire object within the view, but the whole view, in all its variety of objects, that can be taken in by the eye while kept steady, or with the axis in the same position; and that, while the whole field of view remains thus present to our sight, we can, at the very same time, take notice of any change which takes place within that field. The most remarkable of those changes is motion; but it is relative motion, and not absolute motion, which is the subject of our vision. We measure this motion by the angle which the radius vector drawn from the moving body to the eye passes over in a given time; and, in order to perceive this relative motion, we must, at the same time, have an immediate reference to something which we conceive to be at rest, or moving differently. In measuring this angle of motion—the extent of which passed over in equal times is our visible measure of the velocities of different motions—it seems to be of no consequence whether it be the eye or the object which really moves. The fact is, that the radius vector, or common axis of the eye and the object, turns in the focus of the eye as in a centre; and while the external and by much the longer arm of this line sweeps over the apparent angle in space, the shorter arm of it, within the eye, passes over exactly the same angle in the interior of that organ, and the only difference is, that the *retina*, or sentient membrane of the eye, being very near the point on which the radius vector swings, the extremity within the eye passes over a very small arc, while the external end and the moving object passes over a much larger one. Those arcs are, however, the same portions of their corresponding circles, because they are measured by equal angles. As they are on opposite sides of the centre on which the radius vector swings or turns, they must move in opposite directions; as, for instance, if an object passes before the eye from left to right, the passage of the sensation of that object over the sentient parts of the eye will be from right to left; the passage of the sensation of a falling body will ascend over the sentient parts of the eye, and the passage of the sensation of an ascending body will descend over the same. We must not suppose that there is anything wonderful in our feeling that the motion of the body is exactly opposite to that of the sensation of the eye, because our knowledge of direction is a result of experience, and not a primary of sensation. In all cases of sight, indeed, we merely see something, have an impression made on the organ, and the knowledge of what that something is is a matter to be ascertained by experience, and we know it, or know it not, according to the extent of that experience and the correctness with which we can apply it to the particular case.

It is evident, from what has been said, that the perception of motion will be exactly the same whether the body remains at rest, and the eye passes over its arc of a small circle, or the eye remains at rest, and the body passes over an equal arc of its larger circle in the opposite direction, and in the same time. There is nothing which happens to the eye, as an organ of vision, in the one of these cases, which does not equally happen to it in the other; and, therefore, unless there is some other means of knowing whether the eye is or is not at rest, we cannot be certain that the absorbed body is in motion. Still, however, we are so much in the habit of observing moving bodies, on and near the earth around us, at the same time with the relatively stationary ones among which they move, that our general application of this habit leads us, in all cases where we have not a standard which is stationary, to impute to the objects which we observe, the motions which, in reality are produced by the moving of the eye itself.

A striking and rather a curious instance of this occurs when a landsman has been at sea, out of sight of the land, for a week or two, and well rocked upon the waves the while; when he gets on shore, he is astonished to find, that though latterly he had been quite steady and comfortable in the ship, the land has acquired a very singular rocking motion, and, as he passes along the street, he is not only apprehensive of tumbling, but cannot repress some apprehensions that the houses are to fall upon him, and bury him in the ruins.

All motions which pass over the same visual angle in the same time, have exactly the same apparent velocities; we have a striking instance of this in the apparent motion of the sun, and of the shadow on a common sun-dial. A line drawn from the sun by the edge of the style to the face of the dial bears in this instance a perfect analogy to the line which we have described as drawn from the visible object through the centre of the eye to the sentient part of that organ; the edge of the style corresponding to the centre of the eye, and the face of the dial to the immediate organ of sight. Now, on a dial of ordinary size, the distance of two hour-lines may be about an inch; and this is of course the space over which the edge of the shadow travels in an hour. But when we take the other arms of the lines, those which extend from the edge of the style to the sun, we find from the known distance of the sun that their extremities must be twenty-five millions of miles asunder, and that this is the apparent motion of the sun in one hour, and would be the real one if it were not the dial that moves, and not the sun. But if we watch the motion of the shadow upon the dial, and the motion of the sun in the heavens, each for an hour, we shall have a feeling that their velocity is exactly the same, and so slow in each case that we can take no note of it till some time has elapsed. These are both apparent motions, or rather they are the motions of the opposite ends of a radius vector, turning on a centre, and having equal angular velocity at both extremities; but the appearances are exactly the same as though the radius vector turned on the edge of the style, in consequence of the motion of the sun, and not the dial on the same edge of the style as an axis, which is the real motion in this case, exactly equal to the apparent one, and in the opposite direction.

We have the best practical instances of the difference which distance occasions in the apparent velocities of objects when we are carried along and have the means of noticing objects at various distances from us; and none is better than when sailing on a steady course parallel to a straight shore, between us and which there are rocks at different distances from the land, cliffs beyond the rocks, towers and steeples beyond the cliffs, and a great mountain far distant inland beyond the whole.

In sailing along such a coast, we pass all the objects equally in absolute distance, whatever may be their distances from us. Say that we are sailing southward along an east coast, then all objects which are directly to the west of each other will be to the west of us at the same time; and thus in absolute southing, we shall gain equally upon all that we see. But the different angles under which their apparent motions, arising from our real motion, are seen, in consequence of their different distances, will be very striking; and if we are scudding away, in smooth water and with a fair wind, at a rapid rate, but without any disturbance either of ourselves or of the ship, to let us know that we are in motion, the whole of these objects will appear to be reeling about as if they were in utter confusion: the rocks will appear to be running back, as if they were carried on the current of the water, and all the other objects to be moving forward, but at slower and slower rates as they are more distant. The most singular part of the whole appearance is, that those objects which appear to be running the fastest race with us are the most easily beaten, and get the soonest behind. The cliffs advance at a good pace, the towers more slowly, and the mountain barely crawls; yet the cliffs soon get astern, and we can pass the towers and steeples before our patience be much exhausted; but the weary mountain, notwithstanding its sluggish pace, we cannot get past,—it dogs us for hours; as if it be one of those great mountains which are seen far off at sea when no other part of the land is visible, we cannot get away from it for days. The angular differences owing to the distances are the cause of this: ten feet at the distance of one hundred yards subtend as great an angle as a mile does at a distance of thirty miles; and therefore ten feet of such a rock will have as much apparent motion in one minute as a mile of the mountain has in eight hours forty-eight minutes, or in less than three minutes we shall have made more angular departure from the rock than we could make from the mountain thirty miles distant in the course of a whole day.

If the state of things had been reversed in the instance which we have now given, and we had been at rest, and all the visible objects moving northward past us, as we have supposed ourselves to be moving southward past them, appearances would have been exactly the same as those now stated; and, unless we had in either case been in possession of some other means of knowing whether the motion was in ourselves or in the objects which were visible to us, we would have, as a matter of course, and according to our usual experience, imputed the motion to them. We would have done this the more readily the more smoothly the vessel went through the water, and the more still and glossy the surface of that element. But the earth which we inhabit may be considered as a great ship scudding onwards through the regions of space with no waves to rock it, and no winds to disturb. Mighty as it is, compared with any ship which we can launch upon the liquid part of its surface, it careers along without meeting with the slightest obstacle or opposition. The disturbing forces of other planets, to which we made some allusion in last section, do occasion some trifling alterations in its path and in the rate of its motion; but in no case does it touch a single obstacle or come nearer to any one piece of matter than the average distance of 240,000 miles from the moon; and this approach, instead of having any tendency to crush, or press to the surface of the earth, even the most yielding substance upon that surface, has exactly the opposite effect, by taking off a certain portion of the pressure of terrestrial gravitation, and causing the waters of the ocean and the atmospheric air to swell upward into tides. Therefore, there is nothing at all connected with any motion which the earth may have as one whole mass, either of rotation round an axis, or of revolution round some centre, that can in the least make known to us the existence of such motions; and therefore it is that mere unassisted observation has in all ages considered the earth as at rest, and the heavenly bodies in motion around it. So much for the difficulty of distinguishing between apparent motions and real motions in the opposite directions as the causes of the apparent ones.

There are still, however, some phenomena connected with motions in circles or ellipses which require to be understood before we are in a condition for perceiving how perfectly the law of the celestial motions agrees with those motions as they appear to the eye; and of these we must take some brief notice.

The first consideration is the appearance of a circular or elliptic motion, resulting from the direction in which we view it. This may be, in part, understood by simple observation of the mouth of a circular cup. If such a cup is held with the centre of its mouth exactly opposite the eye, it will appear a perfect circle; but if it is turned obliquely, it will appear an oval or ellipse; and this ellipse, while its longest diameter remains the same so long as the cup is held at the same distance, will keep narrowing as the cup is turned more obliquely, and when it is so far turned as that the axis of the eye touches both the nearer and the further sides, the mouth of the cup will appear a straight line of the same length as its diameter. If we were to suppose a fly or any other small animal to travel round the lip of the cup at a uniform rate, it would seem to travel in the circumference of the ellipse, which the cup exhibited according to its position; and in the last position, that in which the axis of the eye touched both sides of the cup, the fly would appear to pass and return from one end to the othe of a straight line equal to the diameter. It would not, however, appear to march at a uniform rate all the time, but would move faster along the half of the lip nearest to the eye than along the opposite half; while in both it would appear to move fastest toward the middle of the line, and gradually slower and slower as it were nearer to the extremities, while at each extremity it would take some time in turning. Remove the fly, and suppose a pepper-corn, a mustard seed, or any other small body, the turning round of which could not be observed, to move in its place, and its apparent motion, if really uniform, would appear to begin from a momentary rest at one extremity of the line, gradually quicken its motion as it approached the middle, slacken it after the middle was passed, pause a little at the extremity, then return by a motion slow at first, but increasing towards the middle of the line, after which it would again slacken, and there would be a momentary pause at the other extremity. Take away the cup, and suppose the small round body to continue its motion, and you would have an exact miniature representation of a planet revolving in a circular or elliptic orbit, and viewed on the plane, or edge of the orbit, from a point without; and if we had supposed the cup so turned as that a small portion of both edges had been seen, then, instead of the straight line, we would have had a very flat ellipse, which would have given us a miniature of the motion of a planet in an orbit, as seen by an observer without the orbit and not exactly in the plane of it.

There are many other instances of motion, of common occurrence, which afford illustrations of the same species of motion in an orbit; and it is of no consequence whether the observed motion is performed in a circle or in an ellipse, because all varieties of ellipses having the same major axis are contained between the circle, and the straight line which is the diameter of that circle. The motion of horses or carriages round a circular or oval course of considerable dimensions, and seen from a point at some distance, will afford perhaps as satisfactory a notion of the apparent motion of a planet, when viewed from a point without its orbit, as can be easily obtained.

The motion of a planet in an ellipse is not uniform, but more rapid near the perihelion than near the aphelion; and as the axis of the orbit, and the relative distance from the observer in the different parts of it, depend on the point from which it is viewed, there may be great irregularities in the apparent motion of a planet so observed. But the general principle is, in all cases, the same: the degree of apparent motion is rapid in proportion to the nearness of the point of observation, the actual rapidity of the motion, and the direction of the line of motion, all taken jointly, the last being a maximum where the direction of the motion is at right angles to the axis of observation, which is the same as the axis of the eye.

If the observer is in motion, and the observed object at rest, the apparent motion will always be an exact counterpart of that of the observer; but if both observer and object are in motion, the resulting apparent motion of the object will be a little more complicated, as the directions and velocities of both have to be taken into the account. But before we consider this, it will be proper to attend to the other cases in which the observer may be regarded as at rest, and the observed body in motion.

We have already considered the appearance when the observer is *without* the orbit of the body which he observes, and so we have only now to consider the appearance when he is *within* the orbit.

Now, in whatever part of the orbit the observer is situated, the body will appear to revolve round him, though the revolution will be modified by the form of the orbit, the point at which he is situated, and the position of its plane. In order to understand these, we must suppose that the observer himself has a standard of position, the most convenient one being the perpendicular, where he stands—the line of his *zenith* over head and *nadir* under foot; and knows whether the point of this line in which his eye is, is or is not in the plane of the orbit.

If the observer is in the plane of the orbit, and this plane is at right angles to the line of his zenith and nadir, the body will appear to revolve round on the same level with his eye, uniformly—if it move uniformly—in a circle, of which he is in the centre, but with varying velocity if he is not in the centre; or if the orbit is an ellipse, when the body is nearest to him it will appear to move fastest, and slowest when it is most distant; but in an elliptic orbit this will be modified by the variable rate of motion in the ellipse. The general principle is easily understood, however, though the details in every particular case involve considerable difficulty.

If the plane of the orbit were still at right angles to the line of the observer's zenith and nadir, but rather above him or below him, the general appearance of the motion would be the same as in the former case; but the path would be above him in the one case, and below him in the other, —the distance of the body from his eye being to the distance of the plane above or below him, measured on the line of his zenith and nadir, as sine 90°, to the sine of the parallactic angle, or angle of the body's elevation above or depression below his horizon. In consequence of this, there would be some apparent irregularity in the position of the apparent path of the body, as it would appear nearest the horizon when at the greatest distance from the observer.

If the plane of the orbit were oblique to the line of the zenith and nadir, the body would appear to be sometimes higher up, and sometimes lower down, in the course of its revolution, and it would do this whether the observer were in a plane above it or below it. The principles are the same in this case as in the others, but there are so many causes of variation, that the details are not easily explainable in words, nor does it appear that diagrams would make them more intelligible. If, however, the reader will, in every case, consider himself placed where we have represented the observer to be, he will be able to fancy to himself the general appearance without any difficulty. This is one of the most perplexing things for a describer—he understands it all as clearly as if it were before his eyes in a tangible machine, and yet it sets both pen and pencil at defiance. There are many similar puzzles in the mechanism of the heavens; but though they annoy those who seek for display, they are very agreeable to all who wish to learn, by affording them the opportunity of acquiring for themselves what they cannot be taught by others; and this is, at once, the most preferable and the most pleasant of all mental labours.

We have now to consider only the apparent motion when the observer himself moves. Of this there are several cases, and one or other of them applies to the apparent motions of every celestial body. When we speak of the motion of the observer, we of course mean that of the planet, or other celestial body on which he is situated, and not his mere change of place upon the surface of that body:—as his personal locomotion is not much in free space or sustained by those balancing forces which give the grand system of nature its stability, it belongs to the common mechanics of matter with which we are familiar in all the every-day occupations of men upon the surface of the earth, and cannot take place without a mechanical support, as well as a specific mechanical force.

In this general sense, the place of the observer —the planet—the earth, for instance, which is the only one to which we can really and practically refer—can have only two motions,—a motion of *rotation* upon an axis, in an imaginary line passing through the centre of gravity, and a motion of *revolution* round some centre of gravity. These two motions are perfectly distinct from each other, both in their origins and in the effects which they produce, though we are equally ignorant of the original causes of both. The rotation of the earth has respect to the earth only, and in so far as it modifies gravitation, and inasmuch as it is a rotation it must do this, it modifies the terrestrial gravitation only; and we could suppose it to go on in the very same manner as it now does, although the orbital motion were ever so much changed, or even though it should cease altogether.

But when once this rotation has taken place, from whatever unknown cause, and the gravitation is adjusted to it, and its momentum established, we cannot, so far as respects the mass of the earth and the position of places on its surface, imagine any change of the axis of rotation, or any alteration in the velocity with which it is carried on, though disturbing forces may change the position of the axis in absolute space.

The general effect of this motion of rotation is abundantly simple; and any one who turns fairly round by the left hand, and notices how all surrounding objects apparently turn round him toward the right hand, will at once understand it, without farther illustration. The observing eye is the very same organ, whether the "stand" which carries it round be a human body, a whirling table, or a rotatory earth; at least, the only differences are in the direction of the axis of rotation, and the time in which it is performed. The line of the zenith and nadir is the axis of individual horizontal rotation to an observer at any point; the position of this is not the same with that of the earth's general rotation at any two places, except the poles or extremities of the axis.

As the axis of rotation cannot shift its position with regard to the earth itself, the apparent motions which it occasions must be all in the same plane—the plane at right angles to the axis, unless they arise from other motions in planes different from this, and only one of these can be occasioned by the earth, as it can have only one other motion—a motion of revolution. The position which the plane of this general apparent rotation of the heavens, with regard to the horizon of any place, will be the same angle as the line of the zenith and nadir makes with the axis of the earth's rotation—parallel to the horizon at the poles, at right angles midway between them, and oblique in all other places.

The two motions among the stars of the pole round which the heavens appear to turn, which we mentioned at page 77, as proofs that this pole can have no relation whatever to any real motion of the heavens, are occasioned by disturbing forces acting on the earth's axis: the one is called the *precession of the equinoxes*, produced through the medium of the orbit of revolution, and the other the *nutation* of the *axis;* but these disturbances will be better understood afterwards. It is necessary to bear in mind, however, that this motion of rotation and all the phenomena dependant upon it, are peculiar to the earth; and that consequently no argument from them can be applied to the peculiar economy of any other planet.

We have next to consider the effects which the orbital revolution of the planet carrying the observer will have on the apparent motions of other bodies; and this may be simplified by dividing it into four cases:—First, the effects which it will have on the apparent motion of the central body—the sun, in the case of the earth, and indeed of every other body which comes within the limits of our mensuration; secondly, the effect upon other planets which are nearer the central body than that which carries the observer; thirdly, the effect on bodies revolving round the same centre, but more distant from it; and fourthly, the effect upon bodies which are so remote that we are wholly ignorant of their magnitudes, their motions, their distances, or anything except their mere appearances as shining specks. To these we might perhaps add the effects upon the apparent motions of a body revolving round the planet which carries the observer; but as this is part of what may be called a secondary system, it will be better to consider it separately.

In case of the central body, the apparent motion of that will be a revolution round the planet, in exactly the same time that the planet performs its real revolution, apparently at the distance that the planet is, and performed in the same direction, only always in the opposite points of the heavens. This apparent revolution of the central body will be performed in the plane of the orbit; and, by this means, the position of the orbit will be determined by observation, which could not be done from the planet itself, because the only points of general information which it gives us are the positions of the axis of rotation and the line of zenith and nadir, the first of which is constant to the whole planet, and the second to the "parallel," or circle everywhere equally distant from the pole, in which the point of observation is situated; but it is common to all points of the parallel, and thus of no value in distinguishing one of them from another. The plane of the earth's orbit, traced out in an imaginary circle on the apparent concave of the heavens among the stars, forms what is called the ECLIPTIC; and it is made the basis of every estimate of celestial positions. Like all other great circles on a sphere, whether real or apparent, it divides the whole of surrounding space into two equal parts, and the poles of the ecliptic are in the centres of these. Each of these poles is 90°, or a quadrant of the circumference of the apparent sphere of the heavens, distant from the ecliptic; and celestial latitudes are estimated from the ecliptic to its pole. Celestial longitudes are reckoned from a point in the ecliptic, which, however, is not quite stationary among the stars.

The earth's orbit, of which the ecliptic marks the position, is an ellipse, having its major axis, or line of the apsides, about 190,000,000 miles long, and consequently its mean distance about 95,000,000 The eccentricity, or distance of the focus from the centre, is about 1,600,000 miles; the semi-conjugate diameter, about 94,900,000; and the whole, about 189,800,000; the difference of the two axes being only about 200,000 miles, and the difference of their halves, 100,000, which, on a mean of 95,000,000, is only one in 950; and thus the form of the orbit differs very little from a circle. The perihelion distance is thus about 93,400,000; and the aphelion distance, about 96,600,000. These are round numbers, or rude approximations; but they will serve to give some notion of the general size and shape of the orbit.

As the earth's orbit, or rather the plane of it, is the foundation upon which all our knowledge of the apparent places of the celestial bodies rests, it is of the utmost importance to have clear notions of it. The place of its plane among the stars is easily found by observation. A line joining the centres of the earth and sun, and produced both ways to the apparent regions of the stars, always marks two points in it; and we have only to find the point opposite to the sun, as that is the nocturnal point when the stars are visible, and trace its path for a whole revolution, or year; or, from a deep pit, which excludes the cross lights of the atmosphere, we can see both sun and stars during the day, and thus trace the apparent motion of the sun itself through the whole circuit of the orbit, which will give us the position in the same manner and with the same accuracy.

When we trace the ecliptic in either of these ways among the stars, we must put the apparent daily motion of the heavens out of the estimate. That arises from the earth's rotation, which, as we have said, has nothing to do with the motion of the earth in its orbit, and produces no effect upon any of the celestial bodies. In the economy of the earth itself, and in the phenomena of the heavens, as seen from the earth, it is highly important; but it does not, in any way, affect the rate or direction of the earth's motion in its orbit, or its general gravitation as part of the system.

It is the slow motion of the sun eastward, estimated from any star that may be most convenient, to which alone we have to attend in tracing the plane of the earth's orbit; and though the apparent concave sphere of the heavens is a merely imaginary sphere,—and the great circle which we thus trace round it as marking the plane of the earth's orbit, or ecliptic, is a merely imaginary line,—yet they are as permanent, and far more stable in space, than any portion of the surface of the solid earth, and any line which we can actually draw upon that surface. The great body of the stars are far more immutable in their observed positions than any other objects. They have no parallax, arising even from the motion of the earth in its orbit; for when the earth is in the perihelion and in the aphelion, although these points are 190,000,000 miles from each other, there is not the slightest change in the relative position of a single star, as compared with the rest. Thus the ecliptic is established on a foundation which is perfectly secure; or if we find that, after long periods of time, its position has altered a little, we must consider the alteration as arising from some disturbance of the earth in its motion, and not from any change in the stars, for they still keep their relative positions.

We do not mean to say that the stars are fixed in absolute space, and have no motion; because, from all that we know, we cannot imagine any body in free space, whether we call it planet, sun, star, or anything else, to be supported in any other way than by the opposing forces of gravitation and motion. That the stars have no motion observable by us, is no proof that they are without motion. When we say that a change of 190,000,000 of miles in the position of the earth, or of the place of the observer, occasions no parallatic change in the apparent place of any one star, we only state what *does not* take place; and, therefore, we are not sure that any parallactic change would be produced, even if the major axis of the earth's orbit were many millions of millions of times greater than it is. Now, if the parallactic change of the earth from one end of its orbit to the other makes, as it does, no measurable angle at the stars, a motion to the same extent in the stars cannot make a measurable angle to an observer on the earth; and, therefore, each of these stars, fixed as they seem to us, may have a motion, compared to the extent of which, that of the earth in its orbit is less than a span or a hair-breadth.

And the sun, which sustains our earth and all the other planets of the system, of which the sun is the centre, may have a motion, which, during the whole period of human observation, may not have occasioned the slightest parallactic change in any star. Traditionary observation does not reach backward more than 4000 years, and accurate observation only to a very small portion of that period; and though, as compared with the momentary observation of our lives upon earth, this is a long period, yet truly, in respect of absolute time, it is nothing. It were as vain for us to take the brief years and centuries which are marked by the revolutions of our little earth for measuring the duration of the universe, as we find it to be to attempt to measure its dimensions with the 190,000,000 miles of the axis of its orbit. We must bear in mind whose works we are speaking of, and what space and duration are in His sight!

When we turn our attention to bodies at distances so immense as the stars are from our earth and its central sun, and the distance from star to star must be as great—as their distances are visible to us, we must bear in mind how gently they must lead each other in the universal bands of gravitation, at these mighty distances, even though their masses are many times greater than that of the sun.

"Gravitation diminishes as the squares of the distances." The mean distance of the moon from the earth is sixty times the earth's radius; the distance of the nearest star from the earth, in any part of its orbit, and consequently from the sun, which is in the plane of that orbit, cannot be less than 4,800,000,000 times the radius. These numbers are as 1 is to 80,000,000. The squares of these numbers are 1 and 6,400,000,000,000,000. Therefore gravitation at the star is 1, and gravitation at the moon is 6,400,000,000,000,000. But 3600 pounds at the earth would weigh only 1 pound at the moon, in respect to terrestrial gravitation; wherefore, 23,040,000,000,000,000,000 pounds at the earth or at the sun would be only one pound in effect at the star. Thus the weight of the sun and all the planets, estimated at the star, cannot be much more than that of a large ship at the surface of the earth, and may be less than that of a thistle-down; nay, it is not only possible, but highly probable, that the distances of these vast and luminous bodies, which we may and must consider as the suns of systems, are so remote from each other, that their gravitating weights, as affecting each other, are reduced to that of the ultimate atoms, beyond which we cannot imagine matter to be divided.

But, even on this mysterious confine, the law is as perfect as where the force of gravitation is strongest, and the counteracting motion most rapid; and thus, if, as we have already said, the planet in its orbit careers more freely and buoyantly than the lightest bark on the sea—aye, the thinnest vapour in the upper air—so systems move more lightly still; and the law which sustains the whole is the most wonderful display of Divine wisdom and power which the human mind can contemplate. Nor, wonderful as the creation of God, received in this light, becomes, is there any fanciful speculation, any idle conjecture, any vain showing off of unmeaning words for the sake of effect, in any one part of it? It is all founded on the most exact measuring and weighing, as they are performed at the surface of the earth, and as they have been stated and verified a thousand times over; and the final estimate in numbers, although infinite to our comprehension, is greatly, and, for aught we know, immeasurably below the truth.

The rapid and imperfect glance which we have thrown upon the region of the stars is not irrelevant to the subject which led to the introduction of it,—the effect of an orbital motion of the observer's planet upon the apparent places of the other bodies which are visible. It is, in fact, the fourth case in our enumeration—the effect upon bodies so remote, as that we are totally ignorant of their distances, magnitudes, and motions. We shall, therefore, return to the remaining cases, those of sister planets, as it were—bodies revolving round the same common centre of gravity with the observer's planet; and of them our notice must be brief.

As all planets that are known move in the same direction, from west to east as we call it, or from our right hand to our left, we have not to consider the effects of contrary motions; but only those which are performed in the same direction in which the observer's planet carries him, but in different planes, and with different velocities; and the planes of the orbits of all known planets are so nearly the same with the plane of the earth's orbit, that is, of the ecliptic, that we view them all nearly on edge.

An inferior planet, that is, one nearer the central sun than the observer's planet, and therefore having its orbit included in the orbit of that, will, according to the law, not only perform its revolution in less time, because of its smaller orbit, but it will move faster in absolute space. It will, therefore, be constantly getting before the observer.

The apparent motion of the inferior planet will still resemble that of the fly on the lip of the cup, or the horse running round the circular course. When the observer, the sun, and the planet are in the same direction, the planet is said to be *conjunction;* if beyond the sun, it is the *superior* conjunction; and if between the sun and the observer, the *inferior;* if, in the superior conjunction, the sun and planet are so nearly in the same straight line as that the sun hides the planet, it is called an *occultation;* and if they were sufficiently near being in the same straight line at the inferior conjunction, the planet would pass over the body of the sun, or make what is called a *transit.* If the orbits of the observer's planet and the observed planet had the same plane, these phenomena would take place at all conjunctions; but if the orbits were inclined to each other, they would happen only occasionally; because, in consequence of the different angular velocities of the two round their common centres, conjunctions would happen at all places of the orbit of each; and thus, to speak relatively, the planet would sometimes be higher up, and sometimes lower down than the sun, at the time of the conjunction. In ellipses, the angular velocity of each planet would vary at different times of its own revolution, and the variations would be greater or less according to the eccentricity. This would render the problem so intricate, especially when the disturbing actions of the planets were taken into the account, that no general explanation can be given,—the case of each planet must be calculated upon its own data.

The general apparent motion of the inferior planet will be, a motion eastward from the sun, beginning at the inferior conjunction, and comparatively rapid there, because it is nearly at right angles to the axis of observation, but becoming slower as the planet turns round, till, at the greatest distance, or *elongation*, eastward, it will, apparently, be *stationary* for some time, as its motion there is nearly in the direction of the axis of vision. From this point it will appear to *retrograde* westward to the inferior conjunction, increasing in speed as it approaches. It will continue retrograding or receding from the sun westward, at a rate gradually diminishing, till it reaches its greatest elongation westward, at which point it will appear to remain stationary for some time; after which it will again move eastward, with an increased velocity, till it shall reach the superior conjunction, and so have performed a revolution.

The parallactic change of its place, or rate of its motion, during this revolution, will depend partly on its distance and partly on the direction of its path, or the angle which that makes with the axis of observation. In consequence of the former, its *direct* motion from the western to the eastern elongation will appear to be slower than its retrograde motion from the eastern to the western; and, in consequence of the latter, the diminished motion towards the points of greatest elongation, and the apparent pauses there, are produced. There are also other minor modifications arising from the form and position of the orbit, and any variations to which it, or the orbit of the observer's planet, may be subject; but these depend on the particular planets, and the particular instance.

Not only is the retrograde motion apparently faster than the direct, as being nearer to the observer, but it is performed in a shorter period of absolute time. Two lines drawn from the eye of the observer to the points of greatest elongation, at which points they must be tangents to the orbit, determine the portion of the orbit in which the retrograde motion takes place; and as these tangents form an angle at the eye, they must be tangents to less than half the orbit, because the tangents to the half of a circle, or an ellipse, are parallel. The elongations in an elliptic orbit will also not be always of the same length, as they may be the length of any radius vector of the observed planet, not less than the perihelion distance, nor greater than the aphelion.

In consequence of the motion of the observer's planet, in the same direction as the inferior one which he observes, the apparent time of the observed planet's period round the sun will be increased. For it is evident, that, as the sun is the centre of its revolution, and the real motion of the observer causes an equal apparent motion of the sun, the sun will appear to have carried the planet, during a revolution from any point of its orbit, to the same point back again, eastward, among the stars, over a portion of the ecliptic equal in angular measure to the portion of its orbit which the earth, or planet carrying the observer, has passed over in the same time. This will differ with the part of the orbit in which the earth happens to be. It will be a maximum if the earth's perihelion is in the middle of the period, and a minimum if the aphelion; because the angular motion is greatest in the perihelion, and least in the aphelion. The real time of the revolution of the observed planet, from any star to the same star back again, is called its *siderial* period, and that estimated by the sum of the two motions is called its *synodical* period, which last means the period of the two motions consenting or going together.

We shall now examine the effect which motion in an orbit has upon the apparent place and motion of a superior planet,—that is, a planet the orbit of which surrounds that of the observer's planet. The inferior conjunction will, in this case, be changed to an opposition; and the motion of the superior planet will be slower in angular velocity than that of the observer's planet, both on account of the larger orbit, and the diminished force of gravitation toward the centre. The variations produced by differences in the form of the orbits, and in their planes, will be much the same as in other cases; and there will be direct, stationary, and retrograde appearances; but there will be no points of greatest elongation: the superior planet will go round from opposition to opposition, and this will be its *synodical* period, though, in the case of elliptic orbits, this period will not be always of the same duration, and the different parts of it will be performed with motions very different both in direction and velocity.

If a horseman rode round a pole in a circle, the pole would appear to travel, on the opposite side of the circle, with the same angular velocity as the horseman rode. This is the simplest case of the observer's planet. If another horseman, worse mounted, rode round the pole in a circle considerably larger, he would represent the superior planet, and, time and velocity excepted, his observation of the pole would be the same as that of the other. Let there be trees, buildings, or any other fixed objects, at great distances around them to represent the stars; then let them range themselves each in his circle, and in the same straight line with the pole, and also with an object beyond the most distant horseman; and so let them start, the well-mounted rider to observe the motions of the other, both with reference to the pole and to the fixed objects outside the larger circle.

In this state of things, the angular space between the observant, or nearest horseman, and the pole, on the one hand, and the other horseman and the fixed object on the other, is half the space where he stands, and consequently two right angles.

They start; the observer makes much more angular way than the other, and if he looks back, he will find that the angular distance between the other horseman and the pole is now less than two right angles, and that the distant object has got in advance of him, and is actually gaining on him, in the same way, and for the same reason, as the tower gained on the cliff, and the mountain on both, in the case of the ship formerly alluded to. Taking the fixed object as the means of judging, the horseman in the larger circle would appear to be riding backwards; and taking the pole as such, he would appear to be approaching that in angular distance. This would diminish gradually, and, after a time, longer or shorter according to the distance of the circles and the rates of motion, the observed man would stand still, in respect of the fixed object.

He would do this when the angular distance between him and the fixed object attained its minimum. The point of the smaller circle at which this takes place would depend on the relation of the circles and the rates of motion; it would take place sooner the more nearly they were equal. After a short pause, he would appear to move on, at first very slowly, but quicker and quicker till he got up to and passed the fixed object; and not only so, but got more or less in advance of it, according to circumstances. At last, however, he would linger to a stand-still, at the same angular distance as that at which he stopped before and appeared to recover from his retrograde motion. But as, notwithstanding the apparent pause and retrogression, the man has been getting on uniformly all the time, as fast and free as his slow steed and long road would permit, he is now found at a considerable distance from the fixed object, from which he appeared to have so much difficulty in getting away at the first.

The moment that he appears to stop, however, another object seems to enchant him, and backward he goes, slowly at the first, but quicker and quicker till his rival gets again between him and the post; he still retreats, though gradually more and more slowly, till he again comes to a stand-still, at the same angular distance from the point of passing him as his first pause was from the starting point; and the same succession of apparent retreats, pauses, and advances is repeated, till at last he gets round the course as well as the other, though during his circuit the other will have made a greater or smaller number of revolutions, or complete number and part, according to circumstances.

The motions of this slow-riding horseman, as observed by his better mounted and shorter-pathed companion, are exactly those of a superior planet as observed by a spectator upon one inferior to it, —the one being told upon the fixed objects around the race-course, just as the other is told upon the fixed stars around the course of the planet; and if the reader has paid attention to the simple cases of the effect of parallatic angles upon apparent motions, he can be at no loss to understand this one.

At the time of opposition, that is, when the inferior planet is exactly opposite to the sun, the superior planet is nearest to it, and its angular motion with regard to it is a maximum, so that it passes rapidly. At the point of conjunction, on the other hand, when the inferior planet is on the one side of the sun, and the superior one on the other, their distance is greatest, and the angular velocity is a maximum, so that the superior planet appears to move faster than the uniform rate.

The points where the pauses take place are those at which there is no change of the angular distance. They are nearer to each other in proportion as the orbits and velocities of the planets are less different, but in no case can there be a semicircle asunder on the side where the opposition and retrograde motion takes place.

From conjunction to conjunction is the secular revolution of the two planets; and the excess of apparently direct or an apparently retrograde motion, is the measure of the portion of the secular revolution made by the superior planet, that is, the angular distance between the two points of opposition. The more distant the superior planet is, the smaller will be the portion it makes of the secular revolution, as told upon the orbit of the inferior one; but as the slowest of them has some motion, the secular period will in every case be longer than the siderial period of the inferior; but the less that it exceeds this, the smaller a portion will it be of the siderial period of the inferior one. Thus, the apparent motions of the most distant of the superior planets will be apparently the more complicated, although the real motions of all of them are performed in elliptic orbits which, excepting the small disturbances that they occasion to each other, are all regular in their forms.

The motion of a secondary planet round its primary partakes of some of the characters of that now described, only as it is always on the same side of the centre as its primary its apparent motion is simple revolution. It has an inferior conjunction between the central body and its primary, and an opposition on the other side; and if the centres of the three are sufficiently near being in a straight line, it will eclipse the central body to its primary in the conjunction, and be eclipsed by the primary in the opposition. Its secular period will always be greater than its siderial one, though not nearly so much so as that of an inferior planet. Its period, compared with that of its primary, will depend on the magnitude of their orbits, the proportions of which are, in all cases of elliptic orbits, the semi-axes or mean distances.

The apparent changes produced in the positions and motions of bodies by parallactic variations, may, in all the simple cases which admit of being generalized, be met and explained by one or other of the principles of which we have attempted to give something like a popular account in this section; so that if we know the motions of any celestial body, and observe its apparent place, we may be enabled to reduce it to its real place, whether *geocentric* or *heliocentric*, that is, whether as it would be seen from the centre of the earth, or from the centre of the sun; and thus we are in so far prepared to go forth and examine the heavens.

But there is still another question. We have seen, in the former part of this section, that we cannot implicitly trust the eye—the organ of observation;—can we trust the light—the medium of observation? Are we certain that the light comes to us—"with perfect rectitude"—fairly upon the axis of vision, in straight lines from those bodies which we see? If this is not the case,—if the apparent place is not *truly* the apparent place, then we have paraded all our labour about parallaxes in vain, and are left in as much uncertainty as ever.

We need not ask this of the heavenly bodies, for they are dumb and distant; and they answer truly and usefully only through the medium of some interpreter with which we are familiar upon earth. The anecdote of Newton and the apple is well known; and it is written in a book whose maxims have many interpretations, "Ask *the beasts*, and they shall teach you." There must be an infallibility about instinct to which human reason can lay no claim: A horse will bring home his master in safety when the night is pitchy dark, apparently by the feeling of his horny hoofs shod with iron, when all the science of the master is at fault. There is the kitten at the looking-glass for the first time, it attempts to paw and play with the image, but instantly peeps round to catch its playmate behind; there is none to be found; and though the kitten frequently looks in the glass again, it does not again peep in behind with arch look and ready paw. Thus, even the kitten knows that the last direction of light is not the one in which to find the body from which the light comes. The sun is not up, yet one can see to read, and the outlines of objects are more beautifully distinct than when the midday orb is in all its splendour. There is some property in the air which, though it cannot show us an image of the sun as a looking-glass does of the human face, yet scatters the light in all directions, and especially sends it down toward the earth. And this property is not in clouds or vapour of any kind, for the clearer that the morning air is, the dawn before sun-rise is the brighter. Besides, if we are on the sea-shore, there are remarkably clear states of the air, in which we not only see distant objects much more distinctly than at other times, but when, with the very same height of tide, we see the tops of far distant rocks which at other times are completely hid by the horizon line of the water; a ship, or a boat, will sometimes appear and disappear, and appear again in exactly the same place. Again, when we put a perfectly straight stick partly into a basin of water, hold it sloping and look at it sideways, it has a bend at the surface, the part in the water being bent up as if there were a knee or angle at the surface. The more sloping we hold it this bend is the greater, and when we set it perfectly upright the bend is gone; but in that case the part in the water appears shorter than it does when we take it out, so much so that if we make a mark exactly at the middle of the stick and plunge half in the water, it will appear shorter than the half above. There is, therefore, some property of the water which bends the rays of light upward, and something in the air which bends them downward.

We examine other substances which are transparent, or allow the light to pass through them, and we come to this conclusion: "When light from a rarer medium falls upon a denser, it is turned into the substance of the latter, if it fall obliquely, but if it fall at right angles to the surface, it then goes directly into the substance, and cannot of course be more turned into it."

We know that the air nearest the surface of the ground is densest, and that it gets rarer and rarer the higher we ascend. Therefore, when light falls obliquely upon the atmosphere, it must be bent more and more into the substance, or downward.

This takes place to the greater extent the more obliquely the light falls, and when it falls perpendicularly it cannot take place. But the eye knows the last direction of light only, just as the kitten fancied that its own image in the looking-glass was another kitten behind it. Therefore, again, all celestial bodies must appear higher than they really are, except those that are in the zenith. Those which are at the horizon or a little below it must have their places shifted the most, both because the light from them falls the most obliquely, and because it passes through the greatest mass of the atmosphere; and their places must be less and less altered by this—*Atmospheric Refraction*—as they are higher and higher above the horizon.

The precise quantity of this refraction is fully as much a matter of individual experiment as of general theory, because it varies with the states of the atmosphere, some of which are very imperfectly understood; but we may state that, on the average of circumstances, it is sufficient to raise, not the light merely but the positive image of a celestial body, rather more than half a degree—thirty-three minutes very nearly—at the horizon; that midway between the horizon and the zenith it is less than one minute—fifty-seven seconds nearly; and that, at the zenith it is nothing, under any state of the atmosphere.

When bodies of large apparent size, or disc—as the sun or the moon—appear just in the horizon, refraction brings up the lower limb proportionally more than the upper one, and gives them an oval shape—not that of a regular ellipse, but an irregular figure, more flattened on the under limb than the upper one.

It requires a passage through a large volume of air to bring up the image of any celestial body, but the upper and rarer portions serve to send down part of the light, and therefore twilight begins a considerable time before the rising, and lasts a considerable time after the setting, of the disc of the sun. The consideration of that belongs, however, more to the earth and air than to the heavens.

Still we may, without any impropriety, mention that this atmospheric refraction affords us a very remarkable view of the delicacy of light. Light has no gravitation whatever, but on the contrary it turns into a transparent body in nearly the ratio of the specific gravity of that body. We are therefore under the necessity of classing it with those powers which we regard as the antagonists to gravitation—that is, motions; or rather, as we can have no idea of real motion in the ordinary sense of the word except when something moves, we may perhaps call them *motive energies*, or causes which originate motion in ways which we cannot explain, but beyond which we are not able to trace the motions themselves. This light, or luminous energy, proceeds as from a centre, and in its intensity it follows the law of all energies that emanate from a centre, that is, it is inversely as the squares of the distances; but whether its velocity does or does not follow the same law, we have no means of ascertaining, although as we know light only as motion, it is probable that the intensity and velocity are one and the same.

But still, rapidly as it does move, its refraction shows that it finds out, and is affected by, even those small particles of which the atmosphere is composed, and which we can discern by no other test.

SECTION IX.

DISTANCES, MAGNITUDES, AND MASSES OF THE HEAVENLY BODIES.

THOSE who are not conversant with the analogical methods of reasoning, that is, of reasoning from quantity of which we can find the magnitude by actual measurement, to other quantities which are millions of miles beyond our reach, in any other way than by the sight, always feel a sort of scepticism when the exact distance, or bulk, or weight, of any such distant body as the sun or the moon is mentioned; and though they do not openly deny the possibility or the truth of such allegations, they refrain from doing so more in deference to the opinion of those whom the world calls wise, than from any conviction in their own minds. They, in fact, give their votes against their consciences—say YES with the lips when the heart feels NO, out of mere deference to the authorities. The "great men" of science have sometimes, though perhaps unintentionally, done as much mischief to the understanding of men, as other "authorities" have done to their morals in a way not very dissimilar. With these latter we have, in the mean time at least, no necessary concern; but we certainly wish that, in matters of science, there were no such thing as an authority. Upon a very general and delightful, and as it would seem a very obvious principle, the knowledge of that creation which God has given to all, should be as comprehendable by all as it is free to all, or if there be a *taboo* laid upon any part of it, we can regard that as the taboo of superstition only, and of superstition the more dangerous the less that it is avowed and apparent as such. When we are once in possession of the knowledge of any subject, we begin to wonder why we could have felt, or others can feel any difficulty about it. It is reported of a very eminent man, that he employed a young tailor as amanuensis in writing a treatise on the science of quantity, which science, as having much of the technical taboo upon it, is always repulsive to the ignorant. The philosopher dictated and the tailor wrote: "Do you understand this?" was asked, as every step had been taken. "Yes," was the invariable answer. After the work had made considerable progress, the amanuensis, annoyed perhaps at the reiteration of the same question, is said to have anticipated it by "Algebra is a great deal easier than making jackets." The simplicity of the book, though it is a very profound one, was demonstrated by this single remark, and there was no necessity for again repeating the question.

Now, though we have not the slightest desire to substitute the pursuit of any one science in the room of any mechanical trade or other professional occupation, further than it may lead to its more easy and successful accomplishment; yet we certainly do wish that each and all should find more pleasure in the pursuit of knowledge than in those frivolous matters—to say nothing about positive vices—in which but too many of all classes of society waste no small portion of their time. It is to further this end that we have made these few introductory remarks at the commencement of this section, in the hope that, by coming unexpectedly upon the reader, they may impress him more forcibly than if we had "blown the trumpet before them," as is, in our opinion more frequently than wisely, done by those who wish to give hints for improvements to others.

We shall only just further remark, that the technicality of any one science is very apt to chain to that particular science those general truths which are equally useful in all sciences and upon all subjects; and this is particularly the case with that correct mode of reasoning by analogy to which the name of "mathematical reasoning" is usually given; and that this stops those who are not technical mathematicians at the very point where the valuable part of the knowledge is completely within their reach.

In attempting to give some slight popular notice of the means by which the dimensions and weight of the heavenly bodies are obtained, we must confine ourselves to the simple notice of the principles; for the practical application of those principles requires instruments and experience, the first of which cannot perhaps be properly explained in words, and the second can be learned only, as all other mechanical operations are learned, by practice.

The foundation of all this branch of our knowledge—that which enables us to connect with each other all those principles and all those results of experience which assist us in this work, is the simplest of all possible figures—a triangle —three straight lines, joined two and two at the ends, and thus having three corners or angles, as well as three sides. This simple figure has many useful properties, and it has this remarkable one, and is the only figure which possesses it,—that it is impossible to put it out of shape. We have seen, in a former section, that a circle, which is a very regular figure, can be easily put out of shape, and can be made to pass through all shapes of ellipses till it is flattened to a perfectly straight line. It will be as readily understood that a four-sided figure, or one with any number of sides greater than four, may also be put out of shape, while the lengths of the sides remain unaltered; because, if we may press any two opposite angles towards each other with sufficient force, the other angles will give and extend outwards. But the triangle is perfectly stubborn, and if we suppose it to be made of three laths, or any other pieces of solid matter instead of imaginary lines, we shall find that, unless the laths are broken, or separated from each other at the angles, we can in no wise alter its shape.

In this figure, the sum of the three angles is the same, whatever be the size or form of the triangle; that is, they are equal to half the space round a point; and thus, if we know two of them, we also know, that is, we can at once find, the third one. In all cases there is a constant proportion between the sides and the angles; so that if the three sides of one triangle be proportional to the three sides of another, each to each, that is in the order in which they are placed, the triangles are similar, the angles are equal, and any reasoning founded upon one of them will apply to the other, whatever may be the lengths of their sides.

On this principle, the sides of an entire set of triangles, answering to every variety of angles, are found by calculation, and expressions for them in numbers are entered in a table, which table is called a table of *sines*. By the help of this, or by reasonings founded upon it, or additional tables in the construction of which it is an element, we are enabled to make use of triangles in extending our mensuration, as far as we can observe with certainty that there is any determinate magnitude to be measured. If we have one side of a triangle to begin with, and can get the quantity of two of the angles, either by direct measurement, or by fair inference from something previously known, we have *data*, or elements given, quite sufficient for determining everything else about the triangle. So also, if we have two sides and the angle between them, it is evident that we have the triangle determined, because while the two given sides and the angle between them remain the same, their opposite extremities, which determine the third side, and also the two remaining angles, must remain unchanged. If we have any three of the six elements—the sides and angles, with the exception of the three angles, we can always find the rest, though there is at least one ambiguous case; but as the doubtful quantity in that case must be one or other of two, we have generally some circumstances which lead us to the knowledge of which one it should be. In the case of the three angles, too, though we cannot determine the size of the triangle, we can determine its shape, and therefore reason respecting it as a whole, though not respecting its particular lineal dimensions. The triangles in our table of sines are of this description; their sides are expressed in numbers, and not in measures of length, and thus they are not lines, they are merely the relations of lines. Indeed, it is our being able to use the relations of quantities instead of the quantities themselves, which makes calculation so wonderful an abridgment of labour, and enables us to measure such a distance as that of the sun, by a mental process, in a few minutes, whereas the doing of it mechanically, even though possible, and there were a smooth and straight road all the way, would take far more time than those who have not thought of the matter would be apt to suppose. Six and twenty miles a day is a very good rate of walking to continue with all the year-round. Now, if we, for the sake of illustration, suppose that there is a straight road all the way to the sun, and that a man could measure accurately by pacing as he went along, it would take him, in round numbers, just about a thousand years, walking twenty-six miles a day every day during the whole thousand, to make out his rude way this single distance, the data for which could be obtained, and the calculation from those data made in certainly not more than ten minutes.

We formerly gave a rude estimate of how the angular distance at the earth's centre of two points on its surface could be obtained by observing the altitude of the sun; and we may now mention that the same may be more accurately done by the observation of a star near the zenith, as stars have no parallax, and there is no refraction at the zenith.

Well, suppose this accurately done,—that is, that we know exactly the portion of the earth's circumference that lies between two points, say the Royal Observatory at Greenwich and York Minster,—any two, in fact. We have next to ascertain how many yards, or any other measures which we use as standards, are in the arc of the earth's circumference between those places. The applying of a yard-wand, or any common measuring instrument, is out of the question in the case of such a line, considering its length, and all the inequalities over which it passes. Therefore, we select some open and level place where we can measure a mile or two of a straight line with the greatest accuracy. This is a nice operation, and we shall not attempt to describe it; but it has been done with wonderful accuracy. The base situated near Londonderry, measured for the survey of Ireland, is understood to be within one-eighth of an inch in the mile of the absolute truth, which would not amount to more than about sixty feet in the diameter of the earth. Triangles are extended from the base so measured, and thus the distance of the two points is ascertained, and from this the diameter of the earth, which becomes the base line in the measuring of the heavens.

Half the diameter of the earth, or its radius, is the line which subtends the angle of the horizontal parallax of any of the heavenly bodies, say of the sun. The most simple view of this is the following:—Two observers, one on the north side of the equator, and the other on the south side, both on the same meridian, or directly north and south of each other, and each as far from the equator as possible, observe the meridian altitudes of the sun on the same day, with the greatest accuracy, and free them from refraction. From what was said in last section, it will follow that the observed place of the sun will be lower than the true place by the parallax answering to the observed altitude of the sun, and therefore the observed zenith distance at each place must be greater than the true zenith distance, by the parallax answering to the altitude at each place. But, as the sun is south of the zenith at the one place, and north of it at the other, the sum of the true zenith distances is equal to the zenith distance of the two places, that is the sum of their latitudes, the one reckoned north and the other south. The excess of the observed zenith distances above this is the sum of the parallaxes in altitude; and if this difference is multiplied by the sum of the sines of the latitudes (sine 90 degrees being =1) the result will be the horizontal parallax. Then, sine horizontal parallax is to co-sine ditto, as earth's radius to distance of sun.

The distance of any other body which has parallax may be found in exactly the same manner, and this process being used for a sufficient number of instances, will give all its different distances from the earth.

The mean distance, and either the aphelion or perihelion distance, or these two, or indeed any two being found, it is easy to refer them to their heliocentric angles, by means of the annual parallax, and thus to obtain all the particulars of the orbit; and indeed, after we have obtained the mean distance of one planet, and observed the line of its periodic revolution, viewed heliocentrically, and reckoned from any star to the same star back again, we can, by merely observing the periodic times of the others, obtain their mean distances, by the law of the proportion of the squares of the times to the cubes of the mean distances. The proportion is: as the square of the period of the planet whose distance is known, is to the square of the period of that whose distance is sought; so is the cube of the mean distance of the one, to the cube of the mean distance of the other; and the root of the cube thus found is the distance required.

There are many other methods by which the planetary distances may be found. In the case of the inferior planets, if we know the distance of the earth from the sun at the time of the planet's greatest elongation, we can have an approximate estimate of their distances from the sun at these times; and the proportion is: as co-sine angle of elongation is to sine ditto, so is distance of earth from sun to distance of planet from sun. This will not be perfectly accurate; first, because the planet is not at its greatest elongation when the radius vector from the earth to the sun is at right angles to the line joining the centres of the sun and planet; and secondly, on account of the extremely slow motion of the planet when it is very near the point of its greatest elongation. A nearer approximation will be: as co-sine angle of elongation is to sine, so is the distance of the earth from the sun to the distance of the planet from the sun.

In the case of a superior planet, a rude approximation of the difference between its distance from the sun and that of the earth, may be obtained from the comparative lengths of the periods of its direct and retrograde motions in the course of a synodic revolution; but they are mere approximations. Enough, however, has been mentioned to show that the mensuration of these distances is not only possible, but comparatively easy, in the case of every body that has an observable parallax; and it is not necessary that the line including the parallactic angle should be only the radius of the earth; for, when the distance of the earth from the sun is once determined, the earth's *annual parallax*, the line which subtends this being the radius vector distance of the centres of the earth and sun at the time, is the base from which any other line in a triangle, of which the earth and sun are in two of the angles, can be readily determined: and upon this principle, though the details are attended with more or less difficulty, according to circumstances, the lineal dimensions of all the measurable heavens, that is—of all bodies which have a geocentric parallax,—that is, of the distances of which the radius of the earth, or four thousand miles, can be a perceptible fraction—may be ascertained with not more difficulty than any lineal dimensions on the surface of the earth.

They are indeed much more readily, or at least perfectly, determinable than long distances of the earth's surface, unless these lie upon a meridian, and can thus be determined by celestial observation in the manner in which we have shown that the dimensions of the earth itself are found,—it being a more easy matter, when the distance of one planet from the sun is correctly ascertained, to find the distances of all the other planets than it is to find the longitudes of places on the earth, or the distances, in terms of the earth's equatorial circumference, which they are apart from each other. Time is the element of the analogy in both cases; but, as we can observe from the very same point the times of the periodical revolutions of all the planets, while we cannot so measure the times at even two places on the earth, the case of the planets is determinate in itself, while that of terrestrial longitudes is indeterminate, unless we have recourse to celestial data, such as the distances of moveable bodies in the heavens, which are equal at the same instant of time, as seen from all parts of the earth at which they are visible; that is, equal after the necessary corrections are made for the geocentric parallax and atmospheric refraction. No doubt, in these cases, an artificial time-keeper or chronometer, (time measurer,) as it is called, gives us the means of carrying the time of any one place on the earth's surface to all other places, and thus we have this standard to compare with the observed time at any particular place, and if the chronometer were as certain in its rate of going as the earth is in its rotation upon its axis, the finding of longitude by the chronometer would be a very simple matter. We would have only to turn the difference of the observed time, and the time of the chronometer, into degrees and minutes, at the rate of fifteen degrees to an hour, and the result would be the longitude—west longitude if the observed time were less time than the time of the chronometer, and east longitude if it were greater, and if the difference were twelve hours, the place of observation would be exactly opposite to the place of the chronometer, or equally distant from it both eastward and westward. Seamen do, in practice, carry the time of the royal observatory at Greenwich, as accurately as they can, by means of their chronometers; but chronometers, how skilfully soever they are made, still partake of that imperfection which is inseparable from all that man can make; and as the comparison is that of the going of man's machine with that of God's machine it is utterly in vain to expect that the one can by possibility have that beautiful uniformity and that perfect stability and duration which belong to the other. A very valuable approximation has been made in the perfection to which the scientific knowledge of principles, and the skilful application of the hands in working, has carried these machines; and this is one of the most forcible, as well as one of the most useful, instances which we have of practical benefit arising from a thorough investigation of the laws of nature.

We can find the periodic times of all the planets, by observing when they cross the orbit of the earth, or shift from north to south, or south to north of the ecliptic, in a manner which will be explained afterwards; and when we have observed the times of those passages sufficiently often, and with sufficient accuracy, for enabling us to get the mean period with the requisite accuracy, we have only to apply Kepler's third law, in order to obtain the whole of their distances.

The next branch of celestial mensuration to which we have to call the attention of the reader, is that of ascertaining the dimensions of the celestial bodies, the diameter of each, or its different diameters if the face or disc which it presents to us is not circular even after clearing it of those deceptions, arising from refraction, to which we alluded in last section.

This problem is exactly the reverse of that by which the distances of their bodies are found. In that case, we have the earth's radius as the base, and the geocentric parallax as the angle which this base will find at the planet; or we may use the diameter, or turn the radius, and also turn the parallactic angle; though by so doing, we should not make our result a jot more accurate, as the error of the angle would be double, if the angle were doubled. This is an important consideration, not in this case only, but in all cases. The structure of our reasoning, like that of our building, can never be more stable than the foundation on which it rests: so that, to whatever extent we may multiply any quantity, we multiply whatever of error there may be in it in the very same proportion as we multiply the truth; and thus, though this kind of multiplication is often of use to us, by increasing a small error which we can detect, to such an extent as to render it visible, we are never in the slightest degree nearer the truth in using the multiplied quantity as a whole, than if we used only the smaller quantity, of whose multiplication it is the product.

In finding the magnitude of the body, or the length of the diameter of its disc—for that is the only quantity which we can find by one observation or operation—we have the angle which the body subtends at the place of observation, instead of the line subtending that angle. This is the parallax of the body itself, the angle which would be made by the axis of vision of two observers situated at the two extremities of its diameter, and both observing the earth at the same instant. In that case, the earth would appear in the horizon to both—that is, it would be 90°, and also the amount of the parrallax, answering to half the diameter of the body, from the zenith, and the excess of the two zenith distances above two right angles, would give the angle subtended at the earth by the whole diameter of the body.

On the earth, this angle is obtained by one direct observation, which may be done either by measuring the angle with an angular instrument of sufficient delicacy, or by observing the time which the diameter of the body requires to pass over a fixed measure, as for instance, a fine wire or spider's thread in a telescope—fifteen seconds of angular motion answering, in round numbers, to one second of time, and the deviation from the exact truth being, in most instances, too minute for being at all taken into the account.

When this angle is obtained, and reduced to what it would be if the body were seen from the centre of the earth,—or even if this reduction is not made, for the error arising from it is so small, the radius of the earth is so minute a fraction of the distance of any body save the moon, —the diameter of the disc of the planet may be found by a simple proportion. In observing, it is better to take the angular dimensions of the whole diameter of the body, because that is more easily obtained than the half; but the half is the preferable term of the analogy; and that being used, this is the statement:—as the co-sine of half the angle which the disc of the body sustains, is to the sine of the same, so is the distance of the body from the earth's centre to the semi-diameter of the body. Then this semi-diameter doubled is, of course, the whole diameter.

When, in the case of any one body at any known distance, the diameter has been, by this means, accurately determined, these two elements become the means of calculating, by a very easy process, the distances answering to all variations of the observed diameters, or the apparent variations of the diameter which should correspond to all known distances.

It has been already mentioned that the apparent length of the same line, seen in the same position, or with the eye opposite to the middle of it, is inversely as the distance at which it is seen. But the diameter of a globe is always seen in the same position, or in other words, in whatever position a globe is seen, the measure across the disc, or round face which it presents to the observer, is always a diameter, and always really of the same length, if the globe is perfect, but different if it is not perfect. But all the heavenly bodies which have a permanent existence as parts of that system which comes within the range of our observation are globes; and though perhaps none of them are strictly and mathematically perfect globes, yet they are all very nearly so; and if the differences of the lengths of their apparent diameters, when at the same distance, are observable, the different lengths of them may be ascertained, and the figures of the bodies may be thence accurately determined.

Now, as the apparent diameter and distance of the body—that is, the line subtending the visual angle, and the axis of vision are always inversely to each other, for all distances, it follows that their product is a constant quantity, that is, the result of the multiplication of the one by the other must be the same for all distances.

This is a very important general principle, and one which applies to all cases,—where two elements enter into any result, and which are inversely to each other, or the one of which always increases in the same proportion as the other diminishes. One of the most familiar instances of this is the time and number of hands necessary to do a certain quantity of work,—say that it takes eight days of six men, the days being understood to be all of the same length, and the men all capable of working alike. In this case, the product forty-eight expresses the quantity of work in terms of one man for one day, and while the work remains the same, this is a constant quantity, always the expression for it. When this product is once known, and it is always known when we know one case of the two elements of which it is made up, we can, when either of the elements is given, find the other one corresponding to it, by simple division. Thus, if the number of men which could do the work above-mentioned in twelve days were the quantity sought, we would, by dividing forty-eight by twelve, find four; and so in all other cases.

When we have once obtained the true distance of any of the celestial bodies, and the diameter correctly at that distance, we have the elements of this product with regard to that body, and, consequently, we have the product itself. When we have once obtained this, it becomes very important in the determining of all other situations of the planet. The diameter we may consider as invariable, at least in the case of those permanent bodies which are solid, and have their orbits permanent, or subject only to small periodical variations; for it is a law of the celestial system, as well as of the system of things in our world, that what is frail and weak is unstable, and what is firm and powerful is durable; and in virtue of this law, some of the more frail tenants of the regions of space are as unstable in their courses as they are filmy in their structure. But, where there is a permanent orbit, whatever may be the fluctuations to which that orbit is periodically subject, there is also a permanent diameter, and this diameter does not appear to be subject to any periodical changes.

In consequence of this permanence, the diameter of a planet becomes an important element in estimating the distance of that planet from the earth at different times. It is, indeed, only a small quantity even at its apparent maximum, in consequence of its great distance, and therefore it affords merely an approximation; but the approximation is so easily made, and serves so well to show the structure of the system, that it is a very useful one, especially for those who have not instruments or leisure for more minute investigations. In the application of it, we have only to divide the constant product, that is, the product of the diameter and distance as correctly ascertained for one position of the planet, by the observed diameter for any other position, and we have the distance for that position.

By this means we can obtain the distance of the planet from the earth at as many points of its orbit as we please; and as we can, in all cases, find the earth's annual parallax, or distance from the sun, for the time of the observation, and also know both the geocentric and the heliocentric angles, we can find the distance of the planet from the sun at all these points.

As the earth moves in an ellipse, as well as the other planets, and, for the reason which we have already stated, every body which moves at all, and is supported by the forces of that motion and of gravitation jointly, must move in an ellipse, if it does not move in one of the other conic sections which have their major axes of interminable length,—as the earth moves in an ellipse, it must be farther from the sun in the aphelion part of its orbit than in the perihelion; and, therefore, as the mean distance, and the apparent diameter of the sun for that distance, are accurately known, their product, divided by the apparent diameter for every other distance, will give the measure of that distance; and as this is a very simple operation, and one which may be performed for the noon of every day in the year, if the sun happens to be visible, this sort of determination of the form of the earth's orbit is easily obtained.

The same applies to the moon, and indeed to all the bodies in the system, although, as the moon is so much nearer to the earth than any of the rest are, the application to the moon is more accurate, as the geocentric parallax of the moon is about one-sixtieth part of the mean distance.

As the moon really revolves round the earth, or rather the two round their common centre of gravity, which is within the body of the earth, the point at which the moon is nearest the earth is a *perigee*, and the most distant point an *apogee*, in the same manner as the corresponding points in the orbit of a planet revolving round the sun are a perihelion and an aphelion. But we use the words perigee and apogee to express the nearest approach to the earth and the farthest recession from it of all bodies whose distances we can measure, whether their changes be the results of their own motion, of the motion of the earth, or of both jointly. Thus we speak of the perigee and apogee of the sun, the former being the perihelion of the earth, and the latter its aphelion: and we in like manner speak of the perigee and apogee of the planets, though these have no necessary connexion with any particular points of the earth's orbit.

The apparent diameter of the sun, although greater when in perigee than when in apogee, is always nearly equal when in either of them during successive revolutions; but that of the planets, though greater in perigee, and less in apogee, like that of the sun, is not necessarily the same at any two times of being in either of these points, and is, in fact, never the same at any two immediately successive times of being in either of them. This is occasioned by their periodic times and the positions of the major axis of their orbits being all different from those of the earth. The particulars will be mentioned afterwards; but the general fact is of importance preliminary to the details.

The differences of the apparent diameters in perigee and in apogee, and the positions of the planets when these occur, would of themselves enable us to form a rough judgment of all the bodies in the system in which they can be observed. If we leave the moon out of consideration, we find that there is less change of the apparent diameter of the sun than in that of any other celestial body which has a measurable disc and parallax, either diurnal or annual, by means of which we can determine its distance and magnitude; and this apparent diameter of the sun is far more constant to the times of the revolution from its maximum to its maximum back again than that of any other body whatever. Hence we might conclude, without any other datum, that the earth has a much more close and constant relation to the sun, than it has to any other body in the system; and also that this, in consequence of the uniformity of the apparent diameter of the sun at corresponding points of successive revolutions, is the result of *one* motion—a motion of the earth itself, and in an elliptic orbit, of which the radii vectores are inversely as the apparent diameters of the sun.

So also, from the variation of the apparent diameters of the planets, both in perigee and in apogee, and the positions with regard to the sun, in which these take place, we might, without any other datum, infer that these planets revolve round the sun. We might also separate them into the two classes of superior and inferior planets, and form at least a guess at their comparative distances from the sun and the earth, and consequently the size of their orbits; and find, after a good deal of careful observation, the lengths of their perihelion and aphelion distances, and the major axes of their orbits.

Thus, every superior planet must have its perigee at or near its inferior conjunction with the sun, and its apogee at or near its superior conjunction, because it is nearer to the earth by the whole diameter of its orbit in the first of these positions than in the second. Its nearest approach to the earth will be when it is in the aphelion of its own orbit at the same time, and its farthest distance from the earth will be when its aphelion and apogee take place at the point of superior conjunction.

Of superior planets, the nearer the orbit approaches to that of the earth, the greater will be the difference of distance and apparent diameter in perigee and in apogee, and along with this its disturbing force upon the earth will be greater in proportion to its quantity of matter.

In the case of superior planets, the perigee will be in or near the opposition, or when they come to the meridian at twelve o'clock at night, and the apogee near the point of their conjunction; and the difference of distance and apparent diameter will vary in successive appearances at each of these points, according to the part of their own orbits in which they are then situated. But the *minimum* or shortest possible distance from the earth in perigee will take place when the earth is at that time in aphelion, and the planet in perihelion. The greatest distance will take place when the earth and planet are both in aphelion at the time of the planet's conjunction with the sun. The distance of the earth and superior planet, when the latter is in perigee, is the difference of their radii vectores, and it is consequently least when the earth is in aphelion and the planet in perihelion at the time; and the distance when the planet is in apogee is the sum of their radii vectores, which is, of course, greatest when both planet and earth are in aphelion at the time. The smaller the orbit of the superior planet, the greater must the radius vector of the earth be in proportion to the planet's radius vector, under all circumstances; the superior planet which has the smallest orbit is the one nearest to the earth, and consequently that one has the greatest change of apparent diameter, and also, in proportion to its quantity of matter, must produce the greatest disturbance in the orbit and motion of the earth.

There is one thing, however, which we must bear in mind when we consider these disturbances, and that is the diminished rate of absolute motion in any revolving body as the dimensions of its orbit are greater. The velocity which enables the planet to resist the gravitating influence of the sun, must also enable it to resist the disturbing action of the gravitation of any other planet; and because gravitation is mutual and reciprocal, when any body is in that state in which it best resists the disturbing influence of other bodies, it also has the least tendency to disturb them. We have already explained how it is at the point where a planet is nearest to the sun, that it, as it were, breaks away from under the control of that luminary, and passes from the minimum circle, which has the perihelion distance for radius, into the ellipse; and also how it is in the point where the planet is at the greatest distance from the sun, that the gravitating influence of the sun brings it back again to the ellipse from the maximum circle in which it is at the moment of the aphelion. This arises from the increase of the orbital motion in perihelion being greater in absolute lineal space than the change in the length of the radius vector.

But at the aphelion the circumstances are reversed, and the body is thereby rendered more unstable in that part of its orbit than it is in those parts which are nearer to the sun. This difference of stability toward the two extremities of the major axis must increase with the increase of the eccentricity. To use a homely expression, the radius vector is always a sort of *lever* upon which any disturbing force on the body is always exerted, and any increase of this lever purchase must give the same disturbing force more effect. Hence it is easy to conceive that the action of a large planet upon a small body which had a very eccentric orbit, and were in a distant part of the system, might not only change the eccentricity of the ellipse in which the smaller body moved, but, by drawing it from the plane of its elliptic orbit, change that orbit to a parabola the one way or to a hyperbola the other.

The circle, which we may call the primary figure, is the section of a cone by a plane at right angles to the axis. The least obliquity in the section turns the circle into an ellipse, and as the obliquity of the section is increased, and the eccentricity increases along with it, there is but one way of passing from the circle to the ellipse; but there are three several ways in which the elliptic motion may be disturbed. First, the eccentricity may be extended till the foci are in the very extremities of the axis, and if this should happen in the case of a central and revolving body, it is perfectly evident that they would unite together, never again to be separated. This would be the ultimate effect of the disturbance of another body acting constantly as a retarding power: and if the periods of two planets were so adjusted to each other as that their conjunctions took place always in the same part of their orbits, this catastrophe would inevitably happen to the one nearest to the central body, after a longer or shorter period, according to circumstances. In this case there would be compensations, or means of return for the disturbed planet, in proportion as the number of its revolutions exceeded those of the other; but whatever the number were, if there were one point of perfect orbital coincidence at the conjunction, the days of the same planet would be numbered. They might be years, or centuries, or thousands of centuries, according to circumstances; but still the end would be sure. Such a catastrophe, in every *planet* with which we are acquainted, is prevented from taking place by the simple fact of the periodic times of all the planets being incommensurable, that is, so apportioned to each other as that their conjunctions never happen twice in exactly the same parts of their orbits. It is probable, however, that some of the comets which move in very eccentric orbits, go this way piecemeal, as they pass their perihelion,—that is, that notwithstanding the vast rapidity with which they then move, the sun lays hold of a portion of their substance every time they pass; for substance it must be, in as much as the planets lay hold of them, in the more distant parts of the system: and we know that the gravitation of matter can lay hold of nothing but the gravitation of other matter.

This retardation, by increasing the eccentricity, diminishing the circumference of the curve, and weakening the motive force, necessarily renders the quantity of motion in an equal time smaller, and thus the major axis, and with it the periodic time, are diminished, though much more slowly than the eccentricity is increased. On the other hand, the exterior or disturbing planet has its motion as much accelerated, as that of the disturbed one is retarded; and thus the motion which is lost by the one may be said to be gained by the other. The consequence of this will be a lessening of its eccentricity, a proportionally small increase of its major axis, and also of its periodic time. Generally speaking, all the planets with which we are acquainted have their orbits and their periods so adapted to one another as that these variations are not permanent but secular, that is, they are counteracted or compensated at the end of periods of time varying in length according to circumstances, though it is possible that, in consequence of the disturbance of those without them, the orbits of all the planets are decreasing at an exceedingly slow rate, a rate so slow as that it would not make any material change of the system in any period of time to which we can give a name. The other limit of the ellipse, as opposed to the straight line, is the circle; and if we could suppose the most distant planet of a system to drive all the others, one by one, to the central body, we may suppose that this last of the planets would have a circular motion until some body from a more distant part of the universe should approach it, and again change its motion to an elliptic one. This, however, is pure speculation, which the reader, who is fond of such subjects, can pursue without our assistance.

The second change of the ellipse may be considered as that which at once affects the eccentricity and the plane of the orbit, so as to make the plane parallel to the opposite side of the cone, the turning point being the upper focus of the ellipse. The third change is that in which a disturbing force may be supposed to act on the other side of the plane of the orbit, and, turning it round in the upper focus as before, bring it to a situation parallel to the axis of the cone. The path in the first of these cases would be a parbola, and in the second it would be a hyperbola. We can hardly suppose a solid planet, or even a comet, unless its orbit had great eccentricity, to be subjected to such an orbital change as this; but in the case of comets in very eccentric orbits, such a change is not impossible, neither is it altogether unlikely. We know that the distant planets, which, like bashaws of remote provinces, exercise complete dominion in proportion as they are remote from the general influence of the central sun, have very materially altered the orbits of some of those flimsy wanderers; and as the orbits of comets are variously, and some of them greatly inclined to those of the superior planets, it is very natural to suppose, and difficult not to suppose, that some positions of the comet and the planet may, indeed must, occur in the course of time, capable of changing the plane of its orbit, either to the parabola or the hyperbola, according as the disturbance turns the plane one way or the other. But the disturbing force which shall do this has a limit; for if the deflection is beyond parallelism to the side of the cone in the case of the parabola, the orbit will pass through the parabola to a reversed ellipse, that is, an ellipse with its inclination changed to the other end of the axis; and in like manner, if the change is beyond parallelism to the axis in the case of the hyperbola, the orbit will pass through the hyperbola, either into a reversed parabola, or through that into a reversed ellipse, according to circumstances.

If the change to the parabolic or hyperbolic orbit is brought about while the comet has passed its perihelion, and is receding from the sun, the comet will, in either case, be launched into the regions of space, to return no more to the system from which it is discharged, unless a similar catastrophe, in some new abode, should turn it back with a velocity sufficient to make it regain its former station. On the other hand, if the change took place while the comet was advancing to the perihelion, it would make one more visit to the sun or central body; but that visit once made it would return no more. Some comets have been observed moving in each of these three descriptions of curves, though the ellipse is the one of most frequent occurrence, and the only one in which the return of a comet can be protected. Even in this case the prediction is not absolutely certain, as the orbit and period may be changed, or even the former may be altered to a parabola or hyperbola on the retreat from the sun, and when it is beyond the reach of our observation.

We have made these allusions to comets, because they, being the most unsubstantial of the heavenly bodies with which we are acquainted, are the ones on which the disturbing influence of planetary gravitation is most conspicuous, and as they show at least one way in which different parts of the system may communicate with each other, or how those lighter bodies may pass from one portion of the universe to the other, changing from system to system, as they have been sometimes ascertained to change from orbit to orbit round the same central body.

We are now prepared to give some account of the means by which the relative weights of the heavenly bodies are known, as one step toward the ascertaining of their comparative densities and absolute quantities of matter. This may be done by attending to the disturbing influences which any two of them produce upon a third; but the most simple and easily explainable means is that of a planet which has a secondary or satellite revolving round it, and there is no better case than that of the earth and moon. It is true that, owing to the various causes, the motions of the moon are very irregular, but that body is so near the earth, and its parallax, as seen from the earth, so much more accurately determinable than that of any other known satellite as seen from its primary, that it answers best for common illustration.

If we consider the moon in the opposite points of its orbit—the opposition to the sun and the conjunction with that luminary, we can easily understand that the distance from the sun will be less, and the gravitation towards the sun greater in the conjunction than in the opposition, and that the joint attractions of the sun and moon act upon the earth at that time, while they oppose each other at the opposite part of the orbit. We may consider the centre of gravity of the earth and moon jointly—that round which the moon really revolves as performing a revolution round the earth, at the same average rate as if the whole matter of the two were converted into that point;

and therefore the only effect in the opposition and conjunction of the moon will be that, in the former case, their common centre will be a little farther from the sun, and in the latter a little nearer. Now, if we suppose the mean distance of the moon from the centre of the sun, and also from the centre of the earth, to be known, and they may be found in the manner hinted at in the former part of this section, we have, according to the law, the squares of the periodic time of the two in the proportion of the cubes of their mean distances. Now, as the forces (the resulting forces) have the same proportion to each other as the distances divided by the squares of the periodic times, and also to the masses or quantities of matter divided by the squares of the distances, we have the proportions of the masses as the cubes of the distances divided by the squares of the periodic times.

Therefore, if we multiply the sun's distance from the earth twice by itself, and divide the last product by the days and parts of a day in a siderial year once multiplied by itself; and also divide the product of the earth's distance from the moon, twice multiplied by itself, by the length of the siderial revolution of the moon, in days, multiplied once by itself, we obtain two numbers, which are not indeed the absolute weights or quantities of matter in the sun and earth, but which express the ratio or proportion of those weights to each other. These numbers, obtained from the distances and periods taken on the average, and which are easily found by observation, are, in a rude and easily remembered estimate, about 355,000 for the sun, and one for the earth,

—the number, by the nearest approximation to the true average distance, is 354,937; but the other number is more easily remembered, and it is sufficient for giving us an idea of what a gigantic body the sun must be—it is equal in weight to about three hundred and fifty-five thousand earths of the same weight as that which we inhabit.

The mass of every other planet which has satellites may be determined upon principles exactly similar, only, in the case of remote planets, the distance of the satellite from the primary is not so easily obtained with accuracy as that of the moon from the earth; and in the case of several satellites at different distances from the primary planet, the difficulties are increased; so that, in the case of them, the disturbances are more accurate, though, as they depend not upon the mean distances and periodic times, but upon the alterations of place and velocity which are occasioned by the approach of the two planets to each other, they require very nice observation in order to find the true places.

When the true places, as observed, are found, we have to compare them with what would have been the places of both at the instant of observation, if there had been no disturbance; and from this comparison we find how far each has deviated from the place it would have held; and these deviations, when cleared of the action of any other force to which the bodies may be unequally subjected, will be inversely as their masses or quantities of matter.

When the magnitudes or quantities of space which the bodies occupy have been found by the methods of mensuration formerly stated, and the masses or quantities of matter have been determined as now explained, the next step is to find the relative densities or average quantities of matter in equal bulks. This is directly as the quantity of matter, and inversely as the space which that matter occupies, that is as the bulks or magnitudes. Now when any quantity is directly as one element and inversely as another, we obtain the relation or ration of its value by dividing the direct element by the inverse one; therefore, if we divide the mass or quantity of matter in each body by the magnitude or volume of the body, we shall obtain a set of numbers expressing the relative densities, or, as we sometimes call them, the *specific gravities.*

It is of no consequence in what unit or denomination the masses and volumes of the bodies are stated, provided that the denomination is the same in the case of them all; and the volume and mass of the earth are perhaps as convenient as any others.

When the magnitudes, masses, and densities, or, which is the same thing, their relations to each other are once obtained in the manner which has been stated, there is only one other step necessary in order to put the whole into the scale, and ascertain their weights in any one unit or denomination, in pounds or tons for instance, as easily, and in proportion to their bulks much more accurately, than we can weigh large portions of matter in the usual way.

This may seem singular, but it is nevertheless perfectly true; for if we could take our measures with perfect accuracy, we should be able to weigh the sun or the moon to greater nicety than we could a large bale or hogshead. The reason is, that our common balance—the scale-beam on which we weigh large weights—cannot be perfectly made; and though it could be brought to the greatest degree of perfection than human skill can employ, there is a source of error in the using of it. If we have a ton to weigh, we must put a ton of weights into one scale, and a ton of the substance to be weighed into the other; and if the scale with the weights is on the ground when we begin to load the other scale, we shall find that, however fine the axis of the beam may be, some quantity is required to start the scale, over and above the exact law which would hold the beam in equilibrium, with both scales at exactly the same height. In this process, we are under the necessity of having one hard substance turning upon another, and the substances are pressed together by the weight of two tons, besides that of the beam and scales. Whatever is the nature and polish of the substances, this will cause a great deal of friction, or rubbing of the one upon the other, so that a few ounces either way will not be sufficient to turn the beam.

But in the case of the heavenly bodies there is no friction. The balance is the force of gravity itself, and therefore it is true and delicate down to the ultimate atom, and consequently the weight which we use may be anything—an ounce or even a feather, if we know that there is nothing to affect it but the force of gravitation alone. It must be admitted, however, that though we have the balance perfectly true, in this case we have to contend with all the imperfections to which the application of the measuring line is subject; and as we can obtain the length of long lines only by considering them as multiples of short ones we carry the error along with as multiplied in the same proportion. But in this little work we have to do with principles only, and not with the accuracy or inaccuracy of practical operations.

The principle here to be found is, how do we know the density of the earth—that is, the number of pounds which an averge solid foot of all the matter in its solid mass, and all the liquid on its surface, contains, and which we, in a former section, stated to be about 2½ cwt.

It is perfectly clear that there can be no true analogy except between quantities of the same kind, and upon this principle, to which there is no exception, we can have no means of knowing the absolute density of the earth, except by comparing it with some other body of which we do know the absolute density. The disparity between any body which we can practically determine in this way, and the earth itself, is so very great that, at first sight, it might seem that we could institute no accurate or even useful comparison between them. But the very gravitation, the intensity of which we are seeking, assists us here. The variation being as the squares of the distances, enables us to place the smaller body so near to that which is to be the means of weighing this smaller body against the earth, that the gravitation of both can be observed.

The observation is made by means of a plummet, and some portion of matter of which both the weight and the specific gravity are known, or, which is the same thing, can be obtained;

and the best position of the plummet and this body is, when they have their centres of gravity at the same height, because then the directions of gravitation of the plummet to the earth, and to the body used in the experiment, will be at right angles to each other. When the experiment is made with a body truly suspended, the weight of that body should be so great as not to be drawn sensibly out of its place by the reaction of the gravitation of the plummet.

This very naturally brings us back to the plumbline and the mountain, to which we, at page 131, alluded as a simple means of observing the change of the force of gravity accordant with change of distance. But in the present case we must have recourse to some particular mountain, of which the magnitude can be measured, and the specific gravity ascertained by means altogether independent of the experiment; for we are not seeking the relative weight of the earth, but its absolute weight, and we can obtain this only by weighing it against a body, the weight of which is known. It is true that what we call an absolute or known weight, and to which we give a name, as a pound, or any number of pounds, or parts of a pound, is only a pressure, a phenomenon of a piece of brass, iron, or other matter which we call a weight, and not the piece of matter itself. It is in fact only a relation; but it is a definite relation, applicable alike to all kinds and qualities of matter, when they are at the same distance from the centre of the earth, or of any other centre toward which they all press, by means of their gravitation.

On this part of the subject we must not, however, conceal that there is much taken for granted, and that if the experiment were made in different places, it is probable that the results would not correspond. The earth is not a perfect sphere, but a spheroid, having its axis of rotation about twenty-two miles shorter than its equatorial diameter, and this departure of its figure from that of a true sphere must, independently of any other circumstance, prevent the lines of zenith and nadir, which are also the directions of terrestrial gravity at the points to which they answer, from meeting each other in one point or the common centre of gravity of the whole. This deviation from the spherical form is general, that is, it applies to the whole circumference equidistant from both poles, and analogy leads us to conclude that it is gradual from that circumference to the poles themselves; and therefore it can be ascertained and estimated for at any place on the surface. But there may be, and probably are, other sources of error which are local, and of which we are unable to take any estimate. We must suppose that the general centre of gravity of the earth, considered as one whole mass, is in the axis of its diurnal rotation, and also that it is so situated in the axis as that the portions toward the two poles balance each other; and farther, as in the lines of the great oceans the surface is covered with water from pole to pole, which water, from its liquidity, accommodates itself exactly to gravitation at all points, without any mechanical assistance, we must suppose that the figure of the earth, taken altogether, is the same that it would be if the whole were a liquid substance of the same density;—but still, as the materials of which the mass of it is composed are, at least in so far as we know them and can guess at them, of different specific gravities; and as there *may* be, in the volcanic districts, especially, internal cavities, in which the expansive heat is an efficient resistance to gravitation, and yet has in itself no gravitating power, we must conclude that there are many deviations of the zenith and nadir line on the surface, from the line which passes through the centre of gravity. The depth to which the substance of the earth has been penetrated is so mere a trifle, in comparison with the length of its radius, that it tells us nothing upon these points, and thus we must regard them as sources of error which must remain for ever unknown to us, and therefore we can refer to them only as causes which must render our estimate both of measure and weight doubtful.

Bearing these indeterminate sources of error in mind, we are to consider the mountain as the weight which we employ in weighing the earth. We find its measure, that is, the number of solid feet, yards, or any other known units that are in it, as accurately as we can, and we find in the same way its average specific gravity, or the number of pounds, or any other unit of weight in a solid foot. These are only approximations, and from the nature of the case they cannot be very accurate ones, but from them we obtain approximations to the absolute weight of the mountain, and also to the specific gravity, or the relation of the weight to the bulk. These being obtained, the distances of the affected plummet from the centre of gravity of the mountain, and the centre of gravity of the earth, become the two arms of our balance.

As the attraction of the mountain is understood to be at right angles to that of the earth, it is evident that the intensities of the two must be to each other as the sine and co-sine of the deflection of the plumbline from the perpendicular. This will appear obvious, when we consider that the sine of the angle of deflection is the measure of the extent to which the plummet is drawn from the direction of the earth's centre of gravity by the mountain, and the co-sine the extent to which it is drawn to the earth's centre. The attraction of the mountain is very small, compared with that of the earth, being, by observation, about one to ten thousand; but they balance each other, and they are inversely as the squares of the distances from the centres of gravity, and the density of the mountain to that of the earth is, in round numbers, nearly five to nine, or, if the mountain is supposed to be composed of rock, equal to two and a half times the weight of an equal bulk of water, the earth is, on the average, about four and a half times the density of water.

The result obtained by the late Mr. Cavendish, from weighing leaden balls against the earth, by means of a very delicate apparatus, is different from this, giving the earth an average specific gravity of rather less than five and a half times that of water, and from the weights of the balls being exactly known, and the experiment repeated a number of times with very great care, it is probable that the above result, which is the average of the whole, is nearer the truth than that obtained from the mountain, although it would be desirable to have this last experiment repeated with the improved instruments of the present time.

The statements given in this section point out the principles according to which the heavenly bodies are measured and weighed, rather than the details of the operations; but if the reader has attended carefully to them, he will be able to see that our estimates, even of these great masses of matter, depend upon the very same principle which we make use of in measuring and weighing common substances upon the earth's surface;—that, in fact, the whole of our accurate knowledge rests on the same foundation, and proceeds upon the same principles, whether it be limited or extended, whether confined to those bodies or portions of matter which are tangible to our immediate examination or to those of which our only informant is the light coming from vast distances in the regions of space. With this preparation, and with that contained in the preceding sections, we shall be able, profitably, to examine the aspect of the heavens.

SECTION X.

SYSTEM OF THE HEAVENS.

Though the only portion of those countless bodies which adorn our sky, that we can measure and determine, are those which revolve round the sun, as their common centre of gravity, and to which we, on that account, give the name of the solar system, yet the more remote ones, which are blended in one apparent distance hitherto unmeasurable, by any means that we have been able to employ, are the foundation or ground-work upon which the appearances of the others are, as it were, "mapped down" to our view. Hence, when we make a miniature picture of the apparent heavens, whether it is delineated on the external surface of a smaller sphere, forming what we call a celestial globe, or reduced to a plane, and forming a celestial map, it is the stars only which we mark upon this miniature as permanently fixed points; and when we wish to point out the place of any body which has motion, we determine that by its angular distances.

These angular distances, considering them with reference to the earth, may be estimated in two ways; first, in terms of the plane of the axis of the earth's rotation, or of a plane at right angles to that, and either of them understood to divide absolute space into two equal parts; and secondly, the plane of the orbit of the earth's revolution, and another plane at right angles to that, either of which divides the whole of space in the same manner, though not in the same direction as the former. But the positions of all these planes, traced on the apparent sphere of the heavens, are great circles, in consequence of each of them dividing the whole of apparent space into two equal parts, and that space being necessarily the same in the case of all of them. Hence, at whatever angles they may lie to each other, each of them will divide every other into two equal parts, and be so divided by it; and, as viewed from the earth's centre—and as the stars have no parallax, viewing from the surface of the earth will have exactly the same effect as viewing from its centre—their apparent diameters will all bisect each other there.

The plane of the earth's rotation is the direction of its axis, and it was mentioned that the axis has some variations of position, which of course affect, to an equal extent, everything which depends upon it; but the earth turns round on this axis, and therefore its plane—that is, any one plane passing through it and through any fixed point on the earth's surface—is directed successively to all parts of surrounding space in the course of a revolution. This plane is the *meridian*, and its positions are as numerous as we can suppose the points taken round the earth to be, though in all cases it remains true to the plane of the axis.

A plane at right angles to the axis, and dividing it into two equal parts, is the *equatorial plane;* where it cuts the surface of the earth is the *terrestrial equator;* and where it marks the circumference of the apparent sphere of the heavens, it is the *celestial equator.* These, and indeed all circles, contain 360° in their entire circumference, 180° in the half, 90° in the quarter or quadrant, and so in proportion; and those degrees are also the angular measures at the centres. Thus, whether on the earth or in the heavens, there are always 180° between the intersections of two great circles, whatever may be the angle of their planes; and if we measure from one point of any great circle to the opposite point the extent is 180°, and the half of it 90°, or a quadrant; 90° from a great circle or a sphere is equally distant from the whole circumference of that circle, and a point so situated is called the pole of the circle, whether it happens to mark the termination of an axis of rotation or not, because if we imagine a straight line to be drawn through this point and the centre of the circle, the circle might be supposed to turn upon that line as an axis, without in any way altering its position. Thus, the poles of every imaginable meridian are somewhere in the equator, but as each of them tells successively upon the entire circumference of the celestial meridian in the course of a single rotation, not one of them can have a fixed point answering to it in the heavens, or a point at all determinable by observation; but we can calculate when any meridian or its pole must be presented to two celestial bodies that change their relative places, when they are at a certain apparent angular distance from each other, as seen from any point on the earth's surface; and this brings us to the problem of the longitude, which is nothing more than the angles made at the earth's axis by planes of different meridians, and of which the circular measures are expressed by portions of the earth's equator answering to the angles of the planes, one degree being very nearly seventy common British miles; but as the celestial equator is beyond the limits of measurable distance, a degree or any other portion of it is not expressible in any definite measure. With fine instruments, angular measures can be taken perhaps the tenth part of one second, of which a degree contains 3,600, and as the earth's orbit has not even this small parallax at the apparently nearest star, the length of one second of the celestial equator, or of any great circle of the celestial sphere, cannot be less than 3,420,000,000,000, and may be many times that amount.

Celestial distances from the equator are called *declinations;* they begin at 0° at the equator, and extend to 90° at each pole. Celestial distances measured on the equator are called *right ascensions*, and they are reckoned from the point where the ecliptic cuts the equator in passing into the northern hemisphere, and estimated from this point round the whole circumference to 360°; the opposite point, where the ecliptic cuts the equator in passing from the northern hemisphere into the southern, being half the circumference distant. The degrees of the equator and ecliptic coincide at these points, and also at the middle of the quadrants half way between them; but in every other position, circles which are at right angles to the equator divide the ecliptic unequally.

The angle of the planes of the ecliptic and equator is, in round numbers, 23½°—or more exactly at present 23° 28′; and of course every circle which has reference to the ecliptic makes the same angle with every corresponding circle having reference to the equator. Thus, the poles of these two circles are distant from each other by an arc of the circumference of the heavens equal to the obliquity.

The celestial meridians all cross each other in the poles of the ecliptic, and also cross the ecliptic at right angles; and in fact all the corresponding circles of the sphere which are referred to the ecliptic, have exactly the same relative magnitudes and relations to each other as the ones which are referred to the equator. These circles represent exactly the same sphere, only the axes are inclined at the angle above mentioned. Celestial latitudes begin at 0° at the ecliptic, and extend to 90° at the poles of that circle; and celestial longitudes begin at the point where the ecliptic cuts the equator in passing into the northern hemisphere, and they are reckoned from 0° at that point to 360° at the same point after a complete revolution. For the convenience of remembering numbers, the ecliptic is divided into twelve signs, of 30° each,—these being begun at the point of intersection above alluded to, and reckoned eastward, as that is the direction of the apparent annual motion of the sun, and consequently of the real motion of the earth. Six signs of the ecliptic lie on the north side of the equator, which have the names of Aries, Taurus, Gemini, Cancer, Leo, and Virgo, given to them—the first point of Aries being the commencement of the celestial reckoning, or the astronomical year; and the remaining six, to which the names of Libra, Scorpio, Sagitarius, Capricornus, Aquarius, and Pisces, are given, are situated on the south of the equator. It must be understood, however, that this is spoken with reference to the apparent place of the sun, which is directly opposite to the real place of the earth; and that therefore, while the sun appears to decline northward of the equator, the earth really declines to the same angular distance southward; and when the sun appears to decline southward, the earth really declines as much northward. The northern signs are thus, in reality, southern signs, and the southern signs northern.

As the earth's orbit makes an angle of 23½° (23° 28′) with the plane of the equator, and as this plane is at right angles to the axis of rotation, it follows that the inclination of the axis to the plane of the orbit must be the difference between this and a right angle, or 66½° (66° 32′). This inclination is to the major axis of the orbit, the extremities of which are the points of perihelion and aphelion; and as the axis of rotation, except for the disturbances already mentioned, retains the same inclination to the major axis, or continues parallel to itself during the whole revolution, it must make all angles with the radius vector on the side toward the sun, from 113° 28′, at the one extremity, to 66° 32′ at the other.

This is not the proper place for explaining the variations of season and climate which result from this obliquity of the earth's axis, estimated on the plane of the major axis of its orbit; but still some notion of the general principles is necessary to a right understanding of the celestial system, the more so that all the bodies of which that system is made up apparently derive their light and heat, the grand agencies in the production of local motion, and growth, and life, in a manner similar to what we observe on the earth. Therefore, if the reader will turn to the VIGNETTE on the title page, a very few words of explanation will enable him to understand the general cause and phenomena of the seasons.

We must bear in mind that it is position only, and not proportional magnitude and distance, which is shown in this figure; for as the earth's diameter is only about $\frac{1}{12000}$ part of its mean distance from the sun, the size of the earth would not be a visible speck, even if the full length of our page had been taken for its proportionate distance. This being understood, the body with rays, in the centre of the vignette, represents the sun, the very faint ellipse, which crosses the vignette obliquely, represents the earth's orbit, shown as it would be seen laterally, by an eye elevated a little above its plane; the mottled body which is shown in three positions, represents the earth, and a fourth position of it may be considered as concealed behind the body of the sun. If this last position is understood, we shall have the earth in those four points of its orbit which correspond to the perihelion, aphelion, and the two mean distances intermediate between these on each side of the orbit. Toward the top of the paper is to be considered as north, toward the bottom as south, the reader's right hand as east, and his left hand as west; and these positions are considered to be as constant throughout the whole revolution, from any point of the orbit to the same point back again,—the axis of rotation remaining constantly parallel to the sides of the page and the earth's equator, and also every circle of latitude upon the earth parallel to the equator remaining as constantly parallel to the sides of the same. The major axis may be supposed to pass through the body of the sun, from the centre of the earth at the extreme position to the left, to the same at that to the right. The angle which this makes with the top or bottom of the page, or with any line parallel to them is the obliquity of the ecliptic to the equator, and the angle which this makes with the side of the page, or with any line parallel to the side, is the inclination of the axis of rotation to the major axis of the orbit. The sun is understood to be in the focus; the position to your right is the perihelion, and that to your left the aphelion; and the intermediate position, as visible between the reader and the sun, and also that concealed behind the luminary, are the points of mean distance. The motion in the orbit is from your left to your right in the half nearer than the sun, and from right to left back again in the other half. If we are to imagine three planes, all parallel to each other and to that of the earth's equator, to pass through the lower, the mean, and the upper positions, the distances of these planes from each other would be to the mean distance, as sine 23½° to sine 90°. This will make a parallel distance of about 76,000,000 miles between the planes of the perihelion and aphelion distances. In other words, the real declination of the earth, or the apparent declination of the sun, northward of the celestial equator, during one half of the year, and southward during the other, is about thirty-eight millions of miles. But this change in declination occasions no difference whatever in the apparent places of the stars, for even the 190,000,000 miles of the whole axis of the orbit occasions none. It does, however, tell upon all bodies which have a parallax, and it tells upon them inversely as their distances, their apparent declinations being in the direction opposite to that of the earth; for instance, the sun has exactly the same apparent declination to the one side of the celestial equator that the earth really has to the opposite side; bodies which are nearer to the earth than the sun is will have more apparent declination, and those which are more distant will have less, than the real declination of the earth; but in all cases the observed declination of the body will be in the opposite direction—that is, on the opposite side of the celestial equator.

The mean position of the earth, as concealed behind the body of the sun in the figure, answers to the vernal equinox in the northern hemisphere of the earth—that is, the sun, as seen geocentrically, or from the centre of the earth, appears to be in the beginning of the celestial longitudes, or in the first point of Aries, as told upon the ecliptic among the stars; and the earth, as seen heliocentrically, or seen from the centre of the sun, appears to be in the opposite point, or the first point of Libra, as told on the position of the ecliptic among the stars in the same manner. In this position the sun has no apparent, because the earth has no real, declination; and therefore, for the day, the sun will appear to revolve in the celestial equator, or perpendicularly over the equator of the earth; and therefore, as the light of a body so large and so distant as the sun is, may be regarded as coming in parallel lines, and therefore illuminating exactly a hemisphere of the earth, the light will, during the whole apparent diurnal revolution of the sun, or real diurnal rotation of the earth, extend as far as both poles of the earth's rotation, but not beyond either of them; and therefore day and night will at this time be exactly equal all over the earth. As the radius vector is the line joining the centre of the earth and sun, it is evident that the centre of the illuminated hemisphere must always be the point where it meets the earth's surface on the side next the sun; and that if we suppose it to be continued to the other side of the earth, it will mark the centre of the dark hemisphere. The position of the radius vector thus determines the length of day and night in all latitudes. It is true that, in consequence of the refraction of the atmosphere, of which some account has already been given, and which causes any luminary near the horizon to appear higher than it really is, the duration of absolute sunshine will, in every latitude, be longer than it really is as depending upon the position of the earth and sun; and consequently it will be a little longer than not only the time of absolute night, but than that together with the twilight of morning and evening.

In this position, the radius vector, or line joining the centres of the sun and earth will be at right angles to the axis of the earth's rotation; and as, from the entire declination of the earth both southward and northward, vanishing, or being equal to 0, at the distance of the stars, the earth, as estimated from them, will appear to move always in the direction or plane of the celestial equator, the declination at other times will be expressed by the deviation from a right angle of the radius vector and axis of rotation. During the first quarter, the earth will continue declining southward, and the sun apparently declining northward, until at the end of the quarter, or position toward the reader's left hand, the earth will have gained its maximum of real declination south, and the sun its maximum of apparent declination north, exactly equal to that of the earth, because measured by it. The radius vector will, in this case, be inclined to the north pole, and from the south, by the whole amount of the apparent declination, or obliquity of the ecliptic; and thus the sun will, for the day, appear to revolve round the earth perpendicularly over the parallel of $23\frac{1}{2}°$ (23° 28′) of north latitude, or the radius vector will appear to travel along that parallel in the course of the day. In this case, the illuminated hemisphere which apparently travels round the earth, with the radius vector in its centre, and its circumference everywhere 90° distant, must extend $23\frac{1}{2}$ beyond the north pole during the whole rotation; and, for the same reason, it must be during the whole rotation, $23\frac{1}{2}°$ distant from the south pole. Hence, when the earth is in this real, and the sun in this apparent, position, circles, or circular segments, of the earth's surface, each of the same magnitude—$23\frac{1}{2}°$ radius—must have no change of light and darkness during the twenty-four hours, but the one of which the north pole is the centre must have continual day, and that of which the south pole is the centre continual night.

But as the earth's equator, and the circumference of the illuminated hemisphere are both great circles, they must divide each other into equal parts: and therefore, at the earth's equator, day and night will (making allowance for refraction) be always equal: and the only difference in the apparent daily course of the sun there, will be, that at noon it will be distant from the zenith by the exact amount of the apparent declination for that day.

This point of greatest apparent declination of the sun northward, or of real declination of the earth southward, and which, as we have already said, is the lower apsis of the earth—its aphelion or greatest distance from the sun, the point at which its velocity changes from a retarded to an accelerated motion, and so returns to the ellipse, after an instant of circular motion at the point—is called the *northern solstice*, because it is the utmost limit of apparent declination northward, at which the sun apparently "stays," or pauses, before it returns back again to the equator, which it does during the quadrant of the orbit which lies between the extreme point toward the left and the mean point at which the earth is represented in the figure, as being between the reader and the sun.

This latter point is the autumnal equinox to the northern hemisphere; the sun, as seen from the earth, appears in the first point of Libra, and the earth, as seen from the sun, would appear in the first point of Aries. In this state of things, the sun again appears for the day to have no declination, but to perform its daily revolution perpendicularly over the earth's equator; and light and darkness except for the refraction, divide the twenty-four hours equally in every latitude.

After this point is passed, and the earth careers onward, still from left to right as seen in the figure, it gets to the northward of the plane of its equator, as told upon any body at a measurable distance, and consequently the sun begins to have apparent south declination. This goes on increasing, till the earth has arrived at the extreme position toward the right hand in the figure; and at this position, its real declination, and consequently the apparent declination of the sun, is of the same amount as it was on the opposite extremity of the axis, but it lies in the other direction—really northward in the earth, and apparently southward in the sun. Its amount is, as before 23½° (23° 28′); and the light and dark segments are of the same measure as they were formerly, but they are reversed, as regards the poles, the dark one being now at the north, and the light one at the south. Of course it is now midsummer in the southern hemisphere, and midwinter in the northern; and the point of mean distance last arrived at, or at the commencement of the quadrant which ends in the extreme northerly position of the earth, is the vernal equinox to the southern hemisphere, and the autumnal one to the northern.

The position to the extreme right, which is the most northerly one in real declination of the earth and apparent declination southward of the sun, is the upper apsis, or point of perihelion, at the extremity of the major axis of the earth's orbit; and from this point, at which its motion changes from an accelerated to a retarded one, it passes over the remaining quadrant, with its declination northward, and the apparent declination of the sun southward, gradually diminishing, until it arrives at the mean position behind the sun, from which we began our examination of it. When it arrives there a complete revolution has been performed, and a new one begins, and the succession will continue while the earth remains part of the system.

From what has been said, it will, we trust, be readily perceived that, for ordinary periods of time, both the plane of the earth's equator, and that of its orbit, or the ecliptic, tell, or are traceable, in the very same position among the stars; and that thus, the annual changes of declination, whether as real in the earth or as apparent and opposite in the sun, may be considered as deviations from a plane passing through the equinoctial points of the ecliptic, and at right angles to the axis of the earth's rotation, during the whole course of the year, or revolution in the orbit. Viewing matters in this light, we may say, that when the plane of the earth's equator coincides with this mean plane of the orbit, the light of the sun falls with equal effect upon both hemispheres of the earth, but with different effects upon the different latitudes of those hemispheres, which are upon lines as the co-sines of the latitudes, and consequently upon surfaces as the squares of these co-sines. These effects are, however, so much modified by local causes, which belong to the earth itself, and not to its relations with the heavenly bodies, that even though our space admitted we could not with propriety introduce them here.

The axis of the earth's rotation is at all parts of the orbit perpendicular to this medium plane, and consequently the plane of the earth's equator is always parallel to it. Thus, when the earth has declination either way, we may say that the hemisphere of it which is at the greatest distance

—the northern when the declination is north, and the southern when it is south—declines away, or recedes from the influence of the sun. The maximum of declination southward, when the earth is in aphelion and it is midsummer in the northern hemisphere, is exactly equal and opposite to the maximum of declination northward, when it is midwinter in the northern hemisphere, and the earth is in perihelion. The diminution of solar influence upon the whole of the hemisphere which declines away from the mean plane, may be rudely estimated as being as the square of the sine of the declination. The maximum declination is about 23½°, and the square of its sine to the square of radius, the latter being reckoned 10, is as 16 to 100 nearly. Therefore, if we call the influence of the sun at the equinoxes, where it is equal upon both hemispheres, 100 for each, the relative proportions for the summer and winter of either hemisphere, taken as a whole, will be 116 for summer, and 84 for winter, the difference of these extreme seasons being 32, or 32-100ths, nearly one-third of the mean.

But though the major axis passing through the apsides, the points of extreme variation of seasons in the two hemispheres, divides the year equally, the same is not the case with the axis of the equatorial points; for the earth moves faster when near the perihelion than when near the aphelion: and therefore the summer half of the year, from equinox to equinox, is rather longer than the winter half in the northern hemisphere, and rather shorter in the south.

The motions of the earth, the rotation on the axis, the revolution in the orbit, and the disturbances to which it is subjected, all have reference to those bodies whose distances, magnitudes, and quantities of matter we are able to ascertain, and not to the stars, which, being beyond the limits of measurable distance, may be supposed to have no more effect upon the earth at one part of its orbit than at another; and though we have no means of ascertaining whether the orbit of the most distant known planet in the solar system, *Uranus*, whose major axis is, in round numbers, 3,600,000,000 miles, or nearly twenty times as long as that of the earth, subtends any measurable parallactic angle at even the nearest star, it is not *very* probable that even it can be much disturbed by siderial gravitation. The intercourse of system with system is carried on through the medium of the centres of gravity of systems which, if we may judge from the case of the sun, and the rest of our system, may be always within the central body. The sun of our system contains very nearly a thousand times as much matter as all the known planets, and this matter is in one mass, while the planets are scattered about in various directions, and always shifting. They could not, if they were all accumulated into one mass, and brought into contact with one side of the sun, occasion any disturbance of that body compared with the disturbance of the earth by the moon. It would not be possible to bring this accumulated mass so near to the centre of the sun as the moon is to the centre of the earth, because the diameter of the sun, estimated by the angle which it subtends, is in round numbers 882,000 miles; so that, if we were to suppose the centre of the sun to be placed where the centre of the earth is, the circumference of the sun would extend every way to nearly double the distance of the moon, or the sun is equal in bulk to more than a million and a third of globes as big as the earth.

The whole of the planets could not be placed in one mass, nearer to the centre of the sun than about three times the distance of the moon from the earth; and therefore, as the sum of all these masses is only a thousandth part of the sun, while that of the moon is a fortieth part of the earth, the destruction of all the planetary motions would not cause above one two-hundreth part of the disturbance in that giant luminary which the moon causes in the earth. Whatever reciprocal attractions may exist between one sun and another, for the mutual support of those mighty bodies, cannot therefore be very much more affected by the attendant planets, than the earth is by those volcanic actions which occasionally disturb small portions of its surface.

Thus, while the sun holds all the planets of the system in firm obedience to the law in the system at home, it preserves them all from the dangers of foreign invasion by other systems, except that, in the manner already explained, a comet may be driven out of one system to another; but, as has been said, comets are unsubstantial and filmy bodies, easily disturbed by the more formidable members of the system, but little capable of disturbing these in return. We may further remark, that this powerful controlling influence of the sun has a tendency to correct and render periodical those perturbations which the planets occasion to each other.

Although, for moderate periods of time, there is no apparent change in the plane either of the ecliptic or plane of the earth's equator among the stars, and though the annual parallel shifting of the latter, of about 75,000,000 of miles, in declination in the course of the year does not amount to a perceptible quantity at the distance of the stars, yet it is obvious that any angular change, which may be produced within the system, will tell to its whole amount in the same manner as the angular motions of the other bodies of the system. In order to see what angular changes, or perturbances, there may be in the case of the earth, we must consider how it is situated, and what connected with it is liable to be changed.

The earth revolves in an orbit, as already described, and rotates upon an axis placed at an angle to the major axis of that orbit. It is attended by one satellite, the moon, containing about one-fortieth as much matter as the earth, revolving —in an orbit making with the plane of the earth's orbit an angle of about 5° 9′, and distant from the earth on the mean about 24,000 miles—in the space of 27 days, 7 hours, 43 minutes, nearly, in absolute revolutions from star to star, as if seen from the common centre of gravity of the earth and moon. The earth is also loaded with an accumulation of matter of rather more than thirteen miles round its equator, and diminishing gradually towards the poles; and though by this means it is perfectly accommodated tothe rotation, the form being exactly what calculation would give; yet an oblique force acting on this accumulation will have some effect on the position of the axis of rotation.

Upon examining the circumstances in which the earth is placed, it will be seen that the ones which admit of being disturbed are, the position of the axis of rotation in absolute space, the position of the major axis of the orbit, the length of that axis, the eccentricity, and the position of the plane of the orbit; and the same circumstances with regard to the orbit of the moon. The axis of rotation, as that motion is peculiar—belonging to the earth only, remains constant to the mass of the earth, and passes through the centre of gravity, on which it is perfectly balanced. The radius vector of the moon, if the moon revolved always over the earth's equator, or if the earth were a perfect sphere, would always pass through the individual centre of gravity of each and the comman centre of gravity of the two, being perfectly balanced on the common centre. The moon's orbit, though nearly a circle, is not exactly so, and it is oblique to the ecliptic by the 5°.9′ above stated, so that the radius vector of the moon may make any angle with the perpendicular to the axis of the earth's rotation, from 0°, to the sum of the obliquities of the orbits, or 28° 37′. Now, if the moon is on the south side of the plane of the earth's equator, the radius vector passing through the common centre of gravity of the two, will, in consequence of the greater diameter of the earth at the equator, intersect the axis of the earth's rotation to the north of the earth's centre of gravity. The effect of this will be to pull the north pole of the earth toward the moon, by turning it upon the centre of gravity, and the south pole of the earth will be, by the same means, turned from the moon. But although there is nothing in the earth's centre of gravity, being a point, to prevent the turning of the axis upon it, it will resist being moved itself, and by this means deflect the moon into a more northerly path, or, in other words, alter the plane of the moon's orbit. When the moon is on the north of the earth's equator, the effect will be reversed. The effect of this, if there were no other body but the earth and moon, would be to give to the moon a sort of undulating motion, by throwing it sometimes to one side of the orbit, and sometimes to the other.

But there is a much more powerful force acting, though its disturbance is but a small part of its general intensity. This is the attractive force of the sun, which, exerted along the radius vector, from the centre of gravity in the sun to the common centre of gravity of the earth and moon, retains both these in their general place in the system. This radius vector forms different angles at different times, both with the axis of the earth's rotation, and with the major axis of the moon's orbit. The disturbing effect of this on the axis of the earth's rotation is very small, but on the moon it is considerable; and as it acts more powerfully when the moon is in the half of its orbit nearest the sun than in the other half, the disturbing force of the earth upon the moon's orbit is thus greatest when the moon is in opposition to the sun, and as this disturbing force tends to throw the moon nearer to the plane of the earth's equator, and consequently to that of the ecliptic which lies between them: the result is, a retrogradation of the moon's orbit, by the major axis turning on the centre of gravity of the earth and moon. As the moon's orbit crosses the plane of the equator both northward and southward, it necessarily also cuts the ecliptic. The points in which it does so are called the *nodes* of the orbit, that in which the moon passes the ecliptic to the north being the *ascending node*, and the opposite one the *descending node*. The orbits of all planets cut the ecliptic in a similar manner, and the same names are given to the nodes of their orbits.

What we have been attempting to give some slight idea of is called the motion of the nodes. The motion of the major axis takes place in about 9 years; and 18 years, 10 days, or 233 lunations, contain the same succession of positions of the earth and the moon to within a very small fraction; and thus eclipses both of the sun and the moon take place in every period of that length, at nearly equal intervals, and nearly to the same extent. There are, however, many minute irregularities, of which it would not be easy to give an intelligible description in popular language.

Every disturbance that takes place in the system of the heavens is reciprocal in its total amount, only it tells more upon the smaller body. We have seen that the axis of the earth's rotation, and the radius vector of the earth's orbit, are both concerned in this disturbance of the moon's motion, and therefore the reaction of the disturbance must be parted between them. The effect on the axis of rotation directly is to cause it to describe a very minute ellipse of about 18¼ by 13¾ seconds of a degree in the course of about nineteen years. This is the *nutation* of the earth's axis, and as the cause of it is an alternate tendency of the axis to and from the ecliptic, the longest axis is directed to the pole of that circle. The effect on the radius vector of the earth is to turn the earth's orbit backwards, but at a very slow rate as compared with the motion of the moon's orbit. This is called the *precession of the* *equinoxes.* It is told on the apparent sphere of the stars in the motion of the pole of the earth's rotation round the pole of the ecliptic, at an angular distance equal to the obliquity of the ecliptic, and with an angular annual velocity of about $50\frac{1}{10}$ seconds of a degree, or is completed in 25,868 years. The effect of these two motions is to make the pole of the earth's rotation travel round the pole of the ecliptic in a path having nearly 1,377 very minute flexures from the uniform line.

This motion of the one pole round the other occasions a similar shifting of the nodes, or points in which the equator and ecliptic cut each other, as told upon the starry sphere; and since observations began to be recorded, this shifting has been extended to about 30° westward on the ecliptic, so that the stars are not now in the same signs of the ecliptic as they were at that time. As the disturbances occasioned by the other planets—for all planets have a tendency to cause a retrograde motion of the orbits of each other—are in part mixed up with the disturbances which have been mentioned, the subject becomes not a little complicated in its details. The principles, however, are all simple, and from the one consideration that, as their orbits and times are all incommensurable, they must in the lapse of years and ages be in all possible positions or *aspects* with regard to each other, and as every possible change of state involves in itself the elements of a return at some time or other, however distant, we may regard the stability of the whole, and of every one, as being as permanent as the matter of which they are composed; and when we do so, the period of time for which these more mighty works of creation appeared fitted for enduring, is every way as wonderful as that unmeasurable extent of space in which they exist.

We have left room for little more than the mere names of the other bodies which make up the solar system as known to our observation. It consists of the central sun, of whose magnitude we have taken some notice, and of eleven primary orbits which are known to us; and we know not how many more there may be which are either too remote or too small for being discovered. We say "primary orbits," because of the primary planets which revolve in them, three besides the earth are attended by secondaries or satellites. Two are inferior planets, or nearer the sun than the earth is, and all the rest are superior, or more distant.

The bodies in the solar system, taken in their order, are as follow:—

1. The Sun, central, retaining the rest in their orbits, by a gravitating influence inversely as the squares of the distances, and illuminating and warming them in the same ratio. Its diameter is 882,000 miles, and the angle which it subtends at the mean distance of the earth is 32′ 3″. Its mean density, obtained by dividing the quantity of matter by the bulk, is little more than one-fourth of that of the earth, or not greatly heavier than water; but owing to its vast quantity of matter, that which is one pound on the earth would be nearly twenty-eight pounds at the sun. Thus, there can be no creatures of such compact materials as those on the earth moving about on the surface of the sun, for they would sink into the mass as lead does

in water. From the appearance of spots on its surface, the sun turns round its axis, in the same direction as the earth does, in twenty-five days, the axis making an angle of 82° 40′ with the plane of the ecliptic.

2. Mercury, 3,200 miles in diameter, revolving, in nearly eighty-eight days, at a mean distance of 37,000,000 of miles, in an orbit eccentric by more than one-fifth of the mean distance, and making an angle of very little more than 7° with the ecliptic; the density of its mass nearly double that of the earth, or nine and a half times the weight of water; and the action of the sun upon it about seven times greater than on the earth. Mercury subtends an angle of from 12″ to 5″, according as it is nearer to or more remote from the earth.

3. Venus is 7,800 miles in diameter, revolving, in rather less than 225 days, at a mean distance of 68,000,000 miles, and in an orbit nearly circular, the eccentricity being less than seven thousandth parts of the mean distance. The density of Venus is rather more than that of the earth, being nearly six times the weight of water.

Mercury and Venus being inferior planets, appear alternately as morning and as evening stars, and, during the course of their revolutions, display all the phases, or variations of illuminated surface, of the moon; the synodical period of Mercury from its greatest brightness as an evening star to the same again is about 116 days, and that of Venus 586; but as the orbit of Mercury is the more eccentric, the extent of elongation varies rather more.

4. The Earth; some of the particulars of this body have already been given.

5. Mars is about 4,200 miles in diameter, revolving in about 687 days, at a mean distance of 144,000,000 miles from the sun, in an orbit whose eccentricity is nearly a tenth of the mean distance, and in its inclination to the ecliptic 1° 51′ 6″. The density of Mars is less than that of the earth, being only about $3\frac{2}{7}$ the weight of water. Mars and all the remaining planets of the system perform their revolutions beyond the orbit of the earth, and therefore only a portion of their dark sides can be ever seen, and this portion is always less than the half, and the less the more distant the planet.

6. Vesta. 7. Juno. 8. Ceres. 9. Pallas. These are four small planets of which neither the magnitudes nor the masses have been accurately determined. Vesta revolves in about 1,326 days, at a mean distance of 225,000,000 miles, in an orbit making an angle of 7° 8′ 9″ with the ecliptic, and having an eccentricity of less that $\frac{1}{10}$ of the mean distance. Juno revolves in about 1,593 days, at a mean distance of 250,000,000 miles, in an orbit making an angle of 13° 4′ 9″ with the ecliptic, and having an eccentricity of more than $\frac{1}{4}$ of the mean distance. Ceres revolves in about 1,681 days, at a mean distance of 262,900,000 miles in an orbit, making an angle of about 10° 37′ 26″ with the ecliptic, and having an eccentricity of less than $\frac{8}{100}$ parts of the mean distance. Pallas revolves in about $1{,}686\frac{1}{2}$ days, at a mean distance of about 263,000,000 miles, in an orbit making an angle of 34° 34′ 55″ with the ecliptic, and having an eccentricity of rather less than $\frac{1}{4}$ of the mean distance. From the great inclinations of the orbits of these planets, and the great eccentricities of

those of Juno and Pallas, their apparent motions are very irregular, and they are all so small as not to be visible, except with telescopes of considerable power. It is a curious fact with regard to Ceres and Pallas, that though the annual period of the latter is between four or five days longer than that of the former, and thus, in mean distance, it is the superior and more remote planet, yet in consequence of the great eccentricity of its orbit, the circumference of that orbit is smaller than that of the former. Hence it is possible that these orbits may intersect each other, not merely in the same plane as all orbits do, but in the very same point, and thus there might be a collision of the two; but the planes of their orbits, and their rates of motion in different parts, are so different, and they are so small, and consequently so subject to the disturbing influence of the larger planets, especially of Jupiter, their next neighbour without, that there is small chance, if any, of such a catastrophe.

10. Jupiter is 87,000 miles in diameter, or about 1,300 times larger than the earth, but the substance of which it is composed is much less dense, being lighter than that of the sun, or only 1_{24} the weight of the same bulk of water. The apparent angular diameter of Jupiter varies from 46″ to 30″, according as it is nearer to the earth or more remote. Jupiter revolves in about 4,333 days, at a mean distance of 490,000,000 miles from the sun, in an orbit inclined to the ecliptic at an angle of 1° 18′ 51″, and having an eccentricity of rather less that $\frac{1}{20}$ of the mean distance. Jupiter, notwithstanding its vast bulk, performs a rotation round an axis in the short period of $9^h\ 55^m\ 50^s$;

and in proof of there being a general accommodation of the figures of the planets to the degrees of their rotation, Jupiter is much flattened at the extremities of the axis of rotation. In consequence of this, and also of the great mass of the planet, it must, on the principle already alluded to in noticing the earth and moon, occasion great disturbances in the motions of its own moons or satellites. Those moons are four in number, and, with their primary, from a miniature system, over which that primary holds sovereign rule, as a satrap of a distant province of the sun's empire; and while he keeps his own subjects under due control, he causes his influence to be left on all the neighbouring planets, and holds captive for a time any comet that may incautiously approach too near his vice-regal throne.

11. SATURN is 79,000 miles in diameter, or nearly 1,000 times the bulk of the earth; but its quantity of matter is much less in proportion to its bulk, its average weight being only about $\frac{13}{32}$, or considerably less than half the weight of the water; and were it possible to launch the planet in that liquid, it would float with nearly the same buoyancy as a ship entirely made of the lightest species of Canadian white pine timber.

Saturn performs a revolution in about 10,759 days, at a mean distance of about 900,000,000 miles, in an orbit making an angle of 2° 29′ 35″ with the ecliptic, and having an eccentricity of rather more than $\frac{1}{20}$ of the mean distance.

The angle which Saturn subtends, as seen from the earth, is about 16″, which does not vary much, in consequence of the vast distance of the planet at all times.

Seven satellites attend upon Saturn, and there are besides two thin flat rings, concentric with the planet and with each other, which surround it in the plane of the equatorial diameter, or at right angles to the axis of rotation, upon which axis the planet turns round in $10^h\ 29^m\ 17^s$. These rings are very thin as compared with their other dimensions, being estimated at only 100 miles. Their other dimensions, and distances from the planet and from each other, are as follow:—

	Miles.
Equatorial semi-diameter of planet .	39,580
Distance of inner ring from planet .	19,090
Breadth of inner ring . . .	17,175
Interval of the rings . . .	1,791
Breadth of exterior ring . . .	10,573
Semi-diameter of exterior ring .	88,209

These rings may each be considered as a continued circle of satellites, ranged around the equatorial diameter of the planet; and though the matter of which they are composed is probably less dense than that of the body of the planet, yet they must occasion very considerable disturbances in the satellites; and from the singular mechanism of the whole, Saturn and his attendants are the most curious study in the whole planetary system. The diameter of Saturn's exterior ring is the largest extent of material substance, at all approaching to solidity, with which we are acquainted except the sun, but in consequence of its small thickness it is only a mere trifle in the system,—its total diameter being 176,418 miles, while the diamcter of the sun exceeds 882,000.

12. Uranus is about 35,112 miles in diameter. It revolves in about 30,686 days, at a mean distance of about 1,800,000,000 miles, in an orbit making an angle of 0° 46′ 28″ with the ecliptic, and having an eccentricity equal to nearly $\frac{1}{20}$th of the mean distance. In consequence of the near coincidence of the plane of its orbit with that of the ecliptic, and its great distance, which is more than 19 times as far from the earth as the earth is from the sun, there is much less difference in declination in this planet than in any of the others, though, in consequence of the length of its period compared with that of the earth, the changes of direct and retrograde motion in the course of an entire siderial revolution of the planet, are very numerous. From its immense distance, it exerts comparatively little disturbing influence upon the earth; and as the angle which it subtends, notwithstanding its being 80 times the bulk of the earth, is only 4″, our knowledge of it is almost wholly telescopic. It certainly is attended by two satellites, and probably by more; but satellites in so very distant a part of the system,—the very extreme of measurable space, as it were,—are difficult to be observed, and therefore we cannot pronounce respecting them with anything like confidence.

Such is a mere list of the solar system. All the primary planets have their major axes passing through the centre of gravity of the system in the sun, and that centre of the gravity is the upper focus of each. Hence they all cross the ecliptic in two opposite points, or *nodes*, an ascending node where they pass to the northward, and a descending node where they return to the southward. We have seen that their inclinations to the ecliptic and their eccentricities, as well s their mean distances, are all different, and we have hinted that there is a retrograde motion, of the nodes of each upon the plane of the ecliptic. This is of course attended with a retrograde movement of their major axes, and consequently of their places of perihelion; but as their orbits are ellipses, not circles, the retrogradation of the nodes and of the perihelion cannot proceed always at the same rate, either in different planets or in the same planet. Thus there are many particulars to be taken into the account before we can become practical astronomers, and be able to determine their places for any one instant of time. Each of them would, in fact, require a volume in order to tell its history intelligibly in popular language; and after we had informed ourselves respecting them, there would remain the history of the wanderers of the system—the comets, whether periodical or singly visitant; and beyond these the vast immeasurable region of the stars, which forms the wonder of the whole, and draws the mind onward from the contemplation of the infinitude of space to the infinitude of wisdom, of power, and of goodness,—from the infinitude of the works of creation, to the infinite number of the attributes of the infinite, eternal, and Almighty Creator, who has formed them all, and who governs them all, according to the good purpose of his will, and to the furtherance of enjoyment and happiness in every sentient and reflective being which he has seen meet to create. But though far more, and of a more inviting character than what we have briefly noticed, still remains behind, we feel that the measure by which we are in the mean time circumscribed is full; and if we shall have impressed the reader with a strong feeling that there is more to be known in the study of the heavens, and with a corresponding desire to know it, then our object will be in part accomplished, and our labour, imperfect as it is, will not be wholly in vain.

THE END.