PRELIMINARY DISSERTATION

IN order to convey some idea of the object of this work it may be useful to offer a few preliminary observations on the nature of the subject which it is intended to investigate, and of the means that have already been adopted with so much success to bring within the reach of our faculties, those truths which might seem to be placed so far beyond them.

All the knowledge we possess of external objects is founded upon experience, which furnishes a knowledge of facts, and the comparison of these facts establishes relations, from which, induction, the intuitive belief that like causes will produce like effects, leads us to general laws. Thus, experience teaches that bodies fall at the surface of the earth with an accelerated velocity, and proportional to their masses. Newton[1] proved, by comparison, that the force which occasions the fall of bodies at the earth's surface, is identical with that which retains the moon in her orbit; and induction led him to conclude that as the moon is kept in her orbit by the attraction of the earth, so the planets might be retained in their orbits by the attraction of the sun. By such steps he was led to the discovery of one of those powers with which the Creator has ordained that matter should reciprocally act upon matter.

Physical astronomy is the science which compares and identifies the laws of motion observed on earth with the motions that take place in the heavens, and which traces, by an uninterrupted chain of deduction from the great principle that governs the universe, the revolutions and rotations of the planets, and the oscillations of the fluids at their surfaces, and which estimates the changes the system has hitherto undergone or may hereafter experience, changes which require millions of years for their accomplishment.

The combined efforts of astronomers, from the earliest dawn of civilization, have been requisite to establish the mechanical theory of astronomy: the courses of the planets have been observed for ages with a degree of perseverance that is astonishing, if we consider the imperfection, and even the want of instruments. The real motions of the earth have been separated from the apparent motions of the planets; the laws of the planetary revolutions have been discovered; and the discovery of these laws has led to the knowledge of the gravitation of matter. On the other hand, descending from the principle of gravitation, every motion in the system of the world has been so completely explained, that no astronomical phenomenon can now be transmitted to posterity of which the laws have not been determined.

Science, regarded as the pursuit of truth, which can only be attained by patient and unprejudiced investigation, wherein nothing is too great to be attempted, nothing so minute as to be justly disregarded, must ever afford occupation of consummate interest and of elevated meditation. The contemplation of the worlds of creation elevates the mind to the admiration of whatever is great and noble, accomplishing the object of all study, which in the elegant language of Sir James Mackintosh[2] is to inspire the love of truth, of wisdom, of beauty, especially of goodness, the highest beauty, and of that supreme and eternal mind, which contains all truth and wisdom, all beauty and goodness. By the love or delightful contemplation and pursuit of these transcendent aims for their own sake only, the mind of man is raised from low and perishable objects, and prepared for those high destinies which are appointed for all those who are capable of them.

The heavens afford the most sublime subject of study which can be derived from science: the magnitude and splendour of the objects, the inconceivable rapidity with which they move, and the enormous distances between them, impress the mind with some notion of the energy that maintains them in their motions with a durability to which we can see no limits. Equally conspicuous is the goodness of the great First Cause in having endowed man with faculties by which he can not only appreciate the magnificence of his works, but trace, with precision, the operation of his laws, use the globe he inhabits as a base wherewith to measure the magnitude and distance of the sun and planets, and make the diameter of the earth's orbit the first step of a scale by which he may ascend to the starry firmament. Such pursuits, while they ennoble the mind, at the same time inculcate humility, by showing that there is a barrier, which no energy**,** mental or physical, can ever enable us to pass: that however profoundly we may penetrate the depths of space, there still remain innumerable systems, compared with which those which seem so mighty to us must dwindle into insignificance, or even become invisible; and that not only man, but the globe he inhabits, nay the whole system of which it forms so small a part, might be annihilated, and its extinction be unperceived in the immensity of creation.

A complete acquaintance with Physical Astronomy can only be attained by those who are well versed in the higher branches of mathematical and mechanical science: such alone can appreciate the extreme beauty of the results, and of the means by which these results are obtained. Nevertheless a sufficient skill in analysis to follow the general outline, to see the mutual dependence of the different parts of the system, and to comprehend by what means some of the most extraordinary conclusions have been arrived at, is within the reach of many who shrink from the task, appalled by difficulties, which perhaps are not more formidable than those incident to the study of the elements of every branch of knowledge, and possibly overrating them by not making a sufficient distinction between the degree of mathematical acquirement necessary for making discoveries, and that which is requisite for understanding what others have done. That the study of mathematics and their application to astronomy are full of interest will be allowed by all who have devoted their time and attention to these pursuits, and they only can estimate the delight of arriving at truth, whether it be in the discovery of a world, or of a new property of numbers.

It has been proved by Newton that a particle of matter placed without the surface of a hollow sphere is attracted by it as if its mass, or the whole matter it contains, were collected in its centre. The same is therefore true of a solid sphere which may be supposed to consist of an infinite number of concentric hollow spheres. This however is not the case with a spheroid, but the celestial bodies are so nearly spherical, and at such remote distances from each other, that they attract and are attracted as if each were a dense point situate in its centre of gravity, a circumstance which greatly facilitates the investigation of their motions.

The attraction of the earth on bodies at its surface in that latitude, the square of whose sine is 1/3, is the same as if it were a sphere; and experience shows that bodies there fall through 16.0697 feet in a second. The mean distance of the moon from the earth is about sixty times the mean radius of the earth. When the number 16.0697 is diminished in the ratio of 1 to 3,600, which is the square of the moon's distance from the earth, It is found to be exactly the space the moon would fall through in the first second of her descent to the earth, were she not prevented by her centrifugal force, arising from the velocity with which she moves in her orbit. So that the moon is retained in her orbit by a force having the same origin and regulated by the same law with that which causes a stone to fall at the earth's surface. The earth may therefore be regarded as the centre of a force which extends to the moon; but as experience shows that the action and reaction of matter are equal and contrary, the moon must attract the earth an equal and contrary force.

Newton proved that a body projected in space will move in a conic section, if it be attracted by a force directed towards a fixed point, and having an intensity inversely as the square of the distance; but that any deviation from that law will cause it to move in a curve of a different nature. Kepler[3] ascertained by direct observation that the planets describe ellipses round the sun, and later observations show that cornets also move in conic sections: it consequently follows that the sun attracts all the planets and comets inversely as the square of their distances from his centre; the sun therefore is the centre of a force extending indefinitely in space, and including all the bodies of the system in its action.

Kepler also deduced from observation, that the squares of the periodic times of the planets, or the times of their revolutions round the sun, are proportional to the cubes of their mean distances from his centre:[4] whence it follows, that the intensity of gravitation of all the bodies towards the sun is the same at equal distances; consequently gravitation is proportional to the masses, for if the planets and comets be supposed to be at equal distances from the sun and left to the effects of gravity, they would arrive at his surface at the same time. The satellites also gravitate to their primaries according to the same law that their primaries do to the sun. Hence, by the law of action and reaction, each body is itself the centre of an attractive force extending indefinitely in space, whence proceed all the mutual disturbances that render the celestial motions so complicated, and their investigation so difficult.

The gravitation of matter directed to a centre, and attracting directly as the mass, and inversely as the square of the distance, does not belong to it when taken in mass; particle acts on particle according to the same law when at sensible distances from each other. If the sun acted on the centre of the earth without attracting each of its particles, the tides would be very much greater than they now are, and in other respects they also would be very different. The gravitation of the earth to the sun results from the gravitation of all its particles, which in their turn attract the sun in the ratio of their respective masses. There is a reciprocal action likewise between the earth and every particle at its surface; were this not the case, and were any portion of the earth, however small, to attract another portion and not be itself attracted, the centre of gravity of the earth would be moved in space, which is impossible.

The form of the planets results from the reciprocal attraction of their component particles. A detached fluid mass, if at rest, would assume the form of a sphere, from the reciprocal attraction of its particles; but if the mass revolves about an axis it becomes flattened at the poles, and bulges at the equator, in consequence of the centrifugal force arising from the velocity of rotation. For, the centrifugal force diminishes the gravity of the particles at the equator, and equilibrium can only exist when these two forces are balanced by an increase of gravity; therefore, as the attractive force is the same on all particles at equal distances from the centre of a sphere, the equatorial particles would recede from the centre till their increase in number balanced the centrifugal force by their attraction, consequently the sphere would become an oblate spheroid; and a fluid partially or entirely covering a solid, as the ocean and atmosphere cover the earth, must assume that form in order to remain in equilibrio. The surface of the sea is therefore spheroidal, and the surface of the earth only deviates from that figure where it rises above or sinks below the level of the sea; but the deviation is so small that it is unimportant when compared with the magnitude of the earth. Such is the form of the earth and planets, but the compression and flattening at their poles is so small, that even Jupiter, whose rotation is the most rapid, differs but little from a sphere. Although the planets attract each other as if they were spheres on account of their immense distances, yet the satellites are near enough to be sensibly affected in their motions by the forms of their primaries. The moon for example is so near the earth, that the reciprocal attraction between each of her particles and each of the particles in the prominent mass at the terrestrial equator, occasions considerable disturbances in the motions of both bodies. For, the action of the moon on the matter at the earth's equator produces a nutation[5] in axis of rotation, and the reaction of that matter on the moon is the cause of a corresponding nutation in the lunar orbit.

If a sphere at rest in space receives an impulse passing through its centre of gravity, all its parts will move with an equal velocity in a straight line; but if the impulse does not pass through the centre of gravity, its particles having unequal velocities, will give it rotatory motion at the same time that it is translated in space. These motions are independent of one another, so that a contrary impulse passing through its centre of gravity will impede its progression, without interfering with its rotation. As the sun rotates about an axis it seems probable if an impulse in a contrary direction has not been given to his centre of gravity, that he moves in space accompanied by all those bodies which compose the solar system, a circumstance that would in no way interfere with their relative motions; for, in consequence of our experience that force is proportional to velocity, the reciprocal attractions of a system remain the same, whether its centre of gravity be at rest, or moving uniformly in space. It is computed that had the earth received its motion from a single impulse, such impulse must have passed through a point about twenty-five miles from its centre.

Since the motions of the rotation and translation of the planets are independent of each other, though probably communicated by the same impulse, they form separate subjects of investigation.

A planet moves in its elliptical orbit with a velocity varying every instant, in consequence of two forces, one tending to the centre of the sun, and the other in the direction of a tangent to its orbit, arising from the primitive impulse given at the time when it was launched into space: should the force in the tangent cease, the planet would fall to the sun by its gravity; were the sun not to attract it, the planet would fly off in the tangent. Thus, when a planet is in its aphelion[6] or at the point where the orbit is farthest from the sun, his action overcomes its velocity, and brings it towards him with such an accelerated motion, that it at last overcomes the sun's attraction, and shoots past him; then, gradually decreasing in velocity, it arrives at the aphelion where the sun's attraction again prevails. In this motion the radii vectores,[7] or imaginary lines joining the centers of the sun and planets, pass over equal areas in equal times.[8]

If the planets were attracted by the sun only, this would ever be their course; and because his action is proportional to his mass, which is immensely larger than that of all the planets put together, the elliptical is the nearest approximation to their true motions, which are extremely complicated, in consequence of their mutual attraction, so that they do not move in any known or symmetrical curve, but in paths now approaching to, and now receding from the elliptical form, and their radii vectores do not describe areas exactly proportional to the time. Thus the areas become a test of the existence of disturbing forces.

To determine the motion of each body when disturbed by all the rest is beyond the power of analysis; it is therefore necessary to estimate the disturbing action of one planet at a time, whence arises the celebrated problem of the three bodies, which originally was that of the moon, the earth, and the sun, namely,—the masses being given of three bodies projected from three given points, with velocities given both in quantity and direction; and supposing the bodies to gravitate to one another with forces that are directly as their masses, and inversely as the squares of the distances, to find the lines described by these bodies, and their position at any given instant.

By this problem the motions of translation of all the celestial bodies are determined. It is one of extreme difficulty, and would be of infinitely greater difficulty, if the disturbing action were not very small, when compared with the central force. As the disturbing influence of each body may be found separately, it is assumed that the action of the whole system in disturbing any one planet is equal to the sum of all the particular disturbances it experiences, on the general mechanical principle, that the sum of any number of small oscillations is nearly equal to their simultaneous and joint effect.

On account of the reciprocal action of matter, the stability of the system depends on the intensity of the primitive momentum of the planets, and the ratio of their masses to that of the sun: for the nature of the conic sections in which the celestial bodies move, depends on the velocity with which they were first propelled in space; had that velocity been such as to make the planets move in orbits of unstable equilibrium, their mutual attractions might have changed them into parabolas or even hyperbolas; so that the earth and planets might ages ago have been sweeping through the abyss of space: but as the orbits differ very little from circles, the momentum of the planets when projected, must have been exactly sufficient to ensure the permanency and stability of the system. Besides the mass of the sun is immensely greater than those of the planets; and as their inequalities bear the same ratio to their elliptical motions as their masses do to that of the sun, their mutual disturbances only increase or diminish the eccentricities of their orbits by very minute quantities; consequently the magnitude of the sun's mass is the principal cause of the stability of the system. There is not in the physical world a more splendid example of the adaptation of means to the accomplishment of the end, than is exhibited in the nice adjustment of these forces.

The orbits of the planets have a very small inclination to the plane of the ecliptic in which the earth moves; and on that account, astronomers refer their motions to it at a given epoch as a known and fixed position. The paths of the planets, when their mutual disturbances are omitted, are ellipses nearly approaching to circles, whose planes, slightly inclined to the ecliptic, cut it in straight lines passing through the centre of the sun; the points where the orbit intersects the plane of the ecliptic are its nodes.

The orbits of the recently discovered planets[9] deviate more from the ecliptic: that of Pallas[10] has an inclination of 35° to it: on that account it will be more difficult to determine their motions. These little planets have no sensible effect in disturbing the rest, though their own motions are rendered very irregular by the proximity of Jupiter and Saturn.

The planets are subject to disturbances of two distinct kinds, both resulting from the constant operation of their reciprocal attraction, one kind depending upon their positions with regard to each other, begins from zero, increases to a maximum, decreases and becomes zero again, when the planets return to the same relative positions. In consequence of these, the troubled planet is sometimes drawn away from the sun, sometimes brought nearer to him; at one time it is drawn above the plane of its orbit, at another time below it, according to the position of the disturbing body. All such changes, being accomplished in short periods, some in a few months, others years, or in hundreds of years, are denominated Periodic Inequalities.

The inequalities of the other kind, though occasioned likewise by the disturbing energy of the planets, are entirely independent of their relative positions; they depend on the relative positions of the orbits alone, whose forms and places in space are altered by very minute quantities in immense periods of time, and are therefore called Secular Inequalities.

In consequence of disturbances of this kind, the apsides,[11] or extremities of the major axes of all the orbits, have a direct, but variable motion in space, excepting those of Venus, which are retrograde;[12] and the lines of the nodes move with a variable velocity in the contrary direction. The motions of both are extremely slow; it requires more than 109,770 years for the major axis of the earth's orbit to accomplish a sidereal[13] revolution, and 20,935 years to complete its tropical[14] motion. The major axis of Jupiter's orbit requires no less than 197,561 years to perform its revolution from the disturbing action of Saturn alone. The periods in which the nodes revolve are also very great. Beside these, the inclination and eccentricity of every orbit are in a state of perpetual, but slow change. At the present time, the inclinations of all the orbits are decreasing; but so slowly, that the inclination of Jupiter's orbit is only six minutes less now than it was in the age of Ptolemy.[15] The terrestrial eccentricity is decreasing at the rate of 3,914 miles in a century; and if it were to decrease equably, it would be 36,300 years before the earth's orbit became a circle. But in the midst of all these vicissitudes, the major axes and mean motions of the planets remain permanently independent of secular changes; they are so connected by Kepler's law of the squares of the periodic times being proportional to the cubes of the mean distances of the planets from the sun, that one cannot vary without affecting the other.

With the exception of these two elements, it appears, that all the bodies are in motion, and every orbit is in a state of perpetual change. Minute as these changes are, they might be supposed liable to accumulate in the course of ages sufficiently to derange the whole order of nature, to alter the relative positions of the planets, to put an end to the vicissitudes of the seasons, and to bring about collisions, which would involve our whole system, now so harmonious, in chaotic confusion. The consequences being so dreadful, it is natural to inquire, what proof exists that creation will be preserved from such a catastrophe? For nothing can be known from observation, since the existence of the human race has occupied but a point in duration, while these vicissitudes embrace myriads of ages. The proof is simple and convincing. All the variations of the solar system, as well secular as periodic, are expressed analytically by the sines and cosines of circular arcs, which increase with the time; and as a sine or cosine never can exceed the radius, but must oscillate between zero and unity, however much the time may increase, it follows, that when the variations have by slow changes accumulated in however long a time to a maximum, they decrease by the same slow degrees, till they arrive at their smallest value, and then begin a new course, thus forever oscillating about a mean value. This, however, would not be the case if the planets moved in a resisting medium, for then both the eccentricity and the major axes of the orbits would vary with the time, so that the stability of the system would be ultimately destroyed. But if the planets do move in an ethereal medium, it must be of extreme rarity, since resistance has hitherto been quite insensible.

Three circumstances have generally been supposed necessary to prove the stability of the system: the small eccentricities of the planetary orbits, their small inclinations, and the revolution of all the bodies, as well planets as satellites, in the same direction. These, however, are not necessary conditions: the periodicity of the terms in which the inequalities are expressed is sufficient to assure us, that though we do not know the extent of the limits, nor the period of that grand cycle which probably embraces millions of years, yet they never will exceed what is requisite for the stability and harmony of the whole, for the preservation of which every circumstance is so beautifully and wonderfully adapted.

The plane of the ecliptic itself, though assumed to be fixed at a given epoch for the convenience of astronomical computation, is subject to a minute secular variation of $52''.109$, occasioned by the reciprocal action of the planets; but as this is also periodical, the terrestrial equator, which is inclined to it at an angle of about $23^{\circ}\,28'$, will never coincide with the plane of the ecliptic; so there never can be perpetual spring. The rotation of the earth is uniform; therefore day and night, summer and winter, will continue their vicissitudes while the system endures, or is untroubled by foreign causes.

Yonder starry sphere
Of planets, and of fix'd, in all her wheels
Resembles nearest, mazes intricate,
Eccentric, intervolved, yet regular
Then most, when most irregular they seem.

The stability of our system was established by Lagrange,[16] '*a discovery,*' says Professor Playfair,[17] '*that must render the name for ever memorable in science, and revered by those who delight in the contemplation of whatever is excellent and sublime. After Newton's discovery of the elliptical orbits of the planets, Lagrange's discovery of their periodical inequalities is without doubt the noblest truth in physical astronomy; and, in respect of the doctrine of final causes, it may be regarded as the greatest of all.*'

Notwithstanding the permanency of our system, the secular variations in the planetary orbits would have been extremely embarrassing to astronomers, when it became necessary to compare observations separated by long periods. This difficulty is obviated by Laplace[18], who has shown that whatever changes time may induce either in the orbits themselves, or in the plane of the ecliptic, there exists an invariable plane passing through the centre of gravity of the sun, about which the whole system oscillates within narrow limits, and which is determined by this property; that if every body in the system be projected on it, and if the mass of each be multiplied by the area described in a given time by its projection on this plane, the sum of all these products will be a maximum. This plane of greatest inertia, by no means peculiar to the solar system, but existing in every system of bodies submitted to their mutual attractions only, always remains parallel to itself, and maintains a fixed position, whence the oscillations of the system may be estimated through unlimited time. It is situate nearly half way between the orbits of Jupiter and Saturn, and is inclined to the ecliptic at an angle of about $1^\circ 35' 31''$.

All the periodic and secular inequalities deduced from the law of gravitation are so perfectly confirmed by observations, that analysis has become one of the most certain means of discovering the planetary irregularities, either when they are too small, or too long in their periods, to be detected by other methods. Jupiter and Saturn, however, exhibit inequalities which for a long time seemed discordant with that law. All observations, from those of the Chinese and Arabs down to the present day, prove that for ages the mean motions of Jupiter and Saturn have been affected by great inequalities of very long periods, forming what appeared an anomaly in the theory of the planets. It was long known by observation, that five times the mean motion of Saturn is nearly equal to twice that of Jupiter; a relation which the sagacity of Laplace perceived to be the cause of a periodic inequality in the mean motion of each of these planets, which completes its period in nearly 929 Julian years, the one being retarded, while the other is accelerated. These inequalities are strictly periodical, since they depend on the configuration of the two planets; and the theory is perfectly confirmed by observation, which shows that in the course of twenty centuries, Jupiter's mean motion has been accelerated by $3^\circ\ 23'$, and Saturn's retarded by $5^\circ\ 13'$.

It might be imagined that the reciprocal action of such planets as have satellites would be different from the influence of those that have none; but the distances of the satellites from their primaries are incomparably less than the distances of the planets from the sun, and from one another, so that the system of a planet and its satellites moves nearly as if all those bodies were united in their common centre of gravity; the action of the sun however disturbs in some degree the motion of the satellites about their primary.

The changes that take place in the planetary system are exhibited on a small scale by Jupiter and his satellites; and as the period requisite for the development of the inequalities of these little moons only extends to a few centuries, it may be regarded as an epitome of that grand cycle which will not be accomplished by the planets in myriads of centuries. The revolutions of the satellites about Jupiter are precisely similar to those of the planets about the sun; it is true they are disturbed by the sun, but his distance is so great, that their motions are nearly the same as if they were not under his influence. The satellites like the planets, were probably projected in elliptical orbits, but the consequence of Jupiter's spheroid is very great in consequence of his rapid rotation; and as the masses of the satellites are nearly 100,000 times less than that of Jupiter, the immense quantity of prominent matter at his equator must soon have given the circular form observed in the orbits of the first and second satellites, which its superior attraction will always maintain. The third and fourth satellites being further removed from its influence move in orbits with a very small eccentricity. The same cause occasions the orbits of the satellites to remain nearly in the plane of Jupiter's equator, on account of which they are always seen nearly in the same line; and the powerful action of that quantity of prominent matter is the reason why the motion of the nodes of these little bodies is so much more rapid than those of a planet. The nodes of the fourth satellite accomplish a revolution in 520 years, while those of Jupiter's orbit require no less than 50,673 years, a proof of the reciprocal attraction between each particle of Jupiter's equator and of the satellites. Although the two first satellites sensibly move in circles, they acquire a small ellipticity from the disturbances they experience.

The orbits of the satellites do not retain a permanent inclination, either to the plane of Jupiter's equator, or to that of his orbit, but to certain planes passing between the two, and through their intersection; these have a greater inclination to his equator the further the satellite is removed, a circumstance entirely owing to the influence of Jupiter's compression.

A singular law obtains among the mean motions and mean longitudes of the three first satellites. It appears from observation, that the mean motion of the first satellite, plus twice that of the third, is equal to three times that of the second, and that the mean longitude of the first satellite, minus three times that of the second, plus twice that of the third, is always equal to two right angles. It is proved by theory, that if these relations had only been approximate when the satellites were first launched into space, their mutual attractions would have established and maintained them. They extend to the synodic motions of the satellites, consequently they affect their eclipses, and have a very great influence on their whole theory. The satellites move so nearly in the plane of Jupiter's equator, which has a very small inclination to his orbit, that they are frequently eclipsed by the planet. The instant of the beginning or end of an eclipse of a satellite marks the same instant of absolute time to all the inhabitants of the earth; therefore the time of these eclipses observed by a traveler, when compared with the time of the eclipse computed for Greenwich or any other fixed meridian, gives the difference of the meridians in time, and consequently the longitude of the place of observation. It has required all the refinements of modern instruments to render the eclipses of these remote moons available to the mariner; now however, that system of bodies invisible to the naked eye, known to man by the aid of science alone, enables him to traverse the ocean, spreading the light of knowledge and the blessings of civilization over the most remote regions, and to return loaded with the productions of another hemisphere. Nor is this all: the eclipses of Jupiter's satellites have been the means of a discovery, which, though not so immediately applicable to the wants of man, unfolds a property of light, that medium, without whose cheering influence all the beauties of the creation would have been to us a blank. It is observed, that those eclipses of the first satellite which happen when Jupiter is near conjunction, are later by $16' 26''$ than those which take place when the planet is in opposition. But as Jupiter is nearer to us when in opposition by the whole breadth of the earth's orbit than when in conjunction, this circumstance was attributed to the time employed by the rays of light in crossing the earth's orbit, a distance of 192 millions of miles; whence it is estimated, that light travels at the rate of 192,000 miles in one second.[19] Such is its velocity, that the earth, moving at the rate of nineteen miles in a second, would take two months to pass through a distance which a ray of light would dart over in eight minutes. The subsequent discovery of the aberration of light confirmed this astonishing result.

Objects appear to be situate in the direction of the rays that proceed from them. Were light propagated instantaneously, every object, whether at rest or in motion, would appear in the direction of these rays; but as light takes some time to travel, when Jupiter is in conjunction, we see him by means of rays that left him $16' 26''$ before; but during that time we have changed our position, in consequence of the motion of the earth in its orbit; we therefore refer Jupiter to a place in which he is not. His true position is in the diagonal of the parallelogram, whose sides are in the ratio of the velocity of light to the velocity of the earth in its orbit, which is as 192,000 to 19. In consequence of aberration, none of the heavenly bodies are in the place in which they seem to be. In fact, if the earth were at rest, rays from a star would pass along the axis of a telescope directed to it; but if the earth were to begin to move in its orbit with its usual velocity, these rays would strike against the side of the tube; it would therefore be necessary to incline the telescope a little, in order to see the star. The angle contained between the axis of the telescope and a line drawn to the true place of the star, is its aberration, which varies in quantity and direction in different parts of the earth's orbit; but as it never exceeds twenty seconds, it is insensible in ordinary cases.

The velocity of light deduced from the observed aberration of the fixed stars, perfectly corresponds with that given by the eclipses of the first satellite. The same result obtained from sources so different, leaves not a doubt of its truth. Many such beautiful coincidences, derived from apparently the most unpromising and dissimilar circumstances, occur in physical astronomy, and prove dependencies which we might otherwise be unable to trace. The identity of the velocity of light at the distance of Jupiter and on the earth's surface shows that its velocity is uniform; and if light consists in the vibrations of an elastic fluid or ether filling space, which hypothesis accords best with observed phenomena, the uniformity of its velocity shows that the density of the fluid throughout the whole extent of the solar system, must be proportional to its elasticity.[20] Among the fortunate conjectures which have been confirmed by subsequent experience, that of Bacon[21] is not the least remarkable. '*It produces in me,*' says the restorer of true philosophy, '*a doubt, whether the face of the serene and starry heavens be seen at the instant it really exists, or not till some time later; and whether there be not, with respect to the heavenly bodies, a true time and an apparent time, no less than a true place and an apparent place, as astronomers say, on account of parallax. For it seems incredible that the species or rays of the celestial bodies can pass through the immense interval between them and us in an instant; or that they do not even require some considerable portion of time.*'

As great discoveries generally lead to a variety of conclusions, the aberration of light affords a direct proof of the motion of the earth in its orbit; and its rotation is proved by the theory of falling bodies, since the centrifugal force it induces retards the oscillations of the pendulum in going from the pole to the equator. Thus a high degree of scientific knowledge has been requisite to dispel the errors of the senses.

The little that is known of the theories of the satellites of Saturn and Uranus is in all respects similar to that of Jupiter. The great compression of Saturn occasions its satellites to move nearly in the plane of its equator. Of the situation of the equator of Uranus we know nothing, nor of its compression. The orbits of its satellites are nearly perpendicular to the plane of the ecliptic.

Our constant companion the moon next claims attention. Several circumstances concur to render her motions the most interesting, and at the same time the most difficult to investigate of all the bodies of our system. In the solar system planet troubles planet, but in the lunar theory the sun is the great disturbing cause; his vast distance being compensated by his enormous magnitude, so that the motions of the moon are more irregular than those of the planets; and on account of the great ellipticity of her orbit and the size of the sun, the approximations to her motions are tedious and difficult, beyond what those unaccustomed to such investigations could imagine. Neither the eccentricity of the lunar orbit, nor its inclination to the plane of the ecliptic, have experienced any changes from secular inequalities; but the mean motion, the nodes, and the perigee, are subject to very remarkable variations.

From an eclipse observed at Babylon by the Chaldeans, on the 19th of March, seven hundred and twenty-one years before the Christian era, the place of the moon is known from that of the sun at the instant of opposition; whence her mean longitude may be found; but the comparison of this mean longitude with another mean longitude, computed back for the instant of the eclipse from modern observations, shows that the moon performs her revolution round the earth more rapidly and in a shorter time now, than she did formerly; and that the acceleration in her mean motion has been increasing from age to age as the square of the time; all the ancient and intermediate eclipses confirm this result. As the mean motions of the planets have no secular inequalities, this seemed to be an unaccountable anomaly, and it was at one time attributed to the resistance of an ethereal medium pervading space; at another to the successive transmission of the gravitating force: but as Laplace proved that neither of these causes, even if they exist, have any influence on the motions of the lunar perigee or nodes, they could not affect the mean motion, a variation in the latter from such a cause being inseparably connected with variations in the two former of these elements. That great mathematician, however, in studying the theory of Jupiter's satellites, perceived that the secular variations in the elements of Jupiter's orbit, from the action of the planets, occasion corresponding changes in the motions of the satellites: this led him to suspect that the acceleration in the mean motion of the moon might be connected with the secular variation in the eccentricity of the terrestrial orbit; and analysis has proved that he assigned the true cause.

If the eccentricity of the earth's orbit were invariable, the moon would be exposed to a variable disturbance from the action of the sun, in consequence of the earth's annual revolution; but it would be periodic, since it would be the same as often as the sun, the earth, and the moon returned to the same relative positions: on account however of the slow and incessant diminution in the eccentricity of the terrestrial orbit, the revolution of our planet is performed at different distances from the sun every year. The position of the moon with regard to the sun, undergoes a corresponding change; so that the mean action of the sun on the moon varies from one century to another, and occasions the secular increase in the moon's velocity called the acceleration, a name which is very appropriate in the present age, and which will continue to be so for a vast number of ages to come; because, as long as the earth's eccentricity diminishes, the moon's mean motion will be accelerated; but when the eccentricity has passed its minimum and begins to increase, the mean motion will be retarded from age to age. At present the secular acceleration is about 10″, but its effect on the moon's place increases as the square of the time. It is remarkable that the action of the planets thus reflected by the sun to the moon, is much more sensible than their direct action, either on the earth or moon. The secular diminution in the eccentricity, which has not altered the equation of the centre of the sun by eight minutes since the earliest recorded eclipses, has produced a variation of $1^\circ\ 48'$ in the moon's longitude, and of $7^\circ\ 12'$ in her mean anomaly.

The action of the sun occasions a rapid but variable motion in the nodes and perigee of the lunar orbit; the former though they recede during the greater part of the moon's revolution, and advance during the smaller, perform their sidereal revolutions in $6793^{\text{days}}.4212$, and the latter, though its motion is sometimes retrograde and sometimes direct, in $3232^{\text{days}}.5807$, or a little more than nine years: but such is the difference between the disturbing energy of the sun and that of all the planets put together, that it requires no less than 109,770 years for the greater axis of the terrestrial orbit to do the same. It is evident that the same secular variation which changes the sun's distance from the earth, and occasions the acceleration in the moon's mean motion, must affect the motion of the nodes and perigee; and it consequently appears, from theory as well as observation, that both these elements are subject to a secular inequality, arising from the variation in the eccentricity of the earth's orbit, which connects them with the acceleration; so that both are retarded when the mean motion is anticipated. The secular variations in these three elements are in the ratio of the numbers 3, 0.735, and 1; whence the three motions of the moon, with regard to the sun, to her perigee, and to her nodes, are continually accelerated, and their secular equations are as the numbers 1, 4, and 0.265, or according to the most recent investigations as 1, 4, 6776 and 0.391. A comparison of ancient eclipses observed by the Arabs, Greeks, and Chaldeans, imperfect as they are, with modern observations, perfectly confirms these results of analysis.

Future ages will develop these great inequalities, which at some most distant period will amount to many circumferences. They are indeed periodic; but who shall tell their period? Millions of years must elapse before that great cycle is accomplished; but '*such changes, though rare in time, are frequent in eternity.*'

The moon is so near, that the excess of matter at the earth's equator occasions periodic variations in her longitude and latitude; and, as the cause must be proportional to the effect, a comparison of these inequalities, computed from theory, with the same given by observation, shows that the compression of the terrestrial spheroid, or the ratio of the difference between the polar and equatorial diameter to the diameter of the equator is 1/505.05. It is proved analytically, that if a fluid mass of homogeneous matter, whose particles attract each other inversely as the square of the distance, were to revolve about an axis, as the earth, it would assume the form of a spheroid, whose compression is 1/230. Whence it appears, that the earth is not homogeneous, but decreases in density from its centre to its circumference. Thus the moon's eclipses show the earth to be round, and her inequalities not only determine the form, but the internal structure of our planet; results of analysis which could not have been anticipated. Similar inequalities in Jupiter's satellites prove that his mass is not homogeneous, and that his compression is 1/13.8.

The motions of the moon have now become of more importance to the navigator and geographer than those of any other body, from the precision with which the longitude is determined by the occultations of stars and lunar distances. The lunar theory is brought to such perfection, that the times of these phenomena, observed under any meridian, when compared with that computed for Greenwich in the *Nautical Almanac,*[22] gives the longitude of the observer within a few miles. The accuracy of that work is obviously of extreme importance to a maritime nation; we have reason to hope that the new Ephemeris,[23] now in preparation, will be by far the most perfect work of the kind that ever has been published.

From the lunar theory, the mean distance of the sun from the earth, and thence the whole dimensions of the solar System are known; for the forces which retain the earth and moon in their orbits, are respectively proportional to the radii vectores of the earth and moon, each being divided by the square of its periodic time; and as the lunar theory gives the ratio of the forces, the ratio of the distance of the sun and moon from the earth is obtained: whence it appears that the sun's distance from the earth is nearly 396 times greater than that of the moon.

The method however of finding the absolute distances of the celestial bodies in miles, is in fact the same with that employed in measuring distances of terrestrial objects. From the extremities of a known base the angles which the visual rays from the object form with it, are measured; their sum subtracted from two right-angles gives the angle opposite the base; therefore by trigonometry, all the angles and sides of the triangle may be computed; consequently the distance of the object is found. The angle under which the base of the triangle is seen from the object, is the parallax[24] of that object; it evidently increases and decreases with the distance; therefore the base must be very great indeed, to be visible at all from the celestial bodies. But the globe itself whose dimensions are ascertained by actual admeasurement, furnishes a standard of measures, with which we compare the distances, masses, densities, and volumes of the sun and planets.

The courses of the great rivers, which are in general navigable to a considerable extent, prove that the curvature of the land differs but little from that of the ocean; and as the heights of the mountains and continents are, at any rate, quite inconsiderable when compared with the magnitude of the earth, its figure is understood to be determined by a surface at every point perpendicular to the direction of gravity, or of the plumbline, and is the same which the sea would have if it were continued all round the earth beneath the continents. Such is the figure that has been measured in the following manner:

A terrestrial meridian is a line passing through both poles, all the points of which have contemporaneously the same noon. Were the lengths and curvatures of different meridians known, the figure of the earth might be determined; but the length of one degree is sufficient to give the figure of the earth, if it be measured on different meridians, and in a variety of latitudes; for if the earth were a sphere, all degrees would be of the same length, but if not, the lengths of the degrees will be greatest where the curvature is least; a comparison of the length of the degrees in different parts of the earth's surface will therefore determine its size and form.

An arc of the meridian may be measured by observing the latitude of its extreme points, and then measuring the distance between them in feet or fathoms; the distance thus determined on the surface of the earth, divided by the degrees and parts of a degree contained in the difference of the latitudes, will give the exact length of one degree, the difference of the latitudes being the angle contained between the verticals at the extremities of the arc. This would be easily accomplished were the distance unobstructed, and on a level with the sea; but on account of the innumerable obstacles on the surface of the earth, it is necessary to connect the extreme points of the arc by a series of triangles, the sides and angles of which are either measured or computed, so that the length of the arc is ascertained with much laborious computation. In consequence of the inequalities of the surface, each triangle is in a different plane; they must therefore be reduced by computation to what they would have been, had they been measured on the surface of the sea; and as the earth is spherical, they require a correction to reduce them from plane to spherical triangles.

Arcs of the meridian have been measured in a variety of latitudes, both north and south, as well as arcs perpendicular to the meridian. From these measurements it appears that the length of the degrees increase from the equator to the poles, nearly as the square of the sine of the latitude; consequently, the convexity of the earth diminishes from the equator to the poles. Many discrepancies occur, but the figure that most nearly follows this law is an ellipsoid of revolution, whose equatorial radius is 3,962.6 miles, and the polar radius 3,949.7 miles; the difference, or 12.9

miles, divided by the equatorial radius, is 1/308.7, or 1/309 nearly; this fraction is called the compression of the earth, because, according as it is greater or less, the terrestrial ellipsoid is more or less flattened at the poles; it does not differ much from that given by the lunar inequalities. If we assume the earth to be a sphere, the length of a degree of the meridian is 69.044 British miles; therefore 360 degrees, or the whole circumference of the globe is 24,856 miles, and the diameter, which is something less than a third of the circumference, is 7,916 or 8,000 miles nearly. Eratosthenes,[25] who died 194 years before the Christian era, was the first to give an approximate value of the earth's circumference, by the mensuration of an arc between Alexandria and Syene.

But there is another method of finding the figure of the earth, totally independent of either of the preceding. If the earth were a homogeneous sphere without rotation, its attraction on bodies at its surface would be everywhere the same; if it be elliptical, the force of gravity theoretically ought to increase, from the equator to the pole, as the square of the sine of the latitude; but for a spheroid in rotation, by the laws of mechanics the centrifugal force varies as the square of the sine of the latitude from the equator where it is greatest, to the pole where it vanishes; and as it tends to make bodies fly off the surface, it diminishes the effects of gravity by a small quantity. Hence by gravitation, which is the difference of these two forces, the fall of bodies ought to be accelerated in going from the equator to the poles, proportionally to the square of the sine of the latitude; and the weight of the same body ought to increase in that ratio. This is directly proved by the oscillations of the pendulum; for if the fall of bodies be accelerated, the oscillations will be more rapid; and that they may always be performed in the same time, the length of the pendulum must be altered. Now, by numerous and very careful experiments, it is proved that a pendulum, which makes 86,400 oscillations in a mean day at the equator, will do the same at every point of the earth's surface, if its length be increased in going to the pole, as the square of the sine of the latitude. From the mean of these it appears that the compression of the terrestrial spheroid is about 1/342 which does not differ much from that given by the lunar inequalities, and from the arcs of the meridian. The near coincidence of these three values, deduced by methods so entirely independent of each other, shows that the mutual tendencies of the centres of the celestial bodies to one another, and the attraction of the earth for bodies at its surface, result from the reciprocal attraction of all their particles. Another proof may be added; the nutation of the earth's axis, and the precession of the equinoxes,[26] are occasioned by the action of the sun and moon on the protuberant matter at the earth's equator; and although these inequalities do not give the absolute value of the terrestrial compression, they show that the fraction expressing it is comprised between the limits 1/279 and 1/578.

It might be expected that the same compression should result from each, if the different methods of observation could be made without error. This, however, is not the case; for such discrepancies are found both in the degrees of the meridian and in the length of the pendulum, as show that the figure of the earth is very complicated; but they are so small when compared with the general results, that they may be disregarded. The compression deduced from the mean of the whole, appears to be about 1/320; that given by the lunar theory has the advantage of being independent of the irregularities at the earth's surface and of local attractions. The form and size of the earth being determined, it furnishes a standard of measure with which the dimensions of the solar system may be compared.

The parallax of a celestial body is the angle under which the radius of the earth would be seen if viewed from the centre of that body; it affords the means of ascertaining the distances of the sun, moon, and planets. Suppose that, when the moon is in the horizon at the instant of rising or setting, lines were drawn from her centre to the spectator and to the centre of the earth, these would form a right-angled triangle with the terrestrial radius, which is of a known length; and as the parallax or angle at the moon can be measured, all the angles and one side are given; whence the distance of the moon from the centre of the earth may be computed. The parallax of an object may he found, if two observers under the same meridian, but at a very great distance from one another, observe its zenith distances on the same day at the time of its passage over the meridian. By such contemporaneous observations at the Cape of Good Hope and at Berlin, the mean horizontal parallax of the moon was found to be $3{,}454''.2$; whence the mean distance of the moon is about sixty times the mean terrestrial radius, or 240,000 miles nearly. Since the parallax is equal to the radius of the earth divided by the distance of the moon; under the same parallel of latitude it varies with the distance of the moon from the earth, and proves the ellipticity of the lunar orbit; and when the moon is at her mean distance, it varies with the terrestrial radii, thus showing that the earth is not a sphere.

Although the method described is sufficiently accurate for finding the parallax of an object so near as the moon, it will not answer for the sun which is so remote, that the smallest error in observation would lead to a false result; but by the transits of Venus that difficulty is obviated. When that planet is in her nodes, or within $1^{\circ}.25$ of them, that is, in, or nearly in the plane of the ecliptic, she is occasionally seen to pass over the sun like a black spot. If we could imagine that the sun and Venus had no parallax, the line described by the planet on his disc, and the duration of the transit would be the same to all the inhabitants of the earth; but as the sun is not so remote but that the semidiameter of the earth has a sensible magnitude when viewed from his centre, the line described by the planet in its passage over his disc appears to be nearer to his centre or farther from it, according to the position of the observer; so that the duration of the transit varies with the different points of the earth's surface at which it is observed. This difference of time, being entirely the effect of parallax, furnishes the means of computing it from the known motions of the earth and Venus, by the same method as for the eclipses of the sun. In fact the ratio of the distances of Venus and the sun from the earth at the time of the transit, are known from the theory of their elliptical motion; consequently, the ratio of the parallaxes of these two bodies, being inversely as their distances, is given; and as the transit gives the difference of the parallaxes, that of the sun is obtained. In 1769, the parallax of the sun was determined by observations of a transit of Venus made at Wardhus in Lapland, and at Otaheite in the South Sea, the latter observation being the object of Cook's first voyage.[27] The transit lasted about six hours at Otaheite, and the difference in the duration at these two stations was eight minutes; whence the sun's parallax was found to be $8''.72$: but by other considerations it has subsequently been reduced to $8''.575$; from which the mean distance of the sun appears to be about 95,996,000 miles or ninety six millions of miles nearly. This is confirmed by an inequality in the motion of the moon, which depends on the parallax of the sun, and which when compared with observation gives $8''.6$ for the sun's parallax.

The parallax of Venus is determined by her transits, that of Mars by direct observation. The distances of these two planets from the earth are therefore known in terrestrial radii; consequently their mean distances from the sun may be computed; and as the ratios of the distances of the planets from the sun are known by Kepler's law, their absolute distances in miles are easily found.

Far as the earth seems to be from the sun, it is near to him when compared with Uranus; that planet is no less than 1,843 millions of miles from the luminary that warms and enlivens the world; to it, situate on the verge of the system, the sun must appear not much larger than Venus does to us. The earth cannot even be visible as a telescopic object to a body so remote; yet man, the inhabitant of the earth, soars beyond the vast dimensions of the system to which his planet belongs, and assumes the diameter of its orbit as the base of a triangle, whose apex extends to the stars.

Sublime as the idea is, this assumption proves ineffectual, for the apparent places of the fixed stars are not sensibly changed by the earth's annual revolution; and with the aid derived from the refinements of modern astronomy and the most perfect instruments, it is still a matter of doubt whether a sensible parallax has been detected, even in the nearest of these remote suns. If a fixed star had the parallax of one second, its distance from the sun would be 20,500,000 millions of miles.[28] At such a distance not only the terrestrial orbit shrinks to a point, but, where the whole solar system, when seen in the focus of the most powerful telescope, might be covered by the thickness of a spider's thread. Light, flying at the rate of 200,000 miles in a second, would take three years and seven days to travel over that space; one of the nearest stars may therefore have been kindled or extinguished more than three years before we could have been aware of so mighty an event. But this distance must be small when compared with that of the most remote of the bodies which are visible in the heavens. The fixed stars are undoubtedly luminous like the sun; it is therefore probable that they are not nearer to one another than the sun is to the nearest of them. In the milky way and the other starry nebulae, some of the stars that seem to us to be close to others, may be far behind them in the boundless depth of space; nay, may rationally be supposed to be situate many thousand times further off: light would therefore require thousands of years to come to the earth from those myriads of suns, of which our own is but *'the dim and remote companion.'*

The masses of such planets as have no satellites are known by comparing the inequalities they produce in the motions of the earth and of each other, determined theoretically, with the same inequalities given by observation, for the disturbing cause must necessarily be proportional to the effect it produces. But as the quantities of matter in any two primary planets are directly as the cubes of the mean distances at which their satellites revolve, and inversely as the squares of their periodic times, the mass of the sun and of any planets which have satellites, may be compared with the mass of the earth. In this manner it is computed that the mass of the sun is 354,936 times greater than that of the earth; whence the great perturbations of the moon and the rapid motion of the perigee and nodes of her orbit. Even Jupiter, the largest of the planets, is 1,070.5 times less than the sun. The mass of the moon is determined from four different sources, from her action on the terrestrial equator, which occasions the nutation in the axis of rotation; from her horizontal parallax, from an inequality she produces in the sun's longitude, and from her action on the tides. The three first quantities, computed from theory, and compared with their observed values, give her mass respectively equal to the 1/71, 1/74.2, and 1/69.2 part of that of the earth, which do not differ very much from each other; but, from her action in raising the tides, which furnishes the fourth method, her mass appears to be about the seventy-fifth part of that of the earth, a value that cannot differ much from the truth.

The apparent diameters of the sun, moon, and planets are determined by measurement; therefore their real diameters may be compared with that of the earth; for the real diameter of a planet is to the real diameter of the earth, or 8,000 miles, as the apparent diameter of the planet to the apparent diameter of the earth as seen from the planet, that is, to twice the parallax of the planet. The mean apparent diameter of the sun is $1920''$, and with the solar parallax $8''.65$ it will be found that the diameter of the sun is about 888,000 miles; therefore, if the centre of the sun were to coincide with the centre of the earth, his volume would not only include the orbit of the moon, but would extend. nearly as far again, for the moon's mean distance from the earth is about sixty times the earth's mean radius or 240,000 miles; so that twice the distance of the moon is

480,000 miles, which differs but little from the solar radius; his equatorial radius is probably not much less than the major axis of the lunar orbit.

The diameter of the moon is only 2,160 miles; and Jupiter's diameter of 88,000 miles is incomparably less than that of the sun. The diameter of Pallas does not much exceed 71 miles, so that an inhabitant of that planet, in one of our steam-carriages, might go round his world in five or six hours.

The oblate form of the celestial bodies indicates rotatory motion, and this has been confirmed, in most cases, by tracing spots on their surfaces, whence their poles and times of rotation have been determined. The rotation of Mercury is unknown, on account of his proximity to the sun; and that of the new planets has not yet been ascertained. The sun revolves in twenty-five days ten hours, about an axis that is directed towards a point half way between the pole star and Lyra, the plane of rotation being inclined a little more than 70° to that on which the earth revolves. From the rotation of the sun, there is every reason to believe that he has a progressive motion in space, although the direction to which he tends is as yet unknown: but in consequence of the reaction of the planets, he describes a small irregular orbit about the centre of inertia of the system, never deviating from his position by more than twice his own diameter, or about seven times the distance of the moon from the earth.

The sun and all his attendants rotate from west to east on axes that remain nearly parallel to themselves in every point of their orbit, and with angular velocities that are sensibly uniform. Although the uniformity in the direction of their rotation is a circumstance hitherto unaccounted for in the economy of Nature, yet from the design and adaptation of every other part to the perfection of the whole, a coincidence so remarkable cannot be accidental; and as the revolutions of the planets and satellites are also from west to east, it is evident that both must have arisen from the primitive causes which have determined the planetary motions.

The larger planets rotate in shorter periods than the smaller planets and the earth; their compression is consequently greater, and the action of the sun and of their satellites occasions a nutation in their axes, and a precession of their equinoxes, similar to that which obtains in the terrestrial spheroid from the attraction of the sun and moon on the prominent matter at the equator. In comparing the periods of the revolutions of Jupiter and Saturn with the times of their rotation, it appears that a year of Jupiter contains nearly ten thousand of his days, and that of Saturn about thirty thousand Saturnian days.

The appearance of Saturn is unparalleled in the system of the world; he is surrounded by a ring even brighter than himself, which always remains in the plane of his equator, and viewed with a very good telescope, it is found to consist of two concentric rings, divided by a dark band. By the laws of mechanics, it is impossible that this body can retain its position by the adhesion of its particles alone; it must necessarily revolve with a velocity that will generate a centrifugal force sufficient to balance the attraction of Saturn. Observation confirms the truth of these principles, showing that the rings rotate about the planet in 10.5 hours, which is considerably less than the time a satellite would take to revolve about Saturn at the same distance. Their plane is inclined to the ecliptic at an angle of 31°; and in consequence of this obliquity of position they always appear elliptical to us, but with an eccentricity so variable as even to be occasionally like a straight line drawn across the planet. At present the apparent axes of the rings are as 1,000 to 160; and on the 29th of September, 1832, the plane of the rings will pass through the centre of the earth when they will be visible only with superior instruments, and will appear like a fine line across the disc of Saturn. On the 1st of December in the same year, the plane of the rings will pass through the centre of the sun.

It is a singular result of the theory, that the rings could not maintain their stability of rotation if they were everywhere of uniform thickness; for the smallest disturbance would destroy the equilibrium, which would become more and more deranged, till at last they would be precipitated on the surface of the planet. The rings of Saturn must therefore be irregular solids of unequal breadth in the different parts of the circumference, so that their centres of gravity do not coincide with the centres of their figures.

Professor Struve[29] has also discovered that the centre of the ring is not concentric with the centre of Saturn; the interval between the outer edge of the globe of the planet and the outer edge of the ring on one side, is $11''.073$, and on the other side the interval is $11''.288$; consequently there is an eccentricity of the globe in the ring of $0''.215$.

If the rings obeyed different forces, they would not remain in the same plane, but the powerful attraction of Saturn always maintains them and his satellites in the plane of his equator. The rings, by their mutual action, and that of the sun and satellites, must oscillate about the centre of Saturn, and produce phenomena of light and shadow, whose periods extend to many years.

The periods of the rotation of the moon and the other satellites are equal to the times of their revolutions, consequently these bodies always turn the same face to their primaries; however, as the mean motion of the moon is subject to a secular inequality which will ultimately amount to many circumferences, if the rotation of the moon were perfectly uniform, and not affected by the same inequalities, it would cease exactly to counterbalance the motion of revolution; and the moon, in the course of ages, would successively and gradually discover every point of her surface to the earth. But theory proves that this never can happen; for the rotation of the moon, though it does not partake of the periodic inequalities of her revolution, is affected by the same secular variations, so that her motions of rotation and revolution round the earth will always balance each other, and remain equal. This circumstance arises from the form of the lunar spheroid, which has three principal axes of different lengths at right angles to each other. The moon is flattened at the poles from her centrifugal force, therefore her polar axis is least; the other two are in the plane of her equator, but that directed towards the earth is the greatest. The attraction of the earth, as if it had drawn out that part of the moon's equator, constantly brings the greatest axis, and consequently the same hemisphere towards us, which makes her rotation participate in the secular variations in her mean motion of revolution. Even if the angular velocities of rotation and revolution had not been nicely balanced in the beginning of the moon's motion, the attraction of the earth would have recalled the greatest axis to the direction of the line joining the centres of the earth and moon; so that it would vibrate on each side of that line in the same manner as a pendulum oscillates on each side of the vertical from the influence of gravitation.

No such libration[30] is perceptible; and as the smallest disturbance would make it evident, it is clear that if the moon has ever been touched by a comet, the mass of the latter must have been extremely small; for if it had been only the hundred-thousandth part of that of the earth, it would have rendered the libration sensible. A similar libration exists in the motions of Jupiter's satellites; but although the comet of 1767 and 1779 passed through the midst of them, their libration still remains insensible. It is true, the moon is liable to librations depending on the position of the spectator; at her rising, part of the western edge of her disc is visible, which is invisible at her setting, and the contrary takes place with regard to her eastern edge. There are also librations arising from the relative positions of the earth and moon in their respective orbits, but as they are only optical appearances, one hemisphere will be eternally concealed from the earth. For the same reason, the earth, which must be so splendid an object to one lunar hemisphere, will be for ever veiled from the other. On account of these circumstances, the remoter hemisphere of the moon has its day a fortnight long, and a night of the same duration not even enlightened by a moon, while the favoured side is illuminated by the reflection of the earth during its long night. A moon exhibiting a surface thirteen times larger than ours, with all the varieties of clouds, land, and water coming successively into view, would be a splendid object to a lunar traveler in a journey to his antipodes.

The great height of the lunar mountains probably has a considerable influence on the phenomena of her motion, the more so as her compression is small, and her mass considerable.

In the curve passing through the poles, and that diameter of the moon which always points to the earth, nature has furnished it permanent meridian, to which the different spots on her surface have been referred, and their positions determined with as much accuracy as those of many of the most remarkable places on the surface of our globe.

The rotation of the earth which determines the length of the day may be regarded as one of the most important elements in the system of the world. It serves as a measure of time, and forms the standard of comparison for the revolutions of the celestial bodies, which by their proportional increase or decrease would soon disclose any changes it might sustain. Theory and observation concur in proving, that among the innumerable vicissitudes that prevail throughout creation, the period of the earth's diurnal rotation is immutable. A fluid, as Mr. Babbage[31] observes, in falling from a higher to a lower level, carries with it the velocity due to its revolution with the earth at a greater distance from its centre. It will therefore accelerate, although to an almost infinitesimal extent, the earth's daily rotation. The sum of all these increments of velocity, arising from the descent of all the rivers on the earth's surface, would in time become perceptible, did not nature, by the process of evaporation, raise the waters back to their sources; and thus again by removing matter to a greater distance from the centre, destroy the velocity generated by its previous approach; so that the descent of the rivers does not affect the earth's rotation. Enormous masses projected by volcanoes from the equator to the poles, and the contrary, would indeed affect it, but there is no evidence of such convulsions. The disturbing action of the moon and planets, which has so powerful an effect on the revolution of the earth, in no way influences its rotation: the constant friction of the trade winds on the mountains and continents between the tropics does not impede its velocity, which theory even proves to be the same, as if the sea together with the earth formed one solid mass. But although these circumstances be inefficient, a variation in the mean temperature would certainly occasion a corresponding change in the velocity of rotation: for in the science of dynamics, it is a principle in a system of bodies or of particles revolving about a fixed centre, that the momentum, or sum of the products of the mass of each into its angular velocity and distance from the centre is a constant quantity, if the system be not deranged by an external cause. Now since the number of particles in the system is the same whatever its temperature may be, when their distances from the centre are diminished, their angular velocity must be increased in order that the preceding quantity may still remain constant. It follows then, that as the primitive momentum of rotation with which the earth was projected into space must necessarily remain the same, the smallest decrease in heat, by contracting the terrestrial spheroid, would accelerate its rotation, and consequently diminish the length of the day. Notwithstanding the constant accession of heat from the sun's rays, geologists have been induced to believe from the nature of fossil remains, that the mean temperature of the globe is decreasing.

The high temperature of mines, hot springs, and above all, the internal fires that have produced, and do still occasion such devastation on our planet, indicate an augmentation of heat towards its centre; the increase of density in the strata corresponding to the depth and the form of the spheroid, being what theory assigns to a fluid mass in rotation, concur to induce the idea that the temperature of the earth was originally so high as to reduce all the substances of which it is composed to a state of fusion, and that in the course of ages it has cooled down to its present state; that it is still becoming colder, and that it will continue to do so, till the whole mass arrives at the temperature of the medium in which it is placed, or rather at a state of equilibrium between this temperature, the cooling power of its own radiation, and the beating effect of the sun's rays. But even if this cause be sufficient to produce the observed effects, it must be extremely slow in its operation; for in consequence of the rotation of the earth being a measure of the periods of the celestial motions, it has been proved, that if the length of the day had decreased by the three hundredth part of a second since the observations of Hipparchus[32] two thousand years ago, it would have diminished the secular equation of the moon by $4''.4$. It is therefore beyond a doubt, that the mean temperature of the earth cannot have sensibly varied during that time; if then the appearances exhibited by the strata are really owing to a decrease of internal temperature, it either shows the immense periods requisite to produce geological changes to which two thousand years are as nothing, or that the mean temperature of the earth had arrived at a state of equilibrium before these observations. However strong the indications of the primitive fluidity of the earth, as there is no direct proof, it can only be regarded as a very probable hypothesis; but one of the most profound philosophers and elegant writers of modern times has found, in the secular variation of the eccentricity of the terrestrial orbit, an evident cause of decreasing temperature. That accomplished author, in pointing out the mutual dependencies of phenomena, says: *'It is evident that the mean temperature of the whole surface of the globe, in so far as it is maintained by the action of the sun at a higher degree than it would have were the sun extinguished, must depend on the mean quantity of the sun's rays which it receives, or, which comes to the same thing, on the total quantity received in a given invariable time: and the length of the year being unchangeable in all the fluctuations of the planetary system, it follows, that the total amount of solar radiation will determine*, *caeteris paribus,*[33] *the general climate of the earth. Now it is not difficult to show, that this amount is inversely proportional to the minor axis of the ellipse described by the earth about the sun, regarded as slowly variable; and that, therefore, the major axis remaining, as we know it to be, constant, and the orbit being actually in a state of approach to a circle, and consequently the minor axis being on the increase, the mean annual amount of solar radiation received by the whole earth must be actually on the decrease. We have, therefore, an evident real cause to account for the phenomenon.*' The limits of the variation in the eccentricity of the earth's orbit are unknown; but if its ellipticity has ever been as great as that of the orbit of Mercury or Pallas, the mean temperature of the earth must have been sensibly higher than it is at present; whether it was great enough to render our northern climates fit for the production of tropical plants, and for the residence of the elephant, and the other inhabitants of the torrid zone, it is impossible to say.

The relative quantity of heat received by the earth at different moments during a single revolution, varies with the position of the perigee of its orbit, which accomplishes a tropical revolution in 20,935 years. In the year 1250 of our era, and 29,653 years before it, the perigee coincided with the summer solstice; at both these periods the earth was nearer the sun during the summer, and farther from him in the winter than in any other position of the apsides: the extremes of temperature must therefore have been greater than at present; but as the terrestrial orbit was probably more elliptical at the distant epoch, the heat of the summers most have been very great, though possibly compensated by the rigour of the winters; at all events, none of these changes affect the length of the day.

It appears from the marine shells found on the tops of the highest mountains, and in almost every part of the globe, that immense continents have been elevated above the ocean, which must have engulfed others. Such a catastrophe would be occasioned by a variation in the position of the axis of rotation on the surface of the earth; for the seas tending to the new equator would leave some portions of the globe, and overwhelm others.

But theory proves that neither nutation, precession, nor any of the disturbing forces that affect the system, have the smallest influence on the axis of rotation, which maintains a permanent position on the surface, if the earth be not disturbed in its rotation by some foreign cause, as the collision of a comet which may have happened in the immensity of time. Then indeed, the equilibrium could only have been restored by the rushing of the seas to the new equator, which they would continue to do, till the surface was every where perpendicular to the direction of gravity. But it is probable that such an accumulation of the waters would not be sufficient to restore equilibrium if the derangement had been great; for the mean density of the sea is only about a fifth part of the mean density of the earth, and the mean depth even of the Pacific ocean is not more than four miles, whereas the equatorial radius of the earth exceeds the polar radius by twenty-five or thirty miles; consequently the influence of the sea on the direction of gravity is very small; and as it appears that a great change in the position of the axes is incompatible with the law of equilibrium, the geological phenomena must be ascribed to an internal cause. Thus amidst the mighty revolutions which have swept innumerable races of organized beings from the earth, which have elevated plains, and buried mountains in the ocean, the rotation of the earth, and the position of the axis on its surface, have undergone but slight variations.

It is beyond a doubt that the strata increase in density from the surface of the earth to its centre, which is even proved by the lunar inequalities; and it is manifest from the mensuration of arcs of the meridian and the lengths of the seconds pendulum that the strata are elliptical and concentric. This certainly would have happened if the earth had originally been fluid, for the denser parts must have subsided towards the centre, as it approached a state of equilibrium; but the enormous pressure of the superincumbent mass is a sufficient cause for these phenomena. Professor Leslie[34] observes, that air compressed into the fiftieth part of its volume has its elasticity fifty times augmented; if it continue to contract at that rate, it would, from its own incumbent weight, acquire the density of water at the depth of thirty-four miles. But water itself would have its density doubled at the depth of ninety-three miles, and would even attain the density of quicksilver at a depth of 362 miles. In descending therefore towards the centre through 4,000 miles, the condensation of ordinary materials would surpass the utmost powers of conception. But a density so extreme is not borne out by astronomical observation. It might seem therefore to follow, that our planet must have a widely cavernous structure, and that we tread on a crust or shell, whose thickness bears a very small proportion to the diameter of its sphere. Possibly too this great condensation at the central regions may be counterbalanced by the increased elasticity due to a very elevated temperature. Dr. Young[35] says that steel would be compressed into one-fourth, and stone into one-eighth of its bulk at the earth's centre. However we are yet ignorant of the laws of compression of solid bodies beyond a certain limit; but, from the experiments of Mr. Perkins,[36] they appear to be capable of a greater degree of compression than has generally been imagined.

It appears then, that the axis of rotation is invariable on the surface of the earth, and observation shows, that were it not for the action of the sun and moon on the matter at the equator, it would remain parallel to itself in every point of its orbit.

The attraction of an exterior body not only draws a spheroid towards it; but, as the force varies inversely as the square of the distance, it gives it a motion about its centre of gravity, unless when the attracting body is situated in the prolongation of one of the axes of the spheroid.

The plane of the equator is inclined to the plane of the ecliptic at an angle of about $23^\circ\ 28'$, and the inclination of the lunar orbit on the same is nearly 5°; consequently, from the oblate figure of the earth, the sun and moon acting obliquely and unequally on the different parts of the terrestrial spheroid, urge the plane of the equator from its direction, and force it to move from east to west, so that the equinoctial points have a slow retrograde motion on the plane of the ecliptic of about $50''.512$ annually. The direct tendency of this action would be to make the planes of the equator and ecliptic coincide; but in consequence of the rotation of the earth, the inclination of the two planes remains constant, as a top in spinning preserves the same inclination to the plane of the horizon. Were the earth spherical this effect would not be produced, and the equinoxes would always correspond to the same points of the ecliptic, at least as far as this kind of action is concerned. But another and totally different cause operates on this motion, which has already been mentioned. The action of the planets on one another and on the sun, occasions a very slow variation in the position of the plane of the ecliptic, which affects its inclination on the plane of the equator, and gives the equinoctial points a slow but direct motion on the ecliptic of $0''.312$ annually, which is entirely independent of the figure of the earth, and would be the same if it were a sphere. Thus the sun and moon, by moving the plane of the equator, cause the equinoctial points to retrograde on the ecliptic; and the planets, by moving the plane of the ecliptic, give them a direct motion, but much less than the former; consequently the difference of the two is the mean precession, which is proved, both by theory and observation, to be about $50''.1$ annually. As the longitudes of all the fixed stars are increased by this quantity, the effects of precession are soon detected; it was accordingly discovered by Hipparchus, in the year 128 before Christ, from a comparison of his own observations with those of Timocharis,[37] 155 years before. In the time of Hipparchus the entrance of the sun into the constellation Aries was the beginning of spring, but since then the equinoctial points have receded 30°; so that the constellations called the signs of the zodiac are now at a considerable distance from those divisions of the ecliptic which bear their names. Moving at the rate of $50''.1$ annually, the equinoctial points will accomplish a revolution in 25,868 years; but as the precession varies in different centuries, the extent of this period will be slightly modified. Since the motion of the sun is direct, and that of the equinoctial points retrograde, he takes a shorter time to return to the equator than to arrive at the same stars; so that the tropical year of 365.242264 days must be increased by the time be takes to move through an arc of $50''.1$, in order to have the length of the sidereal year. By simple proportion it is the 0.014119th part of a day, so that the sidereal year is 365.256383.

The mean annual precession is subject to a secular variation; for although the change in the plane of the ecliptic which is the orbit of the sun, be independent of the form of the earth, yet by bringing the sun, moon and earth into different relative positions from age to age, it alters the direct action of the two first on the prominent matter at the equator; on this account the motion of the equinox is greater by $0''.455$ now than it was in the time of Hipparchus; consequently the actual length of the tropical year is about $4''.154$ shorter than it was at that time. The utmost change that it can experience from this cause amounts to $43''$.

Such is the secular motion of the equinoxes, but it is sometimes increased and sometimes diminished by periodic variations, whose periods depend on the relative positions of the sun and moon with regard to the earth, and occasioned by the direct action of these bodies on the equator.

Dr. Bradley[38] discovered that by this action the moon causes the pole of the equator to describe a small ellipse in the heavens, the diameters of which are $16''$ and $20''$. The period of this inequality is nineteen years, the time employed by the nodes of the lunar orbit to accomplish a revolution. The sun causes a small variation in the description of this ellipse; it runs through its period in half a year. This nutation in the earth's axis affects both the precession and obliquity with small periodic variations; but in consequence of the secular variation in the position of the terrestrial orbit, which is chiefly owing to the disturbing energy of Jupiter on the earth, the obliquity of the ecliptic is annually diminished by $0''.52109$. With regard to the fixed stars, this variation in the course of ages may amount to ten or eleven degrees; but the obliquity of the ecliptic to the equator can never vary more than two or three degrees, since the equator will follow in some measure the motion of the ecliptic.

It is evident that the places of all the celestial bodies are affected by precession and nutation, and therefore all observations of them must be corrected for these inequalities.

The densities of bodies are proportional to their masses divided by their volumes; hence if the sun and planets be assumed to be spheres, their volumes will be as the cubes of their diameters. Now the apparent diameters of the sun and earth at their mean distance, are $1922''$ and $17''.08$, and the mass of the earth is the 1/354936th part of that of the sun taken as the unit; it follows therefore, that the earth is nearly four times as dense as the sun; but the sun is so large that his attractive force would cause bodies to fall through about 450 feet in a second; consequently if he were even habitable by human beings, they would be unable to move, since their weight would be thirty times as great as it is here. A moderate sized man would weigh about two tons at the surface of the sun. On the contrary, at the surface of the four new planets we should be so light, that it would be impossible to stand from the excess of our muscular force, for a man would only weigh a few pounds. All the planets and satellites appear to be of less density than the earth. The motions of Jupiter's satellites show that his density increases towards his centre; and the singular irregularities in the form of Saturn, and the great compression of Mars, prove the internal structure of these two planets to be very far from uniform.

Astronomy has been of immediate and essential use in affording invariable standards for measuring duration, distance, magnitude, and velocity. The sidereal day, measured by the time elapsed between two consecutive transits of any star at the same meridian, and the sidereal year, are immutable units with which to compare all great periods of time; the oscillations of the isochronous pendulum measure its smaller portions. By these invariable standards alone we can judge of the slow changes that other elements of the system may have undergone in the lapse of ages.

The returns of the sun to the same meridian, and to the same equinox or solstice, have been universally adopted as the measure of our civil days and years. The solar or astronomical day is the time that elapses between two consecutive noons or midnights; it is consequently longer than the sidereal day, on account of the proper motion of the sun during a revolution of the celestial sphere; but as the sun moves with greater rapidity at the winter than at the summer solstice, the astronomical day is more nearly equal to the sidereal day in summer than in winter. The obliquity of the ecliptic also affects its duration, for in the equinoxes the arc of the equator is less than the corresponding arc of the ecliptic, and in the solstices it is greater. The astronomical day is therefore diminished in the first case, and increased in the second. If the sun moved uniformly in the equator at the rate of $59' 8''.3$ every day, the solar days would be all equal; the time therefore, which is reckoned by the arrival of an imaginary sun at the meridian, or of one which is supposed to move in the equator, is denominated mean solar time, such as is given by clocks and watches in common life: when it is reckoned by the arrival of the real sun at the meridian, it is apparent time, such as is given by dials. The difference between the time shown by a clock. and a dial is the equation of time given in the *Nautical Almanac*, and sometime amounts to as much as sixteen minutes. The apparent and mean time coincide four times in the year.

Astronomers begin the day at noon, but in common reckoning the day begins at midnight. In England it is divided into twenty-four hours, which are counted by twelve and twelve; but in France, astronomers adopting decimal division, divide the day into ten hours, the hour into one hundred minutes, and the minute into a hundred seconds, because of the facility in computation, and in conformity with their system of weights and measures. This subdivision is not used in common life, nor has it been adopted in any other country, though their scientific writers still employ that division of time. The mean length of the day, though accurately determined, is not sufficient for the purposes either of astronomy or civil life. The length of the year is pointed out by nature as a measure of long periods; but the incommensurability that exists between the lengths of the day, and the revolutions of the sun, renders it difficult to adjust the estimation of both in whole numbers. If the revolution of the sun were accomplished in 365 days, all the years would be of precisely the same number of days, and would begin and end with the sun at the same point of the ecliptic; but as the sun's revolution includes the fraction of a day, a civil year and a revolution of the sun have not the same duration. Since the fraction is nearly the fourth of a day, four years are nearly equal to four revolutions of the sun, so that the addition of a supernumerary day every fourth year nearly compensates the difference; but in process of time further correction will be necessary, because the fraction is less than the fourth of a day. The period of seven days, by far the most permanent division of time, and the most ancient monument of astronomical knowledge, was used by the Brahmins in India[39] with the same denominations employed by us, and was alike found in the Calendars of the Jews, Egyptians, Arabs, and Assyrians; it has survived the fall of empires, and has existed among all successive generations, a proof of their common origin.

The new moon immediately following the winter solstice in the 707th year of Rome was made the 1st of January of the first year of Caesar; the 25th of December in his 45th year, is considered as the date of Christ's nativity; and Caesar's 46th year is assumed to be the first of our era. The preceding year is called the first year before Christ by chronologists, but by astronomers it is called the year 0. The astronomical year begins on the 31st of December at noon; and the date of an observation expresses the days and hours which actually elapsed since that time.

Some remarkable astronomical eras are determined by the position of the major axis of the solar ellipse. Moving at the rate of $61''.906$ annually, it accomplishes a tropical revolution in 20,935 years. It coincided with the line of the equinoxes 4000 or 4089 years before the Christian era, much about the time chronologists assign for the creation of man.[40] In 6485 the Major axis will again coincide with the line of the equinoxes, but then the solar perigee will coincide with the equinox of spring; whereas at the creation of man it coincided with the autumnal equinox. In the year 1250 the major axis was perpendicular to the line of the equinoxes, and then the solar perigee coincided with the solstice of winter, and the apogee with the solstice of summer. On that account Laplace proposed the year 1250 as a universal epoch, and that the vernal equinox of that year should be the first day of the first year.

The variations in the positions of the solar ellipse occasion corresponding changes in the length of the seasons. In its present position spring is shorter than summer, and autumn longer than winter; and while the solar perigee continues as it now is, between the solstice of winter and the equinox of spring, the period including spring and summer will be longer than that including autumn and winter: in this century the difference is about seven days. These intervals will be equal towards the year 6485, when the perigee comes to the equinox of spring. Were the earth's orbit circular, the seasons would be equal; their differences arise from the eccentricity of the earth's orbit, small as it is; but the changes are so gradual as to be imperceptible in the short space of human life.

No circumstance in the whole science of astronomy excites a deeper interest than its application to chronology. '*Whole nations*,' says Laplace, '*have been swept from the earth, with their language, arts and sciences, leaving but confused masses of ruin to mark the place where mighty cities stood; their history, with the exception of it few doubtful traditions, has perished; but the perfection of their astronomical observations marks their high antiquity, fixes the periods of their existence, and proves that even at that early period they must have made considerable progress in science.*'

The ancient state of the heavens may now be computed with great accuracy; and by comparing the results of computation with ancient observations, the exact period at which they were made may be verified if true, or if false, their error may be detected. If the date be accurate, and the observation good, it will verify the accuracy of modern tables, and show to how many centuries they may be extended, without the fear of error. A few examples will show the importance of this subject.

At the solstices the sun is at his greatest distance from the equator, consequently his declination at these times is equal to the obliquity of the ecliptic, which in former times was determined from the meridian length of the shadow of the style of a dial on the day of the solstice. The lengths of the meridian shadow at the summer and winter solstice are recorded to have been observed at the city of Layang, in China, 1100 years before the Christian era. From these, the distances of the sun from the zenith of the city of Layang are known. Half the sum of these zenith distances determines the latitude, and half their difference gives the obliquity of the ecliptic at the period of the observation; and as the law of the variation in the obliquity is known, both the time and place of the observations have been verified by computation from modern tables. Thus the Chinese had made some advances in the science of astronomy at that early period; the whole chronology of the Chinese is founded on the observations of eclipses, which prove the existence of that empire for more than 4700 years. The epoch of the lunar tables of the Indians, supposed by Bailly[41] to be 3000 before the Christian era, was proved by Laplace from the acceleration of the moon, not to be more ancient than the time of Ptolemy. The great inequality of Jupiter and Saturn whose cycle embraces 929 years, is peculiarly fitted for marking the civilization of a people. The Indians had determined the mean motions of these two planets in that part of their periods when the apparent mean motion of Saturn was at the slowest, and that of Jupiter the most rapid. The periods in which that happened were 3102 years before the Christian era, and the year 1491 after it.

The returns of comets to their perihelia may possibly mark the present state of astronomy to future ages.

The places of the fixed stars are affected by the precession of the equinoxes; and as the law of that variation is known, their positions at any time may be computed. Now Eudoxus,[42] a contemporary of Plato, mentions a star situate in the pole of the equator, and from computation it appears that *c* Draconis was not very far from that place about 3000 years ago; but as Eudoxus lived only about 2150 years ago, be must have described an anterior state of the heavens, supposed to be the same that was determined by Chiron,[43] about the time of the siege of Troy. Every circumstance concurs in showing that astronomy was cultivated in the highest ages of antiquity.

A knowledge of astronomy leads to the interpretation of hieroglyphical characters, since astronomical signs are often found on the ancient Egyptian monuments, which were probably employed by the priests to record dates. On the ceiling of the portico of a temple among the ruins of Tentyris,[44] there is a long row of figures of men and animals, following each other in the same direction; among these are the twelve signs of the zodiac, placed according to the motion of the sun: it is probable that the first figure in the procession represents the beginning of the year. Now the first is the Lion as if coming out of the temple; and as it is well known that the agricultural year of the Egyptians commenced at the solstice of summer, the epoch of the inundations of the Nile, if the preceding hypothesis be true, the solstice at the time the temple was built must have happened in the constellation of the lion; but as the solstice now happens $21^o.6$ north of the constellation of the Twins, it is easy to compute that the zodiac of Tentyris must have been made 4000 years ago.

The author had occasion to witness an instance of this most interesting application of astronomy, in ascertaining the date of a papyrus sent from Egypt by Mr. Salt,[45] in the hieroglyphical researches of the late Dr. Thomas Young,[46] whose profound and varied acquirements do honour not only to his country, but to the age in which he lived. The manuscript was found in a mummy case; it proved to be a horoscope of the age of Ptolemy, and its antiquity was determined from the configuration of the heavens at the time of its construction.

The form of the earth furnishes a standard of weights and measures for the ordinary purposes of life, as well as for the determination of the masses and distances of the heavenly bodies. The length of the pendulum vibrating seconds in the latitude of London forms the standard of the British measure of extension. Its length oscillating in vacuo at the temperature of 62° of Fahrenheit, and reduced to the level of the sea, was determined by Captain Kater,[47] in parts of the imperial standard yard, to be 39.1387 inches. The weight of a cubic inch of water at the temperature of 62° Fahrenheit, barometer 30, was also determined in parts of the imperial troy pound, whence a standard both of weight and capacity is deduced. The French have adopted the metre for their unit of linear measure, which is the ten millionth part of that quadrant of the meridian passing through Formentera[48] and Greenwich, the middle of which is nearly in the forty-fifth degree of latitude. Should the national standards of the two countries be lost in the vicissitudes of human affairs, both may be recovered, since they are derived from natural standards presumed to be invariable. The length of the pendulum would be found again with more facility than the metre; but as no measure is mathematically exact, an error in the original standard may at length become sensible in measuring a great extent, whereas the error that must necessarily arise in measuring the quadrant of the meridian is rendered totally insensible by subdivision in taking its ten millionth part. The French have adopted the decimal division not only in time, but in their degrees, weights, and measures, which affords very great facility in computation. It has not been adopted by any other people; though nothing is more desirable than that all nations should concur in using the same division and standards, not only on account of the convenience, but as affording a more definite idea of quantity. It is singular that the decimal division of the day, of degrees, weights and measures, was employed in China 4000 years ago; and that at the time Ibn Junis[49] made his observations at Cairo, about the year 1000, the Arabians were in the habit of employing the vibrations of the pendulum in their astronomical observations.

One of the most immediate and striking effects of a gravitating force external to the earth is the alternate rise and fall of the surface of the sea twice in the course of a lunar day, or $24^h\ 50^m\ 48^s$, of mean solar time. As it depends on the action of the sun and moon, it is classed among astronomical problems, of which it is by far the most difficult and the least satisfactory. The form of the surface of the ocean in equilibrio, when revolving with the earth round its axis, is an ellipsoid flattened at the poles; but the action of the sun and moon, especially of the moon, disturbs the equilibrium of the ocean.

If the moon attracted the centre of gravity of the earth and all its particles with equal and parallel forces, the whole system of the earth and the waters that cover it, would yield to these forces with a common motion, and the equilibrium of the seas would remain undisturbed. The difference of the forces, and the inequality of their directions, alone trouble the equilibrium.

It is proved by daily experience, as well as by strict mechanical reasoning, that if a number of waves or oscillations be excited in a fluid by different forces, each pursues its course, and has its effect independently of the rest. Now in the tides there are three distinct kinds of oscillations, depending on different causes, producing their effects independently of each other, which may therefore be estimated separately.

The oscillations of the first kind which are very small, are independent of the rotation of the earth; and as they depend on the motion of the disturbing body in its orbit, they are of long periods. The second kind of oscillations depends on the rotation of the earth, therefore their period is nearly a day: and the oscillations of the third kind depend on an angle equal to twice the angular rotation of the earth; and consequently happen twice in twenty-four hours. The first afford no particular interest, and are extremely small; but the difference of two consecutive tides depends on the second. At the time of the solstices, this difference which, according to Newton's theory, ought to be very great, is hardly sensible on our shores. Laplace has shown that this discrepancy arises from the depth of the sea, and that if the depth were uniform, there would be no difference in the consecutive tides, were it not for local circumstances: it follows therefore, that as this difference is extremely small, the sea, considered in a large extent, must be nearly of uniform depth, that is to say, there is a certain mean depth from which the deviation is not great. The mean depth of the Pacific ocean is supposed to be about four miles, that of the Atlantic only three. From the formulae which determine the difference of the consecutive tides it is also proved that the precession of the equinoxes, and the nutation in the earth's axis, are the same as if the sea formed one solid mass with the earth.

The third kind of oscillations are the semidiurnal tides, so remarkable on our coasts; they are occasioned by the combined action of the sun and moon, but as the effect of each is independent of the other, they may be considered separately.

The particles of water under the moon are more attracted than the centre of gravity of the earth, in the inverse ratio of the square of the distances; hence they have a tendency to leave the earth, but are retained by their gravitation, which this tendency diminishes. On the contrary, the moon attracts the centre of the earth more powerfully than she attracts the particles of water in the hemisphere opposite to her; so that the earth has a tendency to leave the waters but is retained by gravitation, which this tendency again diminishes. Thus the waters immediately under the moon are drawn from the earth at the same time that the earth is drawn from those which are diametrically opposite to her; in both instances producing an elevation of the ocean above the surface of equilibrium of nearly the same height; for the diminution of the gravitation of the particles in each position is almost the same, on account of the distance of the moon being great in comparison of the radius of the earth. Were the earth entirely covered by the sea, the water thus attracted by the moon would assume the form of an oblong spheroid, whose greater axis would point towards the moon, since the columns of water under the moon and in the direction diametrically opposite to her are rendered lighter, in consequence of the diminution of their gravitation; and in order to preserve the equilibrium, the axes 90^{o} distant would be shortened. The elevation, on account of the smaller space to which it is confined, is twice as great as the depression, because the contents of the spheroid always remain the same. The effects of the sun's attraction are in all respects similar to those of the moon's, though greatly less in degree, on account of his distance; he therefore only modifies the form of this spheroid it little. If the waters were capable of instantly assuming the form of equilibrium, that is, the form of the spheroid, its summit would always point to the moon, notwithstanding the earth's rotation; but on account of their resistance, the rapid motion produced in them by rotation prevents them from assuming at every instant the form which the equilibrium of the forces acting on them requires. Hence, on account of the inertia of the waters, if the tides be considered relatively to the whole earth and open sea, there is a meridian about 30° eastward of the moon, where it is always high water both in the hemisphere where the moon is, and in that which is opposite. On the west side of this circle the tide is flowing, on the east it is ebbing, and on the meridian at 90° distant, it is everywhere low water. It is evident that these tides must happen twice in a day, since in that time the rotation of the earth brings the same point twice tinder the meridian of the moon, once under the superior and once under the inferior meridian.

In the semidiurnal tides there are two phenomena particularly to be distinguished, one that happens twice in a month, and the other twice in a year.

The first phenomenon is, that the tides are much increased in the syzigies,[50] or at the time of new and full moon. In both cases the sun and moon are in the same meridian, for when the moon is new they are in conjunction, and when she is full they are in opposition. In each of these positions their action is combined to produce the highest or spring tides under that meridian, and the lowest in those points that are 90° distant. It is observed that the higher the sea rises in the full tide, the lower it is in the ebb. The neap tides take place when the moon is in quadrature, they neither rise so high nor sink so low it's the spring tides. The spring tides are much increased when the moon is in perigee. It is evident that the spring tides must happen twice a month, since in that time the moon is once new and once full.

The second phenomenon in the tides is the augmentation which occurs at the time of the equinoxes when the sun's declination is zero, which happens twice every year. The greatest tides take place when a new or full moon happens near the equinoxes while the moon is in perigee. The inclination of the moon's orbit on the ecliptic is $5^\circ 9'$; hence in the equinoxes the action of the moon would be increased if her node were to coincide with her perigee. The equinoctial gales often raise these tides to a great height. Beside these remarkable variations, there are others arising from the declination of the moon, which has a great influence on the ebb and flow of the waters.

Both the height and time of high water are thus perpetually changing; therefore, in solving the problem, it is required to determine the heights to which they rise, the times at which they happen, and the daily variations.

The periodic motions of the waters of the ocean on the hypothesis of an ellipsoid of revolution entirely covered by the sea, are very far from according with observation; this arises from the very great irregularities in the surface of the earth, which is but partially covered by the sea, the variety in the depths of the ocean, the manner in which it is spread out on the earth, the position and inclination of the shores, the currents, the resistance the waters meet with, all of them causes which it is impossible to estimate, but which modify the oscillations of the great mass of the ocean. However, amidst all these irregularities, the ebb and flow of the sea maintain a ratio to the forces producing them sufficient to indicate their nature, and to verify the law of the attraction of the sun and moon on the sea. Laplace observes, that the investigation of such relations between cause and effect is no less useful in natural philosophy than the direct solution of problems, either to prove the existence of the causes, or trace the laws of their effects. Like the theory of probabilities, it is a happy supplement to the ignorance and weakness of the human mind. Thus the problem of the tides does not admit of a general solution; it is certainly necessary to analyze the general phenomena which ought to result from the attraction of the sun and moon, but these must be corrected in each particular case by those local observations which are modified by the extent and depth of the sea, and the peculiar circumstances of the port.

Since the disturbing action of the sun and moon can only become sensible in a very great extent of water, it is evident that the Pacific ocean is one of the principal sources of our tides; but in consequence of the rotation of the earth, and the inertia of the ocean, high water does not happen till some time after the moon's southing. The tide raised in that world of waters is transmitted to the Atlantic, and from that sea it moves in a northerly direction along the coasts of Africa and Europe, arriving later and later at each place. This great wave however is modified by the tide raised in the Atlantic, which sometimes combines with that from the Pacific in raising the sea, and sometimes is in opposition to it, so that the tides only rise in proportion to their difference. This great combined wave, reflected by the shores of the Atlantic, extending nearly from pole to pole, still coming northward, pours through the Irish and British channels into the North sea, so that the tides in our ports are modified by those of another hemisphere. Thus the theory of the tides in each port, both as to their height and the times at which they take place, is really a matter of experiment, and can only be perfectly determined by the mean of a very great number of observations including several revolutions of the moon's nodes.

The height to which the tides rise is much greater in narrow channels than in the open sea, on account of the obstructions they meet with. In high latitudes where the ocean is less directly under the influence of the luminaries, the rise and fall of the sea is inconsiderable, so that, in all probability, there is no tide at the poles, or only a small annual and monthly one. The ebb and flow of the sea are perceptible in rivers to a very great distance from their estuaries. In the straits of Pauxis, in the river of the Amazons, more than five hundred miles from the sea, the tides are evident. It requires so many days for the tide to ascend this mighty stream, that the returning tides meet a succession of those which are coming up; so that every possible variety occurs in some part or other of its shores, both as to magnitude and time. It requires a very wide expanse of water to accumulate the impulse of the sun and moon, so as to render their influence sensible; on that account the tides in the Mediterranean and Black Sea are scarcely perceptible.

These perpetual commotions in the waters of the ocean are occasioned by forces that bear a very small proportion to terrestrial gravitation: the sun's action in raising the ocean is only the 1/38,448,000 of gravitation at the earth's surface, and the action of the moon is little more than twice as much, these forces being in the ratio of 1 to 2.35333. From this ratio the mass of the moon is found to be only 1/75th part of that of the earth. The initial state of the ocean has no influence on the tides; for whatever its primitive conditions may have been, they must soon have vanished by the friction and mobility of the fluid. One of the most remarkable circumstances in the theory of the tides is the assurance that in consequence of the density of the sea being only one-fifth of the mean density of the earth, the stability of the equilibrium of the ocean never can be subverted by any physical cause whatever. A general inundation arising from the mere instability of the ocean is therefore impossible.

The atmosphere when in equilibrio is an ellipsoid flattened at the poles from its rotation with the earth: in that state its strata are of uniform density at equal heights above the level of the sea, and it is sensibly of finite extent, whether it consists of particles infinitely divisible or not. On the latter hypothesis it must really be finite; and even if the particles of matter be infinitely divisible, it is known by experience to be of extreme tenuity at very small heights. The barometer rises in proportion to the superincumbent pressure. Now at the temperature of melting ice, the density of mercury is to that of air as 10,320 to 1; and as the mean height of the barometer is 29.528 inches, the height of the atmosphere by simple proportion is 30,407 feet, at the mean temperature of 62°, or 34,153 feet, which is extremely small, when compared with the radius of the earth. The action of the sun and moon disturbs the equilibrium of the atmosphere, producing oscillations similar to those in the ocean, which occasion periodic variations in the heights of the barometer. These, however, are so extremely small, that their existence in latitudes so far removed from the equator is doubtful; a series of observations within the tropics can alone decide this delicate point. Laplace seems to think that the flux and reflux distinguishable at Paris may be occasioned by the rise and fall of the ocean, which forms a variable base to so great a portion of the atmosphere.

The attraction of the sun and moon has no sensible effect on the trade winds; the beat of the sun occasions these aerial currents by rarefying the air at the equator, which causes the cooler and more dense part of the atmosphere to rush along the surface of the earth to the equator, while that which is heated is carried along the higher strata to the poles, forming two currents in the direction of the meridian. But the rotatory velocity of the air corresponding to its geographical situation decreases towards the poles; in approaching the equator it must therefore revolve more slowly than the corresponding parts of the earth, and the bodies on the surface of the earth must strike against it with the excess of their velocity, and by its reaction they will meet with a resistance contrary to their motion of rotation; so that the wind will appear, to a person supposing himself to be at rest, to blow in a contrary direction to the earth's rotation, or from east to west, which is the direction of the trade winds. The atmosphere scatters the sun's rays, and gives all the beautiful tints and cheerfulness of day. It transmits the blue light in greatest abundance; the higher we ascend, the sky assumes a deeper hue, but in the expanse of space the sun and stars must appear like brilliant specks in profound blackness.

The sun and most of the planets appear to be surrounded with atmospheres of considerable density. The attraction of the earth has probably deprived the moon of hers, for the refraction of the air at the surface of the earth is at least a thousand times as great as at the moon. The lunar atmosphere, therefore, must be of a greater degree of rarity than can be produced by our best air-pumps; consequently no terrestrial animal could exist in it. Many philosophers of the highest authority concur in the belief that light consists in the undulations of a highly elastic ethereal medium pervading space, which, communicated to the optic nerves, produce the phenomena of vision. The experiments of our illustrious countryman, Dr. Thomas Young, and those of the celebrated Fresnel,[51] show that this theory accords better with all the observed phenomena than that of the emission of particles from the luminous body. As sound is propagated by the undulations of the air, its theory is in a great many respects similar to that of light. The grave or low tones are produced by very slow vibrations, which increase in frequency progressively as the note becomes more acute. When the vibrations of a musical chord, for example, are less than sixteen in a second, it will not communicate a continued sound to the ear; the vibrations or pulses increase in number with the acuteness of the note, till at last all sense of pitch is lost. The whole extent of human hearing, from the lowest notes of the organ to the highest known cry of insects, as of the cricket, includes about nine octaves.

The undulations of light are much more rapid than those of sound, but they are analogous in this respect, that as the frequency of the pulsations in sound increases from the low tones to the higher, so those of light augment in frequency, from the red rays of the solar spectrum to the extreme violet. By the experiments of Sir William Herschel,[52] it appears that the heat communicated by the spectrum increases from the violet to the red rays; but that the maximum of the hot invisible rays is beyond the extreme red. Heat in all probability consists, like light and sound, in the undulations of an elastic medium. All the principal phenomena of heat may actually be illustrated by a comparison with those of sound. The excitation of heat and sound are not only similar, but often identical, as in friction and percussion; they are both communicated by contact and by radiation; and Dr. Young observes, that the effect of radiant beat in raising the temperature of a body upon which it falls, resembles the sympathetic agitation of a string, when the sound of another string, which is in unison with it, is transmitted to it through the air. Light, heat, sound, and the waves of fluids are all subject to the same laws of reflection, and, indeed, their undulating theories are perfectly similar. If, therefore, we may judge from analogy, the undulations of the heat producing rays must be less frequent than those of the extreme red of the solar spectrum; but if the analogy were perfect, the interference of two hot rays ought to produce cold, since darkness results from the interference of two undulations of light, silence ensues from the interference of two undulations of sound; and still water, or no tide, is the consequence of the interference of two tides.

The propagation of sound requires a much denser medium than that of either light or heat; its intensity diminishes as the rarity of the air increases; so that, at a very small height above the surface of the earth, the noise of the tempest ceases, and the thunder is heard no more in those boundless regions where the heavenly bodies accomplish their periods in eternal and sublime silence.

What the body of the sun may be, it is impossible to conjecture; but he seems to be surrounded by an ocean of flame, through which his dark nucleus appears like black spots, often of enormous size. The solar rays, which probably arise from the chemical processes that continually take place at his surface, are transmitted through space in all directions; but, notwithstanding the sun's magnitude, and the inconceivable heat that must exist where such combustion is going on, as the intensity both of his light and heat diminishes with the square of the distance, his kindly influence can hardly be felt at the boundaries of our system. Much depends on the manner in which the rays fall, as we readily perceive from the different climates on our globe. In winter the earth is nearer the sun by 1/30th than in summer, but the rays strike the northern hemisphere more obliquely in winter than in the other half of the year. In Uranus the sun must be seen like a small but brilliant star, not above the hundred and fiftieth part so bright as he appears to us; that is however 2,000 times brighter than our moon to us, so that he really is a sun to Uranus, and probably imparts some degree of warmth. But if we consider that water would not remain fluid in any part of Mars, even at his equator, and that in the temperate zones of the same planet even alcohol and quicksilver would freeze, we may form some idea of the cold that must reign in Uranus, unless indeed the ether has a temperature. The climate of Venus more nearly resembles that of the earth, though, excepting perhaps at her poles, much too hot for animal and vegetable life as they exist here; but in Mercury the mean heat, arising only from the intensity of the sun's rays, must be above that of boiling quicksilver, and water would boil even at his poles. Thus the planets, though kindred with the earth in motion and structure, are totally unfit for the habitation of such a being as man.

The direct light of the sun has been estimated to be equal to that of 5,563 wax candles of a moderate size, supposed to be placed at the distance of one foot from the object: that of the moon is probably only equal to the light of one candle at the distance of twelve feet; consequently the light of the sun is more than three hundred thousand times greater than that of the moon; for which reason the light of the moon imparts no heat, even when brought to a focus by a mirror.

In adverting to the peculiarities in the form and nature of the earth and planets, it is impossible to pass in silence the magnetism of the earth, the director of the mariner's compass, and his guide through the ocean. This property probably arises from metallic iron in the interior of the earth, or from the circulation of currents of electricity round it: its influence extends over every part of its surface, but its accumulation and deficiency determine the two poles of this great magnet, which are by no means the same as the poles of the earth's rotation. In consequence of their attraction and repulsion, a needle freely suspended, whether it be magnetic or not, only remains in equilibrio when in the magnetic meridian, that is, in the plane which passes through the north and south magnetic poles. There are places where the magnetic meridian coincides with the terrestrial meridian; in these a magnetic needle freely suspended, points to the true north, but if it be carried successively to different places on the earth's surface, its direction will deviate sometimes to the east and sometimes to the west of north. Lines drawn on the globe through all the places where the needle points due north and south, are called lines of no variation, and are extremely complicated. The direction of the needle is not even constant in the same place, but changes in a few years, according to a law not yet determined. In 1657, the line of no variation passed through London. In the year 1819, Captain Parry,[53] in his voyage to discover the north-west passage round America, sailed directly over the magnetic pole; and in 1824, Captain Lyon, when on an expedition for the same purpose, found that the variation of the compass was $37^\circ\ 30'$ west, and that the magnetic pole was then situate in $63^\circ\ 26'51''$ north latitude, and in $80^\circ\ 51'25''$ west longitude. It appears however from later researches that the law of terrestrial magnetism is of considerable complication, and the existence of more than one magnetic pole in either hemisphere has been rendered highly probable. The needle is also subject to diurnal variations; in our latitudes it moves slowly westward from about three in the morning till two, and returns to its former position in the evening.

A needle suspended so as only to be moveable in the vertical plane, dips or becomes more and more inclined to the horizon the nearer it is brought to the magnetic pole. Captain Lyon found that the dip in the latitude and longitude mentioned was $86^\circ\ 32'$. What properties the planets may have in this respect, it is impossible to know, but it is probable that the moon has become highly magnetic, in consequence of her proximity to the earth, and because her greatest diameter always points towards it.

The passage of comets has never sensibly disturbed the stability of the solar system; their nucleus is rare, and their transit so rapid, that the time has not been long enough to admit of a sufficient accumulation of impetus to produce a perceptible effect. The comet of 1770 passed within 80,000 miles of the earth without even affecting our tides, and swept through the midst of Jupiter's satellites without deranging the motions of those little moons. Had the mass of that comet been equal to the mass of the earth, its disturbing action would have shortened the year by the ninth of a day; but, as Delambre's[54] computations from the Greenwich observations of the sun, show that the length of the year has not been sensibly affected by the approach of the comet, Laplace proved that its mass could not be so much as the 5,000th part of that of the earth. The paths of comets have every possible inclination to the plane of the ecliptic, and unlike the planets, their motion is frequently retrograde. Comets are only visible when near their perihelia. Then their velocity is such that its square is twice as great as that of a body moving in a circle at the same distance; they consequently remain a very short time within the planetary orbits; and as all the conic sections of the same focal distance sensibly coincide through a small arc on each side of the extremity of their axis, it is difficult to ascertain in which of these curves the comets move, from observations made, as they necessarily must be, at their perihelia: but probably they all move in extremely eccentric ellipses, although, in most cases, the parabolic curve coincides most nearly with their observed motions. Even if the orbit be determined with all the accuracy that the case admits of, it may be difficult, or even impossible, to recognize a comet on its return, because its orbit would be very much changed if it passed near any of the large planets of this or of any other system, in consequence of their disturbing energy, which would be very great on bodies of so rare a nature. Halley[55] and Clairaut[56] predicted that, in consequence of the attraction of Jupiter and Saturn, the return of the comet of 1759[57] would be retarded 618 days, which was verified by the event as nearly as could be expected.

The nebulous appearance of comets is perhaps occasioned by the vapours which the solar heat raises at their surfaces in their passage at the perihelia, and which are again condensed as they recede from the sun. The comet of 1680[58] when in its perihelion was only at the distance of one-sixth of the sun's diameter, or about 148,000 miles from its surface; it consequently would be exposed to a heat 27,500 times greater than that received by the earth. As the sun's heat is supposed to be in proportion to the intensity of his light, it is probable that a degree of heat so very intense would be sufficient to convert into vapour every terrestrial substance with which we are acquainted.

In those positions of comets where only half of their enlightened hemisphere ought to be seen, they exhibit no phases even when viewed with high magnifying powers. Some slight indications however were once observed by Hevelius[59] and Lahire[60] in 1682; and in 1811 Sir William Herschel discovered a small luminous point, which he concluded to be the disc of the comet. In general their masses are so minute, that they have no sensible diameters, the nucleus being principally formed of denser strata of the nebulous matter, but so rare that stars have been seen through them. The transit of a comet over the sun's disc would afford the best information on this point. It was computed that such an event was to take place in the year 1827; unfortunately the sun was hid by clouds in this country, but it was observed at Viviers and at Marseilles at the time the comet must have been on it, but no spot was seen. The tails are often of very great length, and are generally situate in the planes of their orbits; they follow them in their descent towards the sun, but precede them in their return, with a small degree of curvature; but their extent and form must vary in appearance, according to the position of their orbits with regard to the ecliptic. The tail of the comet of 1680[61] appeared, at Paris, to extend over sixty-two degrees. The matter of which the tail is composed must be extremely buoyant to precede a body moving with such velocity; indeed the rapidity of its ascent cannot be accounted for. The nebulous part of comets diminishes every time they return to their perihelia; after frequent returns they ought to lose it altogether, and present the appearance of a fixed nucleus; this ought to happen sooner in comets of short periods. Laplace supposes that the comet of 1682 must be approaching rapidly to that state. Should the substances be altogether or even to a great degree evaporated, the comet will disappear for ever. Possibly comets may have vanished from our view sooner than they otherwise would have done from this cause. Of about six hundred comets that have been seen at different times, three are now perfectly ascertained to form part of our system; that is to say, they return to the sun at intervals of 76, 6.33, and 3.25 years nearly.

A hundred and forty comets have appeared within the earth's orbit during the last century that have not again been seen; if a thousand years be allowed as the average period of each, it may be computed by the theory of probabilities, that the whole number that range within the earth's orbit must be 1,400; but Uranus being twenty times more distant, there may be no less than

11,200,000 comets that come within the known extent of our system. In such a multitude of wandering bodies it is just possible that one of them may come in collision with the earth; but even if it should, the mischief would be local, and the equilibrium soon restored. It is however more probable that the earth would only be deflected a little from its course by the near approach of the comet, without being touched. Great as the number of comets appears to be, it is absolutely nothing when compared to the number of the fixed stars. About two thousand only are visible to the naked eye, but when we view the heavens with a telescope, their number seems to be limited only by the imperfection of the instrument. In one quarter of an hour Sir William Herschel estimated that 116,000 stars passed through the field of his telescope, which subtended an angle of 15′. This however was stated as a specimen of extraordinary crowding; but at an average the whole expanse of the heavens must exhibit about a hundred millions of fixed stars that come within the reach of telescopic vision.

Many of the stars have a very small progressive motion, especially μ Cassiopeia and 61 Cygni, both small stars; and, as the sun is decidedly, a star, it is an additional reason for supposing the solar system to be in motion. The distance of the fixed stars is too great to admit of their exhibiting a sensible disc; but in all probability they are spherical, and must certainly be so, if gravitation pervades all space. With a fine telescope they appear like a point of light; their twinkling arises from sudden changes in the refractive power of the air, which would not be sensible if they had discs like the planets. Thus we can learn nothing of the relative distances of the stars from us and from one another, by their apparent diameters; but their annual parallax being insensible, shows that we must be one hundred millions of millions of miles from the nearest; many of them however must be vastly more remote, for of two stars that appear close together, one may be, far beyond the other in the depth of space. The light of Sirius, according to the observations of Mr. Herschel, is 324 times greater than that of a star of the sixth magnitude; if we suppose the two to be really of the same size, their distances from us must be in the ratio of 57.3 to 1, because light diminishes as the square of the distance of the luminous body increases.

Of the absolute magnitude of the stars, nothing is known, only that many of them must be much larger than the sun, from the quantity of light emitted by them. Dr. Wollaston[62] determined the approximate ratio that the light of a wax candle bears to that of the sun, moon, and stars, by comparing their respective images reflected from small glass globes filled with mercury, whence a comparison was established between the quantities of light emitted by the celestial bodies themselves. By this method he found that the light of the sun is about twenty millions of millions of times greater than that of Sirius, the brightest, and supposed to be the nearest of the fixed stars. If Sirius had a parallax of half a second, its distance from the earth would be 525,481 times the distance of the sun from the earth; and therefore Sirius, placed where the sun is, would appear to us to be 3.7 times as large as the sun, and would give 13.8 times more light; but many of the fixed stars must be immensely greater than Sirius. Sometimes stars have all at once appeared, shone with a brilliant light, and then vanished. In 1572 a star was discovered in Cassiopeia, which rapidly increased in brightness till it even surpassed that of Jupiter;[63] it then gradually diminished in splendour, and after exhibiting all the variety of tints that indicates the changes of combustion, vanished sixteen months after its discovery, without altering its position. It is impossible to imagine any thing more tremendous than a conflagration that could be visible at such a distance. Some stars are periodic, possibly from the intervention of opaque bodies revolving about them, or from extensive spots on their surfaces. Many thousands of stars that seem to be only brilliant points, when carefully examined are found to be in reality systems of two or more suns revolving about a common centre. These double and multiple stars are extremely remote, requiring the most powerful telescopes to show them separately.

The first catalogue of double stars in which their places and relative positions are determined, was accomplished by the talents and industry of Sir William Herschel, to whom astronomy is indebted for so many brilliant discoveries, and with whom originated the idea of their combination in binary and multiple systems, an idea which his own observations had completely established, but which has since received additional confirmation from those of his son[64] and Sir James South,[65] the former of whom, as well as Professor Struve of Dorpat,[66] have added many thousands to their numbers. The motions of revolution round a common centre of many have been clearly established, and their periods determined with considerable accuracy. Some have already since their first discovery accomplished nearly a whole revolution, and one, if the latest observations can be depended on, is actually considerably advanced in its second period. These interesting systems thus present a species of sidereal chronometer, by which the chronology of the heavens will be marked out to future ages by epochs of their own, liable to no fluctuations from planetary disturbances such as obtain in our system.

Possibly among the multitudes of small stars, whether double or insulated, some may be found near enough to exhibit distinct parallactic motions, or perhaps something, approaching to planetary motion, which may prove that solar attraction is not confined to our system, or may lead to the discovery of the proper motion of the sun. The double stars are of various hues, but most frequently exhibit the contrasted colours. The large star is generally yellow, orange, or red; and the small star blue, purple, or green. Sometimes a white star is combined with a blue or purple, and more rarely a red and white are united. In many cases, these appearances are due to the influences of contrast on our judgment of colours. For example, in observing a double star where the large one is of a full ruby red, or almost blood colour, and the small one a fine green, the latter lost its colour when the former was hid by the cross wires of the telescope. But there are a vast number of instances where the colours are too strongly marked to be merely imaginary. Mr. Herschel observes in one of his papers in the *Philosophical Transactions*, as a very remarkable fact, that although red single stars are common enough, no example of an insulated blue, green, or purple one has as yet been produced.

In some parts of the heavens, the stars are so near together as to form clusters, which to the unassisted eye appear like thin white clouds: such is the milky way, which has its brightness from the diffused light of myriads of stars. Many of these clouds, however, are never resolved into separate stars, even by the highest magnifying powers. This nebulous matter exists in vast abundance in space. No fewer than 2,500 nebulae were observed by Sir William Herschel, whose places have been computed from his observations, reduced to a common epoch, and arranged into a catalogue in order of right ascension by his sister Miss Caroline Herschel,[67] a lady so justly celebrated for astronomical knowledge and discovery. The nature and use of this matter scattered over the heavens in such a variety of forms is involved in the greatest obscurity. That it is a self-luminous, phosphorescent material substance, in a highly dilated or gaseous state, but gradually subsiding by the mutual gravitation of its particles into stars and sidereal systems, is the hypothesis which seems to be most generally received; but the only way that any real knowledge on this mysterious subject can be obtained, is by the determination of the form, place, and present state of each individual nebula, and a comparison of these with future observations will show generations to come the changes that may now be going on in these rudiments of future systems. With this view, Mr. Herschel is now engaged in the difficult and laborious investigation, which is understood to be nearly approaching its completion, and the results of which we may therefore hope ere long to see made public. The most conspicuous of these appearances are found in Orion, and in the girdle of Andromeda. It is probable that light must be millions of years travelling to the earth from some of the nebulae.

So numerous are the objects which meet our view in the heavens, that we cannot imagine a part of space where some light would not strike the eye: but as the fixed stars would not be visible at such distances, if they did not shine by their own light, it is reasonable to infer that they are suns; and if so, they are in all probability attended by systems of opaque bodies, revolving about them as the planets do about ours. But although there be no proof that planets not seen by us revolve about these remote suns, certain it is, that there are many invisible bodies wandering in space, which, occasionally coming within the sphere of the earth's attraction are ignited by the velocity with which they pass through the atmosphere, and are precipitated with great violence on the earth. The obliquity of the descent of meteorites, the peculiar matter of which they are composed, and the explosion with which their fall is invariably accompanied, show that they are foreign to our planet. Luminous spots altogether independent of the phases have occasionally appeared on the dark part of the moon, which have been ascribed to the light arising from the eruption of volcanoes; whence it has been supposed that meteorites have been projected from the moon by the impetus of volcanic eruption; it has even been computed, that if a stone were projected from the moon in a vertical line, and with an initial velocity of 10,992 feet in a second, which is more than four times the velocity of a ball when first discharged from a cannon, instead of falling back to the moon by the attraction of gravity, it would come within the sphere of the earth's attraction, and revolve about it like a satellite. These bodies, impelled either by the direction of the primitive impulse, or by the disturbing action of the sun, might ultimately penetrate the earth's atmosphere, and arrive at its surface. But from whatever source meteoric stones may come, it seems highly probable, that they have a common origin, from the uniformity, we may almost say identity, of their chemical composition.

The known quantity of matter bears a very small proportion to the immensity of space. Large as the bodies are, the distances that separate them are immeasurably greater; but as design is manifest in every part of creation, it is probable that if the various systems in the universe had been nearer to one another, their mutual disturbances would have been inconsistent with the harmony and stability of the whole. It is clear that space is not pervaded by atmospheric air, since its resistance would long ere this have destroyed the velocity of the planets; neither can we affirm it to be void, when it is traversed in all directions by light, heat, gravitation, and possibly by influences of which we can form no idea; but whether it be replete with an ethereal medium, time alone will show.

Though totally ignorant of the laws which obtain in the more distant regions of creation, we are assured, that one alone regulates the motions of our own system; and as general laws form the ultimate object of philosophical research, we cannot conclude these remarks without considering the nature of that extraordinary power, whose effects we have been endeavouring to trace through some of their mazes. It was at one time imagined, that the acceleration in the moon's mean motion was occasioned by the successive transmission of the gravitating force; but it has been proved, that, in order to produce this effect, its velocity must be about fifty millions of times greater than that of light, which flies at the rate of 200,000 miles in a second: its action even at the distance of the sun may therefore be regarded as instantaneous; yet so remote are the nearest of the fixed stars, that it may be doubted whether the sun has any sensible influence on them.

The analytical expression for the gravitating force is a straight line; the curves in which the celestial bodies move by the force of gravitation are only lines of the second order; the attraction of spheroids according to any other law would be much more complicated; and as it is easy to prove that matter might have been moved according to an infinite variety of laws, it may be concluded, that gravitation must have been selected by Divine wisdom out of an infinity of other laws, as being the most simple, and that which gives the greatest stability to the celestial motions.

It is a singular result of the simplicity of the laws of nature, which admit only of the observation and comparison of ratios, that the gravitation and theory of the motions of the celestial bodies are independent of their absolute magnitudes and distances; consequently if all the bodies in the solar system, their mutual distances, and their velocities, were to diminish proportionally, they would describe curves in all respects similar to those in which they now move; and the system might be successively reduced to the smallest sensible dimensions, and still exhibit the same appearances. Experience shows that a very different law of attraction prevails when the particles of matter are placed within inappreciable distances from each other, as in chemical and capillary attractions, and the attraction or cohesion; whether it be a modification of gravity, or that some new and unknown power comes into action, does not appear; but as a change in the law of the force takes place at one end of the scale, it is possible that gravitation may not remain the same at the immense distance of the fixed stars. Perhaps the day may come when even gravitation, no longer regarded as an ultimate principle, may be resolved into a yet more general cause, embracing every law that regulates the material world.

The action of the gravitating force is not impeded by the intervention even of the densest substances. If the attraction of the sun for the centre of the earth, and for the hemisphere diametrically opposite to him, was diminished by a difficulty in penetrating the interposed matter, the tides would be more obviously affected. Its attraction is the same also, whatever the substances of the celestial bodies may be, for if the action of the sun on the earth differed by a millionth part from his action on the moon, the difference would occasion a variation in the sun's parallax mounting to several seconds, which is proved to be impossible by the agreement of theory with observation. Thus all matter is pervious to gravitation, and is equally attracted by it.

As far as human knowledge goes, the intensity of gravitation has never varied within the limits of the solar system; nor does even analogy lead us to expect that it should; on the contrary, there is every reason to be assured, that the great laws of the universe are immutable like their Author. Not only the sun and planets, but the minutest particles in all the varieties of their attractions and repulsions, nay even the imponderable matter of the electric, galvanic, and magnetic fluids are obedient to permanent laws, though we may not be able in every case to resolve their phenomena into general principles. Nor can we suppose the structure of the globe alone to be exempt from the universal fiat, though ages may pass before the changes it has undergone, or that are now in progress, can be referred to existing causes with the same certainty with which the motions of the planets and all their secular variations are referable to the law of gravitation. The traces of extreme antiquity perpetually occurring to the geologist, give that information as to the origin of things which we in vain look for in the other parts of the universe. They date the beginning of time; since there is every reason to believe, that the formation of the earth was contemporaneous with that of the rest of the planets, but they show that creation is the work of Him with whom '*a thousand years are as one day, and one day as a thousand years*.'

Notes

[1] Newton, Sir Isaac, 1642-1727, physicist and mathematician. Born in Woolsthorpe, England. Newton's major work, the *Principia* was published in 1687. The *Principia* demonstrated that celestial bodies follow the laws of dynamics and formulated the law of universal gravitation. Newton also independently developed the methods of integral and

differential calculus which he called his "method of Fluxions." The Fluxions method was documented in his *Methodis Serierum et Fluxionum* written in 1671, but unpublished until 1736. This delay led to a bitter rivalry between Newton and Leibniz who independently developed both the foundations of and notation of calculus in use today.
[2] Mackintosh, Sir James, 1765-1832, physician, lawyer, and philosopher. Born near Inverness, Scotland.
[3] Kepler, Johannes, 1571-1630, astronomer, born in Weil-der-Stadt, Germany. Kepler worked with Tycho Brahe, showing that planetary motions were far simpler than had been imagined. He announced his first and second laws of planetary motion in *Astronomia nova* (1609). Kepler's third law was formulated in *Harmonice mundi* (1619). Kepler also made several important contributions to mathematics including a method for finding the volume of a solid of revolution (1616) which contributed to the later development of calculus.
[4] *…proportional to the cubes of their mean distance from his centre.* Kepler's 3rd law.
[5] *nutation.* An oscillatory movement of the axis of a rotating body (as the earth). *Merriam-Webster's Dictionary.*
[6] *aphelion.* The point that is farthest from the sun in the orbit of a planet or comet.
[7] *vectores.* Archaic spelling for "vectors."
[8] *equal areas in equal times.* Kepler's 2nd law.
[9] *Pallas.* The "recently discovered planets" are the first four asteroids (Ceres, Pallas, Juno and Vesta) discovered in the first decade of the 19th century. Ceres was discovered by the Italian monk Giuseppe Piazzi (1746-1826) at the Palermo Observatory on January 1, 1801. Pallas was discovered by Olbers in 1802, Juno by Harding in 1804, and Vesta by Olbers in 1807. The four asteroids are all over 200 km in diameter with Ceres the largest (1,003 km). Several hundred thousand asteroids are now known and 26 of those larger than 200 km in diameter.
[10] See previous note.
[11] *apsides.* The point in an astronomical orbit at which the distance of the body from the center of attraction is either greatest or least. *Merriam-Webster's Collegiate Dictionary.*
[12] *retrograde.* In astronomy, moving in a direction opposite to that of the movement of the earth around the sun.
[13] *Sidereal revolution (or year)*. In astronomy, the period in which the fixed stars apparently complete a revolution and come to the same point in the heavens. *Webster's 1828 Dictionary.*
[14] *tropical year.* The space or period of time in which the sun moves through the twelve signs of the ecliptic, or whole circle, and returns to the same point. This is the solar year, and the year, in the strict and proper sense of the word. It is called also the tropical year. This period comprehends what are called the twelve calendar months, or 365 days, 5 hours, and 49 minutes, within a small fraction. But in popular usage, the year consists of 365 days, and every fourth year of 366; a day being added to February, on account of the 5 hours and 49 minutes. *Webster's 1828 Dictionary.*
[15] Ptolemy, fl.127-145, Greek astronomer and geographer. Ptolemy's major work, the *Almagest* formulated the principles of the geocentric system of the world. Ptolemy also compiled works in geography and music.
[16] Lagrange, Joseph Louis, 1736-1813 an Italian-French mathematician and astronomer, born in Turin, Italy. His major work was the *Mécanique analytique* (1788). Lagrange taught at the École Polytechnique, and was instrumental in the reform of the metric system (1795). Lagrange made important contributions to number theory, the calculus of variations, the principle of least action, kinetic energy, and on the stability of the solar system.
[17] Playfair, John, 1748-1819, mathematician and geologist, born in Benvie, Dundee, Scotland, UK. He taught at Edinburgh (1785), where he held a joint appointment in mathematics and natural philosophy. He wrote on geometry.
[18] See note 4, *Foreword to the Second Edition.*
[19] *speed of light.* The modern value is nearly 186,000 miles/s or 300,000 km/s.
[20] Book III, Chapter VI considers the properties of an ethereal medium.
[21] Bacon, Francis, 1561-1626, philosopher and scientist, born in London, England. He studied at Cambridge and Gray's Inn (1576), and was called to the bar in 1582. His major works *are The Advancement of Learning* (1605) and *Novum Organum* (1620). Bacon is considered by many as the founder of the modern scientific method.
[22] The Royal Greenwich Observatory (RGO) was founded in 1675 by decree of Charles II for the sole purpose of improving the level of astronomical knowledge required to support navigation at sea. Almost a century was to elapse between the founding of the RGO and the first edition of *The Nautical Almanac* (1767) under the fifth Astronomer Royal, Nevil Maskelyne. This almanac contained tabulations of the distances of the Moon's centre from the Sun and from the bright stars for every three hours, so that the navigator could determine Greenwich time and hence his longitude from observations of such lunar distances. *HM Nautical Almanac Office, Rutherford Appleton Laboratory.*
[23] *Ephemeris.* Tables giving the projected positions of celestial bodies for every day of a certain period.
[24] *parallax.* The apparent change in the position of an observed object when seen from two different points.
[25] Eratosthenes, c. 194 BC, Greek astronomer, born in Cyrene. He was chief librarian at Alexandria, and is remembered for the first scientific calculation of the Earth's circumference.

[26] *precession of the equinoxes.* The earlier occurrence of the equinoxes in each sidereal year because of a slow variation in the rotation of the earth, caused by the gravitational pull of the sun and moon. *The Wordsmyth Educational Dictionary-Thesaurus.*
[27] Cook, James, 1728-1779, navigator, born in Marton, England. In an expedition to Tahiti for the Royal Society he observed a transit of Venus across the Sun (1768-71). In his second voyage he sailed round Antarctica (1772-75). His third voyage (1776-79) attempted to find a Northwest passage from the Pacific.
[28] At 4.2 light years, the nearest star *Proxima Centuri* is approximately 10 times farther than this distance.
[29] Struve, Friedrich Georg Wilhelm, 1793-1864, astronomer, born in Altona, Germany. He taught at Dorpat (1813), and directed the observatory there. In 1838 he made one of the first measurements of the parallax of the star Vega. Friedrich Bessel was the first to measure stellar parallax on star 61 Cygni (see also note 37, *bk. II, Chap. XIV*). Struve is remembered most for his pioneering studies of binary stars. In 1837 he published a catalogue of over 3000 binary systems in his *Stellarum Duplicium Mensurae Micrometricae*.
[30] *libration.* An oscillation in the apparent aspect of a secondary body (as a planet or a satellite) as seen from the primary object around which it revolves. *Merriam-Webster's Collegiate Dictionary.*
[31] See note 14, *Foreword to the Second Edition.*.
[32] Hipparchus, c. 150 BC, astronomer, born in Nicaea, Rhodes. He discovered the precession of the equinoxes, the eccentricity of the Sun's path, and the length of the solar year. He also drew up a catalogue of 1080 stars.
[33] *caeteris paribus.* New Latin, "other things being equal." *Merriam-Webster's Collegiate Dictionary.*
[34] Leslie, Sir John, 1766-1832, physicist, born in Largo, Scotland, UK. He taught mathematics and natural philosophy at Edinburgh. His inventions included a differential thermometer, a hygrometer, and a photometer.
[35] Young, Thomas, 1773-1829, physicist, physician, and Egyptologist (he helped decipher the Rosetta stone), born in Milverton, Somerset, England. He was professor of natural philosophy to the Royal Institution (1801). Young's research on interference established the wave theory of light. In the first draft of her autobiography Mary Somerville expresses great sympathy for Young who she says was forced to suffer the scorn of British science [which supported Newton's corpuscular theory of light] in reacting to Young's original results on the diffraction of light: "Young had to endure this for 14 years until Fresnel [and Arago] in France verified the results (Dep c.355, 22, MSAU-2: p. 118-120, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University)." Young was also the first to use the word energy in its modern sense. Young's modulus, a constant in the expression for elasticity, is named after him.
[36] Perkins, Jacob, 1766-1849, inventor; born in Newburyport, USA. An apprentice goldsmith. He developed steel plates as a replacement for copper in the bank note engraving process. Perkins moved to England (1818) where he produced the first penny postage stamps (1840).
[37] Timocharis, Aristarchus and Aristyllus were three astronomers who all worked at Alexandria. Timocharis observed around 290 BC while Aristyllus observed a generation later around 260 BC. We know that Aristarchus measured the ratio of the distances to the moon and to the sun and, although his methods could never yield accurate results, they did show that the sun was much further from the earth than was the moon. There is some evidence that the observations of Timocharis and Aristyllus were made to determine the constants in the heliocentric theory of Aristarchus and that Timocharis certainly began his observations some time before Aristarchus proposed his heliocentric universe. *The MacTutor History of Mathematics archive.*
[38] Bradley, James, 1693-1762, astronomer, born in Sherborne, England. Bradley taught astronomy at Oxford from 1721. He later succeeded Edmond Halley as professor of astronomy at Greenwich. His work on the aberration of light (1729) provided the first direct evidence of the Copernican hypothesis.
[39] *Brahmins.* A Hindu of the highest caste traditionally assigned to the priesthood. *Merriam-Webster's Collegiate Dictionary.*
[40] According to traditional literal interpretations of biblical chronologies.
[41] Bailly, Jean Sylvain, 1736-1793, astronomer, born in Paris, France. Bailly studied Halley's comet and the satellites of Jupiter. His major work, the *Histoire de l'astronomie* was published between 1775 and 1787.
[42] Eudoxus of Cnidus, c. 353 BC, Greek astronomer and mathematician, born in Cnidus, Asia Minor. Eudoxus introduced a system of 27 nested spheres to account for planetary motion. He also established geometric principles that helped in laying the foundations for Euclid.
[43] Chiron, a wise centaur. In Greek mythology Chiron received the legendary Achilles as a disciple.
[44] Known today as Dendera, Egypt. Site of the ancient temple of Aset and Hathor.
[45] Salt, Henry, 1780-1828, Essay on Dr. Young's and M. Champollion's phonetic system of hieroglyphics; with some additional discoveries, by which it may be applied to decipher the names of the ancient kings of Egypt and Ethiopia. London, Longman, Hurst, Rees, Orme, Brown, and Green, 1825.

[46] See note 35.
[47] Kater, Captain Henry, 1777-1835, *Mechanics*, London : Printed for Longman, Rees, Orme, Brown, and Green, and John Taylor, 1830.
[48] Formentera is the smallest inhabited island in the archipelago of the Balears (Balearic Islands) and also the closest to the meridian. It is situated at 38l N and 1l E.
[49] Ibn Junis, c. 1009, Muslim astronomer, author of the "Hakimite Tables."
[50] *sysigies (or sysygies).* in astronomy, the alignment, either in conjunction or opposition, of three celestial bodies within the same gravitational system, esp. the sun, moon, and earth. *The Wordsmyth Educational Dictionary-Thesaurus.*
[51] Fresnel, Augustin Jean, 1788-1827, physicist, born in Broglie, France. Fresnel's investigations on interference were instrumental in establishing the wave theory of light demonstrated earlier by Thomas Young in England.
[52] Herschel, Sir William (Frederick), 1738-1822, astronomer, born in Hanover, Germany. Herschel moved to England in 1757 and discovered Uranus, the first planet to be discovered since antiquity, in 1781. His fame spread quickly and was appointed private astronomer to King George III. He continued his research, assisted by his sister Caroline and his son John. In 1785 Herschel developed a cosmogony, a theory about the origin of the universe based on his hypothesis that nebulae were really large clusters of stars.
[53] Parry, Sir William Edward, 1790-1855, navigator, born in Bath, England. Parry commanded five Arctic expeditions (1818-27). Mary Somerville presented Parry with 'a large quantity of marmalade' for his 1824 Arctic expedition. Parry later named an island $(74^\circ\ 44' \mathrm{N}\ 96^\circ\ 10' \mathrm{W})$ in the Canadian Arctic after her.
[54] Delambre, Jean Baptiste Joseph, 1749-1822, *Astronomie théorique et pratique*, Paris, Ve. Courcier, 1814.
[55] Halley, Edmund, 1656-1742, astronomer and mathematician, born in London, England. Halley correctly predicted the return in 1758 of the comet now named after him (see note 57). He encouraged and financed Isaac Newton's *Principia* (1687).
[56] Clairaut, Alexis Claude, 1713-1765, *Theorie de la figure de la terre, tirée des principes de l'hydrostratique*, Paris, 1743.
[57] In 1705 Edmund Halley predicted, using Newton's newly formulated laws of motion, that the comet seen in 1531, 1607, and 1682 would return in 1758 (after his death in 1742).
[58] Isaac Newton in the *Principia* (1687), applied his theory of gravitation to show that the 1680 comet moved in an elliptical very nearly parabolic orbit.
[59] Hevelius, Johannes, 1611-1687, astronomer, born in Gdansk, Poland. Hevelius catalogued over 1,500 stars in *Prodromus Astronomiae* (1690), and is credited with the discovery of four comets. Many features of the Moon were named by him in his lunar atlas, *Selenographia* (1647).
[60] Lahire, [Philippe] de, 1640-1718, *Memoires de mathematique et de physique, contenant un traité des epicycloïde, & de leurs usages dans les mechanique*, Paris, De l'Imprimerie royale, 1694.
[61] See note 58.
[62] Wollaston, William Hyde, 1766-1828, chemist, born in East Dereham, England. After an eleven year practice as a physician, Wollaston devoted his time to studies in chemistry, optics, and physiology. He discovered palladium and rhodium, and is credited with several important inventions.
[63] Known also as Cassiopeiae 1572. The Danish astronomer Tycho Brahe's precise measurements of parallax demonstrated that this Nova was not a nearby phenomenon. The Nova remained visible to the naked eye until 1574.
[64] Herschel, Sir John Frederick William, 1792-1871, a contemporary and close astronomer friend of Mary Somerville. Herschel was born in Slough, England. He was the son of Sir William Herschel. John Herschel was instrumental in the introduction of Leibniz notation into English mathematics. He was also a strong advocate of the wave nature of light, an active observational astronomer, and a pioneer in celestial photography. In 1849 he wrote a book for educated lay persons *Outlines of Astronomy*. Herschel also spent four years observing stars in the southern hemisphere where he recorded the locations of nearly 69,000 stars and other important objects.
[65] South, Sir James, Practical observations on the Nautical Almanac and Astronomical Ephemeris, London : William Sams, 1822.
[66] see note 29.
[67] Herschel, Caroline Lucretia, 1750-1848, astronomer, born in Hanover, Germany. She was the sister and assistant of Sir William Herschel. She is credited with the discovery of eight comets. She published a catalogue of 2500 nebulae and star clusters in 1822.