WONDERS OF THE HEAVENS

HERSCHEL'S TELESCOPE

J. H. Wilson

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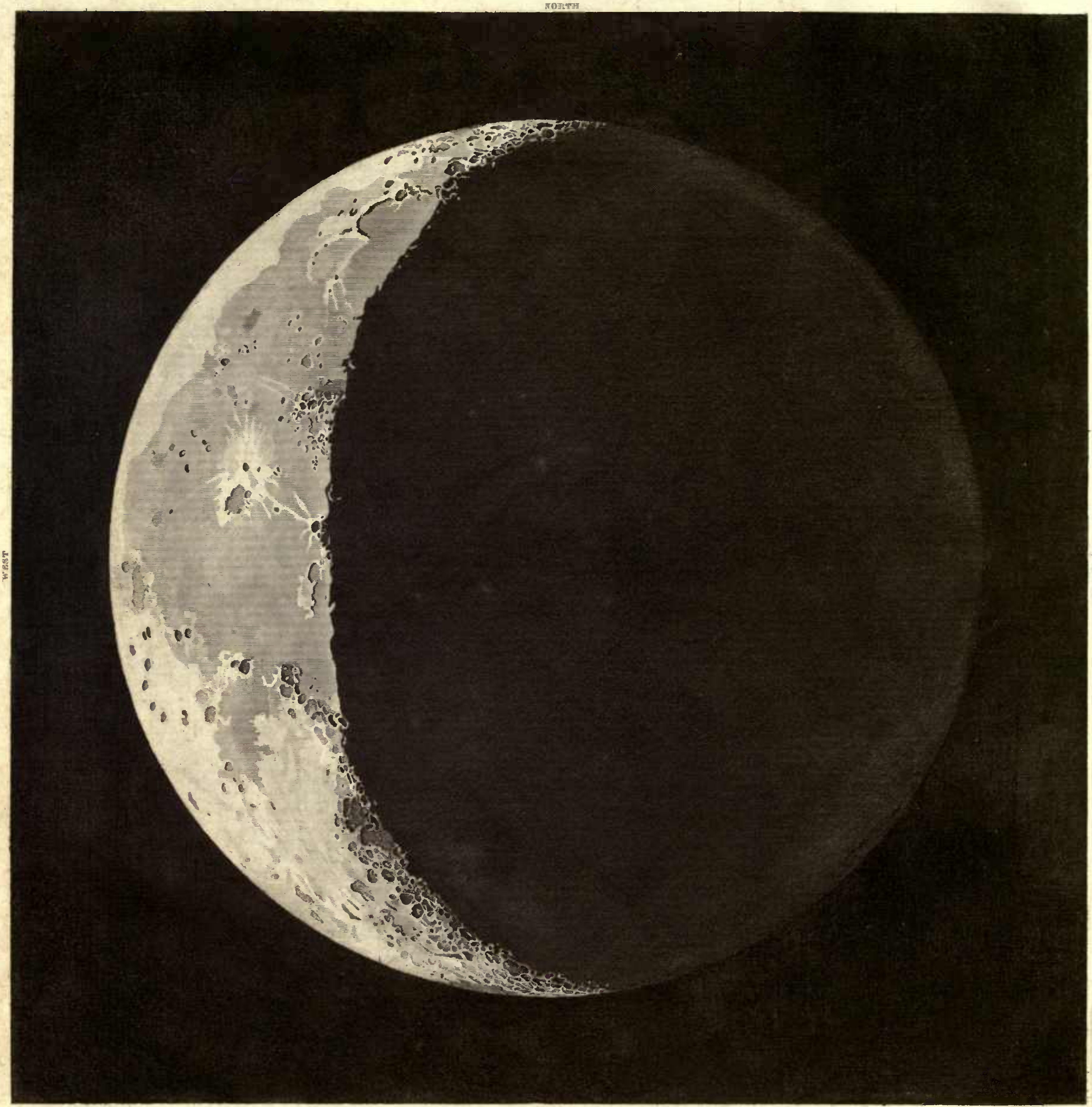
HERSCHEL'S FORTY-FOOT REFLECTING TELESCOPE.

WONDERS
OF THE
HEAVENS.

ILLUSTRATED BY ENGRAVINGS.

TELESCOPIC VIEW OF THE MOON

PAST THE LAST QUADRATURE



From an Original Drawing.

THE WONDERS OF THE HEAVENS,

[lacks pp. 11-14]

BEING

A POPULAR VIEW OF ASTRONOMY,

INCLUDING A FULL ILLUSTRATION OF THE

MECHANISM OF THE HEAVENS;

EMBRACING THE

SUN, MOON, AND STARS,

WITH DESCRIPTIONS OF

THE PLANETS, COMETS, FIXED STARS, DOUBLE STARS, THE CONSTELLATIONS, THE GALAXY,
OR MILKY-WAY, THE ZODIACAL LIGHT, AURORA BOREALIS, OR NORTHERN
LIGHTS, METEORS, CLOUDS, FALLING STARS, AËROLITES, &c.

Illustrated by Numerous Maps and Engravings.

BY DUNCAN BRADFORD.

"The Heavens declare the glory of God."

BOSTON:
OTIS, BROADERS, AND COMPANY.

1845.

Gift
Pacific Theol. Sem.

PREFACE.

In the preparation of this volume for the press, the main purpose, kept constantly in view, was to make the subject plain and interesting to the people. It has been heretofore too much kept from them, by the practice of mingling mathematics with it to such an extent as to alarm the neophyte at the very threshold of the temple of astronomy.

To succeed in my attempt, I have judged it best to select, from such books as have fallen into my hands, those parts that were least encumbered with the abstruse and unintelligible, rather than to trust to my own powers of making a subject simple and attractive that is in itself almost too difficult for the majority of minds. How far I have succeeded, I must leave, not to the learned or the critic, but to the people themselves for whose perusal these pages are intended.

The principal works used in the compilation were "Uranographie par Francœur," "Manuel d'Astronomie par Bailly," "Astronomie Physique par Biot," "Herschel's Astronomy," "Arago on Comets, translated by Farrar," Brewster's Ferguson," Silliman's Journal," Dick's Christian Philosopher," "Chalmer's Astronomical Discourses," "Forster's Atmospheric Phenomena," &c. From many of these I have largely drawn, and the least I can do is to make a general acknowledgment of the fact. Finally, I must rest my hopes of the success of this compilation, on the curiosity so natural to the human mind, that "awakes in us when free from cares a desire to learn what is going on even in the heavens."

Duncan Bradford.

THE ENGLISH AND LATIN NAMES OF THE CONSTELLATIONS DESCRIBED IN THIS VOLUME.

English Names.	Latin Names.
The Bull.	*Taurus.*
Orion.	*Orion.*
The Hare.	*Lepus.*
Noah's Dove.	*Columba Noachi.*
The River Po.	*Eridanus.*
The Charioteer.	*Auriga.*
The Camelopard.	*Camelopardalis.*
The Lynx.	*Lynceus.*
The Twins.	*Gemini.*
The Little Dog.	*Canis Minor.*
The Unicorn.	*Monoceros.*
The Great Dog.	*Canis Major.*
The Ship Argo.	*Argo Navis.*
The Crab.	*Cancer.*
The Lion.	*Leo.*
The Little Lion.	*Leo Minor.*
The Sextant.	*Sextans.*
The Water Snake.	*Hydra.*
The Cup.	*Crater.*
The Great Bear.	*Ursa Major.*
Berenice's Hair.	*Coma Berenices.*
The Crow.	*Corvus.*
The Virgin.	*Virgo.*
The Bear Driver.	*Bootes.*
The Greyhounds.	*Asterion et Chara, vel Canes Venatici.*
The Centaur.	*Centaurus.*
The Cross.	*Crux.*
The Wolf.	*Lupus.*
The Balance.	*Libra.*
The Serpent Bearer.	*Serpentarius vel Ophiucus.*
The Serpent.	*Serpens.*
The Northern Crown.	*Corona Borealis.*
The Little Bear.	*Ursa Minor.*
The Scorpion.	*Scorpio.*
Hercules.	*Hercules.*
Cerberus.	*Cerberus.*
The Dragon.	*Draco.*
The Harp.	*Lyra.*
The Archer.	*Sagittarius.*
The Eagle.	*Aquila.*
Antinous.	*Antinous.*
The Dolphin.	*Delphinus.*
The Swan.	*Cygnus.*
The Capricorn.	*Capricornus.*
Andromeda.	*Andromeda.*
The Fishes.	*Pisces.*
Cepheus.	*Cepheus.*
Cassiopeia.	*Cassiopeia.*
The Flying Horse.	*Pegasus.*
The Little Horse.	*Equulus vel Equi Sectio.*
The Water Bearer.	*Aquarius.*
The Southern Fish.	*Piscis Australis.*
Perseus.	*Perseus.*
The Head of Medusa.	*Caput Medusæ.*
The Ram.	*Aries.*
The Sea Monster.	*Cetus.*

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WONDERS OF THE HEAVENS.

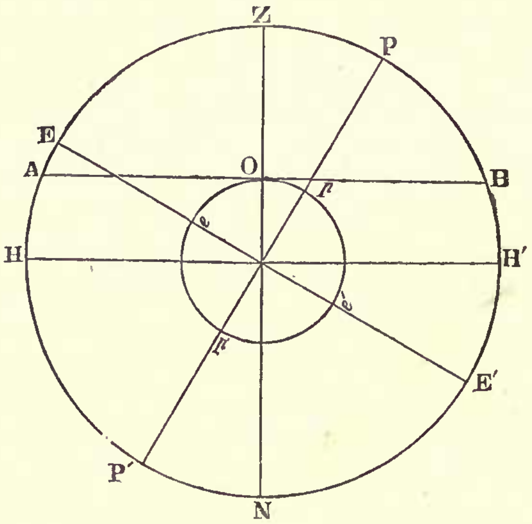
CHAPTER I.

SECTION I.

Appearances of the heaven—by day—by night—Diurnal motion—Celestial sphere—Its poles—Zenith—Nadir—Sensible horizon—Rational horizon—Meridian—Equator—Hemispheres—East, west, north and south points—Circumpolar stars—Declination and right ascension—Equality of a star's successive revolutions—how made known—Use of this regular motion to astronomers—Sidereal day—Time-keepers used by the ancients—Chronometers—Illustration of the preceding—Deductions from appearances—Stars called Fixed—Idea of immensity impressed by the study of the stars—Annual parallax—Each star the centre of a system, and possibly the satellite of some more magnificent primary.

Take a man who had been blind from his birth, and who had imbibed no ideas of any existences but those that were immediately and intimately connected with his other senses, restore him suddenly to perfect and healthy vision, and place him in some extensive champaign, where there were no obstacles to confine his view; would he not discover a scene the most brilliantly beautiful mortal eye ever beheld? That azure dome sown broadcast, as it were, with living light! How would he desire to understand the causes of the changes he would witness, the regular and constant succession of day and night; phenomena so different, yet each so interesting to his new-born and startled sense. Soon after the dawn of day, he would observe in one part of heaven a dazzling circle rising apparently out of the earth, and scattering about it in all directions numberless rays of brilliant light. It ascends slowly the gorgeous dome, the heat and light increasing as it ascends, until it attains a point nearly overhead, where it seemingly rests but a moment in its midway course, then descends as it arose, and disappears at last in a part of the horizon opposite to that where it first appeared. The light soon fades away, and night comes on, bringing a new and more interesting, if not so brilliant a spectacle. During the day, a single body had attracted all admiration to himself, by his majestic motion and the splendor of his rays. Now there appear on all sides shining points, variable in size and brightness, decorating in countless numbers the vault of heaven, and increasing still in proportion as the darkness becomes more profound, till the whole celestial space seems to be filled. The motion of these bodies adds also to the beauty and interest of the scene. Some, moving in the same direction as the sun, disappear like him from our view in the west. Others are rising in or near the east, and ascending in their turn. Such are the general phenomena of the rising and setting of the heavenly bodies. Yet all do not thus disappear below the horizon. There are some which never reach that circle, and whose track can be followed during the whole night. Those stars which form the cluster called the *Great Bear*, or *Charles' Wain*, are among this number in our latitude; and if one stations himself with his right hand toward the east and his left toward the west, he will see this group, so well known in our climate, assume successively different positions, while the individual stars of the group maintain the same mutual relations of figure and distance. Meantime the darkness diminishes, the dawn reappears, the light increases, the sun by his superior brightness dims the light of the stars, and the phenomena of morning are renewed in the same order as before. This general movement of the heavenly bodies from east to west, in the course of a day and night, is called the *diurnal* motion. In what we have said above, we have brought forward only those phenomena, which appear on a simple inspection.

The different motions that we have observed in the heavens may have led us to think that we were situated in a point of the universe, around which as a centre revolves a sphere sprinkled with shining drops. This sphere seems to turn on an imaginary line, which is called the axis of the earth, the points where this line touches the heaven being the celestial poles; the one that is elevated in our latitude being called the *northern* or *Arctic* pole, and that which is diametrically opposite, and which we cannot perceive, the *southern* or *Antarctic* pole. We must be careful not to confound these two points with that situated directly over our head and its opposite, the first of which is the *zenith*, the last the *nadir*. Every point on the surface of the earth has its zenith and its nadir; yet there are but two points whose zeniths coincide with the poles of the heaven, and these are the poles of the earth. Thus, let O be the place of the observer, P and P′ the poles of the heaven, *p* and *p′* the poles of the earth; Z is the zenith and N the nadir of the observer at O. If the observer were at *e*, his zenith would be E and his nadir E′.



If now a plane, A B, be imagined tangent to the surface of the earth at O, it will represent the *sensible horizon* of a spectator at that point, separating the parts of the heaven and earth visible, from the parts invisible to him. There is another horizon, called the *rational*. It is a plane, parallel to the sensible, and passes through the centre of the earth, which is also the centre of this circular plane; thus H H′ represents the rational horizon of the observer at O. Every place, then, must have a sensible and rational horizon peculiar to itself. These planes are quite important in astronomy. From them we measure the altitude of the heavenly bodies; and these measures are the foundation of astronomy.

The great circle which passes through the poles of heaven and the zenith of a place is the *meridian* (north and south line) of that place.

The stars, supposed fixed to this celestial sphere, describe every day circles, smaller according as they are situated nearer the poles of the heaven. The largest of these circles, whose points are all equally distant from the poles, is called the *equator*, while the circles parallel to it are called simply parallels. The equator divides the sphere into two equal parts; one forms the northern, the other the southern hemisphere.

The *east* is that point in which a heavenly body (describing the equator) rises; the *west*, the point where the same body sets. The intersection of the horizon by the meridian determines two other points; the *south*, where the sun is at noon in regard to us, and the *north*, where the sun is at noon in regard to those situated as far south, as we are north of the equator. These four points are known under the name of the *cardinal* points.

If we have observed the movements of the various stars, we must have noticed, that some of them never set, but are constantly above the horizon. Among these, a few experience but a very slight displacement, and scarcely appear to move at all. These, being near the axis about which all the heavenly bodies revolve, describe diurnal circles of so small a diameter, that they are scarcely discernible by the eye. Yet during their revolution they are seen to pass the meridian twice, once over the *upper* meridian, that is, between the pole and the zenith, and once over the *lower* meridian, that is, between the pole and the horizon. These heavenly bodies are denominated *circumpolar*.

is no north or south point, and we shall hereafter see that the phenomena from which we deduced our definition of these points, namely, the rising and setting of stars, do not take place at these situations. We have already seen that P, *p*, are points in the meridian of every place; all these meridians therefore intersect each other at the two poles. If *p*, the south pole, be above the horizon, P, the north pole, will of course be below it.

One circumstance may here require explanation before we proceed farther. We have already seen that the centre of the heavenly sphere is a point in the axis P *p*, and that this centre appears to be the situation of the observer; and we have also said that the results of observation are the same, whereever on the earth's surface he be placed. If two observers be at situations, the one, one thousand miles east of the other, the situation of both cannot be in the line P *p;* but if the one is in it, the other must be nearly one thousand miles out of it: yet they both appear to be in it. We know from very simple reasoning, or we may easily satisfy ourselves by trial, that a small change of position in the observer does not affect the apparent position of a very distant object. Thus, if there be two trees, or two spires, distant ten miles from each other, and two men stand half-way between them, the one precisely in the line joining them, and the other a yard on one side of it, each will alike feel that, to all common observation, he is exactly in the line which unites them. The angle between the two directions, in this case, would be considerably less than half a minute, and would not be observable except by instruments of some delicacy. In the same manner, if the distance to the points P, *p*, be excessively great in proportion to the distance between the situations of different observers, each observer will seem to be in the same position with respect to the points P, *p*, and the line joining them. There is therefore nothing absurd or contradictory in the apparent coincidence of each situation with the line P *p*, if we only suppose the points P, *p*, so remote from the earth, that any line drawn on its surface is too small to be estimated in comparison with that distance; and we get therefore a notion of the vast distance of those points, instead of a difficulty affecting the notion of such a revolution as we have supposed to take place. If however every point on the earth's surface be apparently in the line P *p*, so must its centre be also, which lies in the midst between these points. The axis P *p* therefore may be considered to pass through the centre of the earth.

The fixed stars are so called because the ancients believed they never changed their positions in respect to each other. Although their motions are very slow and almost imperceptible, yet the skilful and assiduous observations of modern astronomers, and particularly of Herschel, have proved that many of them do change their mutual relations in a sensible degree.

There is nothing so well calculated as the study of the stars to impress us with an idea of the immensity of space. Suppose when the earth is at a certain part of her orbit, we were to take the bearing of some star and note down accurately its angular direction from us, and when the earth had arrived at the opposite point in her orbit, that is, just six months after our observation, we were again to take the bearing of the same star and see how our real change of position had affected its apparent place. The nearer the star, the greater would be the angle these bearings make with each; the more distant the star, the less the angle. This angle, whatever be its magnitude, is called the *annual parallax* of the star. Now it has been found that this parallax is imperceptible with such instruments as the most skilful mechanic can construct. Suppose then a globe of fire, whose diameter should be equal to that of the earth's orbit, and whose circumference would consequently be six hundred millions of miles, situated where the earth now is, it would scarcely be seen from the nearest star, or only seen as a small luminous point. If the nearest of the stars are at such distances, who will attempt to conceive the distance of those which we call the smaller and most distant! We shall take occasion to refer to this subject again hereafter.

The brightness of the light of the stars situated at such immense distances as they are proved to be, has induced astronomers to look upon them as centres around which circulate systems imperceptible to us. Perhaps, also, (and this supposition will not appear destitute of probability to those who reflect on the infinite variety of phenomena which are discerned in the dome above us,) these centres which carry with them through space their planetary satellites, are themselves but satellites subject to the laws of other and more powerful primaries. We may be allowed to repeat that thought of Pascal, than which none can be more simple and sublime, and none express so well the extent of the universe; *It is a sphere whose centre is everywhere and whose circumference is nowhere.*

SECTION II.

Division of the stars according to their apparent magnitudes—Their number infinite—Impartial distribution over the heavens—Milky way—Distance of the stars—Their probable dimensions and nature —Periodical stars—Temporary stars—Double stars—Their revolution round each other—Subject to the laws of gravity—Colored stars—Proper motion of the stars—Compound sidereal systems—Clusters—Nebulæ—Nebulous stars—Stars are visible in the day.

The stars are arranged in several classes, according to their brightness; the most brilliant being of the first magnitude, the next of the second, and so on up to the sixteenth magnitude. Only those of the first six classes are visible to the naked eye. The rest are called telescopic stars, from the instrument whose use is requisite to enable us to perceive them.

In a clear night, we might suppose that the number of stars visible to the unassisted vision was immense; but this is a deception, owing to the confusion produced by viewing at once or in rapid succession the different parts of the heaven. The images on the retina do not fade quick enough for our eyes to decide what number of bright points are really before them; as the burning rod whirled rapidly round by the hand of a child presents to his delighted eyes the semblance of a continuous and fiery circle. The number actually discoverable without glasses, in either hemisphere, does not exceed *thirteen hundred.* But if we have recourse to a telescope, we shall discover an innumerable multitude of small stars, which before escaped our observation. Lalande observed 50,000, and Herschel calculated that he saw 44,000 in a space of the heavens 8° long and 3° broad. Taking this as a basis, there would not be less than *seventy-five millions in the whole heaven.* There are, however, many more than this. It has been computed by some, that the telescope has made visible *one hundred millions* at least. All this vast assemblage of suns and worlds may bear no proportion to what lies beyond our ken. Count the leaves of the forest, the sands on the sea-shore, the drops in the ocean; then may you think to set limits to the extent of God's creation; then may you look on this earth as the universe, and not as a mere pebble on the shore of infinite space.

It can be but one of the many mansions created for the accommodation of God's children. He may now, in regions beyond the imagination of the most gifted, be creating worlds more numerous than man can count, and more glorious than thought can fancy.

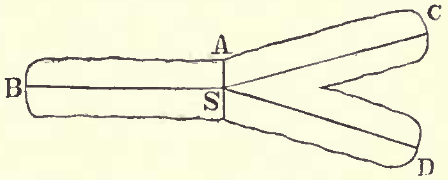
There is no shadow of a reason for assigning any bounds to the number of the stars. Every increase in the dimension and power of instruments, which successive improvements in optical science have attained, having brought into view innumerable multitudes of objects invisible before. So that the number of the stars may be really *infinite,* in any sense we can apply to that word.

The classification into magnitudes, however, it must be observed, is entirely arbitrary. Of a multitude of bright objects, differing probably intrinsically both in size and in splendor, and arranged at unequal distances from us, one must of necessity appear the brightest, one next below it, and so on. An order of succession (relative, of course, to our local situation among them) *must* exist, and it is a matter of absolute indifference where, in that infinite progression downwards, from the one brightest to the invisible, we choose to draw our lines of demarkation. All this is a matter of pure convention. Usage, however, has established such a convention, and though it is impossible to determine exactly where one magnitude ends and the next begins, and although different observers have differed in their magnitudes, yet, on the whole, astronomers have restricted their first magnitude to about 15 or 20 principal stars; their second to 50 or 60 next inferior; their third to about 200 yet smaller, and so on; the numbers increasing very rapidly as we descend in the scale of brightness, the whole number of stars already registered, down to the seventh magnitude inclusive, amounting to 15,000 or 20,000.

As we do not see the actual disc of a star, but judge only of its brightness by the total impression made upon the eye, the apparent magnitude of any star will, it is evident, depend, 1. on the star's distance from us; 2. on the absolute magnitude of its illuminated surface; 3. on the intrinsic brightness of that surface. Now, as we know nothing, or next to nothing, of any of these data, and have every reason for believing that each of them may differ in different individuals, in the proportion of many millions to one, it is clear that we are not to expect much satisfaction in any conclusions we may draw from numerical statements of the number of individuals arranged in our artificial classes.

If the comparison of the apparent magnitudes of the stars with their numbers leads to no definite conclusion, it is otherwise when we view them in connection with their local distribution over the heavens. If indeed we confine ourselves to the three or four brightest classes, we shall find them distributed with tolerable impartiality over the sphere; but if we take in the whole amount visible to the naked eye, we shall perceive a great and rapid increase of number as we approach the borders of the milky way. And when we come to telescopic magnitudes, we find them crowded beyond imagination along the extent of that circle, and of the branch which it sends off from it; so that in fact its whole light is composed of nothing but stars, whose average magnitude may be stated at about the tenth or eleventh.

These phenomena agree with the supposition that the stars of our firmament, instead of being scattered in all directions indifferently through space, form a stratum, of which the thickness is small, in comparison with its length and breadth; and in which the earth occupies a place somewhere about the middle of its thickness, and near the point where it subdivides into two principal laminæ, inclined at a small angle to each other. For it is certain that, to an eye so situated, the apparent density of the stars, supposing them pretty equally scattered through the space they occupy, would be least in a direction of the visual ray (as S A) perpendicular to the lamina, and greatest in that of its breadth, as S B, S C, S D; increasing rapidly in passing from one to the other direction, just as we see a slight haze in the atmosphere thickening into a decided fog bank near the horizon, by the rapid increase of the mere length of the visual ray. Accordingly, such is the view of the construction of the starry firmament taken by Sir William Herschel, whose powerful telescopes have effected a complete analysis of this wonderful zone, and demonstrated the fact of its entirely consisting of stars. So crowded are they in some parts of it, that by counting the stars in a single field of his telescope, he was led to conclude that 50,000 had passed under his review in a zone two degrees in breadth, during a single hour's observation. The immense distances at which the remoter regions must be situated will sufficiently account for the vast predominance of small magnitudes which are observed in it.



When we speak of the comparative remoteness of certain regions of the starry heavens beyond others, and of our own situation in them, the question immediately arises, What is the distance of the nearest fixed star? What is the scale on which our visible firmament is constructed? And what proportion do its dimensions bear to those of our own immediate system? To this, however, astronomy has hitherto proved unable to supply an answer. All we know on the subject is negative. We have attained, by delicate observations and refined combinations of theoretical reasoning, to a correct estimate, first, of the dimensions of the earth; then, taking that as a base, to a knowledge of those of its orbit about the sun; and again, by taking our stand, as it were, on the opposite borders of the circumference of this orbit, we have extended our measurements to the extreme verge of our own system, and by the aid of what we know of the excursions of comets, have felt our way, as it were, a step or two beyond the orbit of the remotest known planet. But between that remotest orb and the nearest star there is a gulf fixed, to whose extent no observations yet made have enabled us to assign any distinct approximation, or to name any distance, however immense, which it may not, for any thing we can tell, surpass.

The diameter of the earth has served us as the base of a triangle, in the *trigonometrical survey* of our system, by which to calculate the distance of the sun; but the extreme minuteness of the sun's parallax renders the calculation from this "ill-conditioned" triangle so delicate, that nothing but the fortunate combination of favorable circumstances, afforded by the transits of Venus, could render its results even tolerably worthy of reliance. But the earth's diameter is too small a base for direct triangulation to the verge even of our own system; and we are, therefore, obliged to substitute the *annual parallax* for the diurnal, or, which comes to the same thing, to ground our calculation on the relative velocities of the earth and planets in their orbits, when we would push our triangulation to that extent. It might be naturally enough expected, that by this enlargement of our base to the vast diameter of the earth's orbit, the next step in our survey would be made at a great advantage; that our change of station, from side to side of it, would produce a perceptible and measurable amount of annual parallax in the stars, and that by its means we should come to a knowledge of their distance. But, after exhausting every refinement of observation, astronomers have been unable to come to any positive and coincident conclusion upon this head; and it seems, therefore, demonstrated, that the amount of such parallax, even for the nearest fixed star which has hitherto been examined with the requisite attention, remains still mixed up with, and concealed among, the errors incidental to all astronomical determinations. Now, such is the nicety to which these have been carried, that did the quantity in question amount to a single second, (i. e. did the radius of the earth's orbit subtend at the nearest fixed star that minute angle,) it could not possibly have escaped detection and universal recognition.[*]

Radius is to the sine of 1″, in round numbers, as 200,000 to 1. In this proportion, then, *at least*, must the distance of the fixed stars from the sun exceed that of the sun from the earth. The latter distance, as we shall hereafter see, exceeds the earth's radius in the proportion of 24,000 to 1; and, lastly, to descend to ordinary standards, the earth's radius is 4,000 of our miles. The distance of the stars, then, *cannot be so small* as 4,800,000,000 radii of the earth, or 19,200,000,000,000 miles! How much larger it may be we know not.

In such numbers the imagination is lost. The only mode we have of conceiving such intervals at all is by the time which it would require for light to traverse them. Now light, as we know, travels at the rate of 192,000 miles per second. It would, therefore, occupy 100,000,000 seconds, or upwards of three years, in such a journey, at the very low-

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[*] Astronomers are generally agreed in the opinion that the annual parallax of the stars is less than 1″, and consequently that the nearest of them is placed at a much greater distance from us than these calculations make it. It was, however, announced within a few years, that M. D'Assas, a French astronomer, had satisfactorily established the annual parallax of *Keid* (a small star eight degrees north of Gamma Eridani) to be 2″, that of *Rigel* in Orion 1″. 43, and that of *Sirius* 1″. 24. If these results may be relied on, then Keid is but 10,000,000,000,000 miles from the earth, Rigel but 13,708,524,066,400, and Sirius 15,809,023,721,735 miles. A distance, however, so great that if it were to fall towards the earth at the rate of a million of miles a day, it would take it forty-three thousand three hundred years to reach the earth; or if the Almighty were now to blot it out of the heavens, its brilliancy would continue undiminished in our hemisphere for the space of three years!

est estimate. What, then, are we to allow for the distance of those innumerable stars of the smaller magnitude which the telescope discloses to us! If we admit the light of a star of each magnitude to be half that of the magnitude next above it, it will follow that a star of the first magnitude will require to be removed to 362 times its distance to appear no larger than one of the sixteenth. It follows, therefore, that among the countless multitude of such stars visible in telescopes, there must be many whose light has taken at least *a thousand years* to reach us; and that when we observe their places, and note their changes, we are, in fact, reading only their history of a thousand years' date, thus wonderfully recorded. We cannot escape this conclusion, but by adopting as an alternative an intrinsic inferiority of light in *all* the smaller stars of the milky way. We shall be better able to estimate the probability of this alternative, when we have made acquaintance with other sidereal systems, whose existence the telescope discloses to us, and whose analogy will satisfy us that the view of the subject we have taken above is in perfect harmony with the general tenor of astronomical facts.

Quitting, however, the region of speculation, and confining ourselves within certain limits which we are sure are less than the truth, let us employ the negative knowledge we have obtained respecting the distances of the stars to form some conformable estimate of their real magnitudes. Of this, telescopes afford us no direct information. The discs which good telescopes show us of the stars are not real, but *spurious*, a mere optical illusion. Their light, therefore, must be our only guide. Now Dr. Wollaston, by direct photometrical experiments, open, as it would seem, to no objections, has ascertained the light of Sirius, as received by us, to be to that of the sun as 1 to 20,000,000,000. The sun, therefore, in order that it should appear to us no brighter than Sirius, would require to be removed to 141,400 times its actual distance. We have seen, however, that the distance of Sirius cannot be so small as 200,000 times that of the sun. Hence it follows, that, upon the lowest possible computation, the light really thrown out by Sirius cannot be so little as double that emitted by the sun; or that Sirius must, in point of intrinsic splendor, be at least equal to two suns, and is in all probability vastly greater.*

Now, for what purpose are we to suppose such magnificent bodies scattered through the abyss of space? Surely not to illuminate *our* nights, which an additional moon of the thousandth part of the size of our own would do much better, nor to sparkle as a pageant void of meaning and reality, and bewilder us among vain conjectures. Useful, it is true, they are to man as points of exact and permanent reference; but he must have studied astronomy to little purpose, who can suppose man to be the only object of his Creator's care, or who does not see in the vast and wonderful apparatus around us provision for other races of animated beings. The planets, as we have seen, derive their light from the sun; but that cannot be the case with the stars. These, doubtless, then, are themselves suns, and may, perhaps, each in its sphere, be the presiding centre round which other planets, or bodies of which we can form no conception from any analogy offered by our own system, may be circulating.

Analogies, however, more than conjectural, are not wanting to indicate a correspondence between the dynamical laws which prevail in the remote regions of the stars and those which govern the motions of our own system. Wherever we can trace the law of periodicity—the regular recurrence of the same phenomena in the same times—we are strongly impressed with the idea of rotary or orbitual motion. Among the stars are several which, though no way distinguishable from others by any apparent change of place, nor by any difference of appearance in telescopes, yet undergo a regular periodical increase and diminution of lustre, involving, in one or two cases, a complete extinction and revival. These are called *periodical stars*. One of the most remarkable is the star *Omi-*

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* Dr. Wollaston, assuming, as he is perfectly justified in doing, a much lower limit of *possible* parallax in Sirius than we have adopted in the text, has concluded the intrinsic light of Sirius to be nearly that of fourteen suns.

cron, in the constellation *Cetus*, first noticed by Fabricius in 1596. It appears about twelve times in eleven years, or, more exactly, in a period of 334 days; remains at its greatest brightness about a fortnight, being then, on some occasions, equal to a large star of the second magnitude; decreases during about three months, till it becomes completely invisible, in which state it remains during about five months, when it again becomes visible, and continues increasing during the remaining three months of its period. Such is the general course of its phases. It does not always, however, return to the same degree of brightness, nor increase and diminish by the same gradations. Hevelius, indeed, relates that during the four years between October, 1672, and December, 1676, it did not appear at all.

Another very remarkable periodical star is that called Algol. It is usually visible as a star of the second magnitude, and such it continues for the space of two days and fourteen hours, when it suddenly begins to diminish in splendor, and in about three and a half hours is reduced to the fourth magnitude. It then begins again to increase, and in three and a half hours more is restored to its usual brightness, going through all its changes in two days, twenty hours, forty-eight minutes, or thereabouts. This remarkable law of variation certainly appears strongly to suggest the revolution round it of some opaque body, which, when interposed between us and Algol, cuts off a large portion of its light, and this is accordingly the view taken of the matter by Goodricke, to whom we owe the discovery of this remarkable fact, in the year 1782; since which time the same phenomena have continued to be observed, though with much less diligence than their high interest would appear to merit. Taken any how, it is an indication of a high degree of *activity*, in regions where, but for such evidences, we might conclude all lifeless. Our own sun requires nine times this period to perform a revolution on its own axis. On the other hand, the periodic time of an opaque revolving body, sufficiently large, which should produce a similar temporary obscuration of the sun, seen from a fixed star, would be less than fourteen hours.

There are many other variable stars, with great differences in the periods of their changes. It is not requisite to enumerate them in this work.

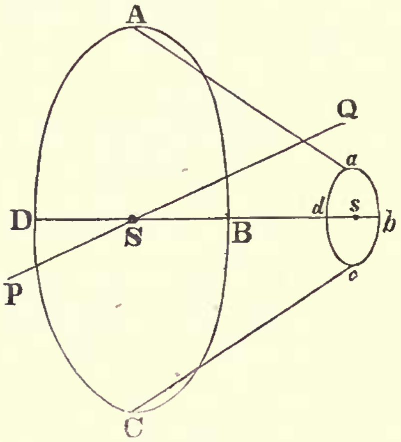
The variations of these stars, however, appear to be affected, perhaps in duration of period, but certainly in extent of change, by physical causes at present unknown. The non-appearance of Omicron Ceti, during four years, has already been noticed; and to this instance we may add that of Chi Cygni, which is stated by Cassini to have been scarcely visible throughout the years 1699, 1700, and 1701, at those times when it ought to have been most conspicuous.

These irregularities prepare us for other phenomena of stellar variation, which have hitherto been reduced to no law of periodicity, and must be looked upon, in relation to our ignorance and inexperience, as altogether casual; or, if periodic, of periods too long to have occurred more than once within the limits of recorded observation. The phenomena we allude to are those of temporary stars, which have appeared, from time to time, in different parts of the heavens, blazing forth with extraordinary lustre; and after remaining awhile apparently immovable, have died away, and left no trace. Such is the star which, suddenly appearing in the year 125 B. C., is said to have attracted the attention of Hipparchus, and led him to draw up a catalogue of stars, the earliest on record. Such, too, was the star which blazed forth, A. D. 389, near Alpha Aquilæ, remaining for three weeks as bright as Venus, and disappearing entirely. In the years 945, 1264, and 1572, brilliant stars appeared in the region of the heavens between Cepheus and Cassiopeia; and, from the imperfect account we have of the places of the two earlier, as compared with that of the last, which was well determined, as well as from the tolerably near coincidence of the intervals of their appearance, we may suspect them to be one and the same star, with a period of about 300, or, as Goodricke supposes, of 150 years. The appearance of the star of 1572 was so sudden, that Tycho Brahe, a celebrated Danish astronomer, returning one evening (the 11th of November) from his laboratory to his dwelling-house, was surprised to find a group of country people gazing at a star, which he was sure did not exist half an hour before. This was the star in question. It was then as bright as Sirius, and continued to increase till it surpassed Jupiter when brightest, and was visible at mid-day. It began to diminish in December of the same year, and in March, 1574, had entirely disappeared. So, also, on the 10th of October, 1604, a star of this kind, and not less brilliant, burst forth in the constellation of Serpentarius, which continued visible till October, 1605.

Similar phenomena, though of a less splendid character, have taken place more recently, as in the case of the star of the third magnitude discovered in 1670, by Anthelm, in the head of the Swan; which, after becoming completely invisible, reappeared, and after undergoing one or two singular fluctuations of light, during two years, at last died away entirely, and has not since been seen. On a careful re-examination of the heavens, too, and a comparison of catalogues, many stars are now found to be missing ; and although there is no doubt that these losses have often arisen from mistaken entries, yet in many instances it is equally certain that there is no mistake in the observation or entry, and that the star has really been observed, and as really has disappeared from the heavens. This is a branch of practical astronomy which has been too little followed up, and it is precisely that in which amateurs of the science, provided with only good eyes, or moderate instruments, might employ their time to excellent advantage. It holds out a sure promise of rich discovery, and is one in which astronomers in establishing observatories are almost of necessity precluded from taking a part by the nature of the observations required. Catalogues of the comparative brightness of the stars in each constellation have been constructed by Sir William Herschel, with the express object of facilitating these researches.

We come now to a class of phenomena of quite a different character, and which give us a real and positive insight into the nature of at least some among the stars, and enable us unhesitatingly to declare them subject to the same dynamical laws, and obedient to the same power of gravitation, which governs our own system. Many of the stars, when examined with telescopes, are found to be *double*, i. e. to consist of two (in some cases three) individuals placed near together. This might be attributed to accidental proximity, did it occur only in a few instances; but the frequency of this companionship, the extreme closeness, and, in many cases, the near equality of the stars so conjoined, would alone lead to a strong suspicion of a more near and intimate relation than mere casual juxtaposition. The bright star Castor, for example, when much magnified, is found to consist of two stars of between the third and fourth magnitude, within 5″ of each other. Stars of this magnitude, however, are not so common in the heavens as to render it at all likely that, if scattered at random, any two would fall so near. But this is only one out of numerous such instances. Sir William Herschel has enumerated upwards of 500 *double stars*, in which the individuals are within half a minute of each other; and to this list Professor Struve, prosecuting the inquiry by the aid of instruments more conveniently mounted for the purpose, has recently added nearly five times that number. Other observers have still further extended the catalogue, already so large, without exhausting the fertility of the heavens. Among these are great numbers in which the interval between the centres of the individuals is less than a single second. They are divided into classes according to their distances, the closest forming the first class.

When these combinations were first noticed, it was considered that advantage might be taken of them, to ascertain whether or not the annual motion of the earth in its orbit might not produce a relative apparent displacement of the individuals constituting a double star. Supposing them to lie at a great distance one behind the other, and to appear only by casual juxtaposition nearly in the same line, it is evident that any motion of the earth must subtend different angles at the two stars so juxtaposed, and must therefore produce different parallactic displacements of them on the surface of the heavens, regarded as infinitely distant. Every star, in consequence of the earth's annual motion, should appear to describe in the heavens a small ellipse, (distinct from that which it would appear to describe in consequence of the aberration of light, and not to be confounded with it,) being a section, by the concave surface of the heavens, of an oblique elliptic cone, having its vertex in the star, and the earth's orbit for its base; and this section will be of less dimensions the more distant is the star. If, then, we regard two stars, apparently situated close beside each other, but in reality at very different distances, their parallactic ellipses will be similar, but of different dimensions. Suppose, for instance, S and *s* to be the positions of two stars of such an apparently or *optically* double star as seen from the sun, and let A B C D, *a b c d*, be their parallactic ellipses; then, since they will be at all times similarly situated in these ellipses, when the one star is seen at A, the other will be seen at *a*. When the earth has made a quarter of a revolution in its orbit, their apparent places will be B *b;* when another quarter, C *c;* and when another, D *d*. If, then, we measure carefully, with micrometers adapted for the purpose, their apparent situation with respect to each other, at different times of the year, we should perceive a periodical change, both in the *direction* of the line joining them, and in the *distance* between their centres. For the lines A *a* and C *c* cannot be parallel, nor the lines B *b* and D *d* equal, unless the ellipses be of equal dimensions, i. e. unless the two stars have the same parallax, or are equidistant from the earth.



Now, micrometers, properly mounted, enable us to measure very exactly both the distance between two objects which can be seen together in the same field of a telescope, and the position of the line joining them with respect to the horizon, or the meridian, or any other determinate direction in the heavens. The meridian is chosen as the most convenient; and the situation of the line of junction between the two stars of a double star is referred to its direction, by placing in the focus of the eye-piece of a telescope, equatorially mounted, two cross wires making a right angle, and adjusting their position so that one of the two stars shall just run along it by its diurnal motion, while the telescope remains at rest; noting their situation; and then turning the whole system of wires round in its own plane by a proper mechanical movement, till the other wire becomes exactly parallel to their line of junction, and reading off on a divided circle the angle the wires have moved through. Such an apparatus is called a position micrometer; and by its aid we determine the *angle of position* of a double star, or the angle which their line of junction makes with the meridian; which angle is usually reckoned round the whole circle, from 0 to 360.

The advantages which this mode of operation offers for the estimation of parallax are many and great. In the first place, the result to be obtained, being dependent only on the relative apparent displacement of the two stars, is unaffected by almost every cause which would induce error in the separate determination of the place of either by right ascension and declination. Refraction, that greatest of all obstacles to accuracy in astronomical determinations, acts equally on both stars; and is therefore eliminated from the result. We have no longer any thing to fear from errors of graduation in circles, from levels or plumb-lines, from uncertainty attending the uranographical reductions of aberration, precession, &c., all which bear alike on both objects. In a word, if we suppose the stars to have no proper motions of their own by which a *real* change of relative situation may arise, no other cause but their difference of parallax can possibly affect the observation.

Such were the considerations which first induced Sir William Herschel to collect a list of double stars, and to subject them all to careful measurements of their angles of position and mutual distances. He had hardly entered, however, on these measurements, before he was diverted from the original object of the inquiry (which, in fact, promising as it is, still remains open and untouched, though the only method which seems to offer a chance of success in the research of parallax) by phenomena of a very unexpected character, which at once engrossed his whole attention. Instead of finding, as he expected, that annual fluctuation to and fro of one star of a double star with respect to the other, that alternate annual increase and decrease of their distance and angle of position, which the parallax of the earth's annual motion would produce, he observed, in many instances, a regular progressive change; in some cases bearing chiefly on their distance, in others on their position, and advancing steadily in one direction, so as clearly to indicate either a real motion of the stars themselves, or a general rectilinear motion of the sun and whole solar system, producing a parallax of a higher order than would arise from the earth's orbitual motion, and which might be called systematic parallax.

Supposing the two stars in motion independently of each other, and also the sun, it is clear that for the interval of a few years, these motions must be regarded as rectilinear and uniform. Hence a very slight acquaintance with geometry will suffice to show that the *apparent motion* of one star of a double star, referred to the other as a centre, and mapped down, as it were, on a plane in which that other shall be taken for a fixed or zero point, can be no other than a right line. This, at least, must be the case if the stars be independent of each other; but it will be otherwise if they have a physical connection, such as, for instance, real proximity and mutual gravitation would establish. In that case, they would describe orbits round each other, and round their common centre of gravity; and therefore the apparent path of either, referred to the other as fixed, instead of being a portion of a straight line, would be bent into a curve concave towards that other. The observed motions, however, were so slow, that many years' observation was required to ascertain this point; and it was not, therefore, until the year 1803, twenty-five years from the commencement of the inquiry, that any thing like a positive conclusion could be come to, respecting the rectilinear or orbitual character of the observed changes of position.

In that, and the subsequent year, it was distinctly announced by Sir William Herschel, in two papers, that there exist sidereal systems, composed of two stars revolving about each other in regular orbits, and constituting what may be termed *binary stars*, to distinguish them from double stars generally so called, in which these physically connected stars are confounded, perhaps, with others only *optically* double, or casually juxtaposed in the heavens at different distances from the eye; whereas the individuals of a binary star are, of course, equidistant from the eye, or, at least, cannot differ more in distance than the semidiameter of the orbit they describe about each other, which is quite insignificant compared with the immense distance between them and the earth. Between fifty and sixty instances of changes, to a greater or less amount, in the angles of position of double stars, are adduced in the memoirs above mentioned; many of which are too decided, and too regularly progressive, to allow of their nature being misconceived. In particular, among the more conspicuous stars, Castor, Gamma Virginis, Xi Ursæ, 70 Ophiuchi, Sigma Coronæ, Eta Cassiopeiæ, Gamma Leonis, Lambda Ophiuchi, and Zeta Aquarii, are enumerated as among the instances of the observed motion; and to some of them even periodic times of revolution are assigned, approximative only, of course, and rather to be regarded as rough guesses than as results of any exact calculation, for which the data were at the time quite inadequate. For instance, the revolution of Castor is set down at 334 years, that of Gamma Virginis at 708, and that of Gamma Leonis at 1200 years.

Subsequent observation has fully confirmed these results, not only in their general tenor, but for the most part in individual detail. Of all the stars above named, there is not one which is not found to be fully entitled to be regarded as binary; and, in fact, this list comprises nearly all the most considerable objects of that description which have yet been detected, though (as attention has been closely drawn to the subject, and observations have multiplied) it has, of late, begun to extend itself rapidly. The number of double stars which are certainly known to possess this peculiar character is between thirty and forty, and more are emerging into notice with every fresh mass of observations which comes before the public. They require excellent telescopes for their observation, being for the most part so close as to necessitate the use of very high magnifiers to perceive an interval between the individuals which compose them.

It may easily be supposed, that phenomena of this kind would not pass without attempts to connect them with dynamical theories. From their first discovery, they were naturally referred to the agency of some power, like that of gravitation, connecting the stars thus demonstrated to be in a state of circulation about each other; and the extension of the Newtonian law of gravitation to these remote systems was a step so obvious, and so well warranted by our experience of its all-sufficient agency in our own, as to have been expressly or tacitly made by every one who has given the subject any share of his attention. We owe, however, the first distinct system of calculation, by which the elliptic elements of the orbit of a binary star could be deduced from observations of its angle of position and distance at different epochs, to M. Savary, who showed, that the motions of one of the most remarkable among them were explicable, within the limits allowable for error of observation, on the supposition of an elliptic orbit described in the short period of fifty-eight and one fourth years. A different process of computation has conducted professor Encke to an elliptic orbit for 70 Ophiuchi, described in a period of seventy-four years; and Sir John Herschel's skill has not failed to add others to the number.

Of these, perhaps, the most remarkable is Gamma Virginis, not only on account of the length of its period, but by reason also of the great diminution of apparent distance, and rapid increase of angular motion about each other, of the individuals composing it. It is a bright star of the fourth magnitude, and its component stars are almost exactly equal. It has been known to consist of two stars since the beginning of the eighteenth century, their distance being then between six and seven seconds; so that any tolerably good telescope would resolve it. Since that time they have been constantly approaching, and are at present hardly more than a single second asunder; so that no telescope, that is not of very superior quality, is competent to show them otherwise than as a single star somewhat lengthened in one direction. It fortunately happens, that Bradley, in 1718, noticed, and recorded in the margin of one of his observation books, the apparent direction of their line of junction, as being parallel to that of two remarkable stars, Alpha and Delta of the same constellation, as seen by the naked eye; and this note, which has been recently rescued from oblivion by the diligence of professor Rigaud, has proved of signal service in the investigation of their orbit. They are entered also as distinct stars in Mayer's catalogue; and this affords also another means of recovering their relative situation at the date of his observations, which were made about the year 1756.

If the great length of the periods of some of these bodies be remarkable, the shortness of those of others is hardly less so. Eta Coronæ has already made a complete revolution since its first discovery by Sir William Herschel, and is far advanced in its second period; and Xi Ursæ, Zeta Cancri, and 70 Ophiuchi, have all accomplished by far the greater parts of their respective ellipses since the same epoch. If any doubt, therefore could remain as to the reality of their orbitual motions, or any idea of explaining them by mere parallactic changes, these facts must suffice for their complete dissipation. We have the same evidence, indeed, of their rotations about each other that we have of those of Uranus and Saturn about the sun; and the correspondence between their calculated and observed places in such very elongated ellipses, must be admitted to carry with it a proof of the prevalence of the Newtonian law of gravity in their systems, of the very same nature and cogency as that of the calculated and observed places of comets round the central body of our own.

But it is not with the revolutions of bodies of a planetary or cometary nature round a solar centre that we are now concerned; it is with that of sun around sun, each, perhaps, accompanied with its train of planets and *their* satellites, closely shrouded from our view by the splendor of their respective suns, and crowded into a space bearing hardly a greater proportion to the enormous interval which separates *them*, than the distances of the satellites of our planets from their primaries bear to their distances from the sun itself. A less distinctly characterized subordination would be imcompatible with the stability of their systems, and with the planetary nature of their orbits. Unless closely nestled under the protecting wing of their immediate superior, the sweep of their other sun in its perihelion passage round their own might carry them off, or whirl them into orbits utterly incompatible with the conditions necessary for the existence of their inhabitants. It must be confessed, that we have here a strangely wide and novel field for speculative excursions, and one which it is not easy to avoid luxuriating in.

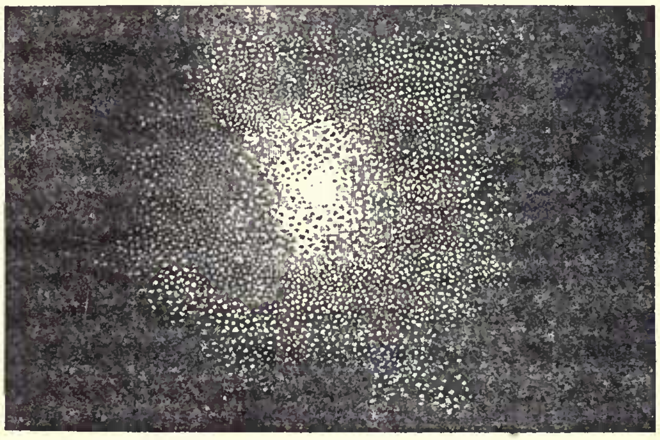
Many of the double stars exhibit the curious and beautiful phenomenon of contrasted or complementary colors. In such instances, the larger star is usually of a ruddy or orange hue, while the smaller one appears blue or green, probably in virtue of that general law of optics, which provides that when the retina is under the influence of excitement by any bright, colored light, feebler lights, which seen alone would produce no sensation but of whiteness, shall for the time appear colored with the tint complementary to that of the brighter. Thus, a yellow color predominating in the light of the brighter star, that of the less bright one in the same field of view will appear blue; while, if the tint of the brighter star verge to crimson, that of the other will exhibit a tendency to green, or even appear as a vivid green, under favorable circumstances. The former contrast is beautifully exhibited by Iota Cancri, the latter by Gamma Andromedæ; both fine double stars. If, however, the colored star be much the less bright of the two, it will not materially affect the other. Thus, for instance, Eta Cassiopeiæ exhibits the beautiful combination of a large white star, and a small one of a rich ruddy purple. It is by no means, however, intended to say, that in all such cases one of the colors is a mere effect of contrast; and it may be easier suggested in words, than conceived in imagination, what variety of illumination *two suns*, a red and a green, or a yellow and a blue one, must afford a planet circulating about either; and what charming contrasts and "grateful vicissitudes"—a red and a green day, for instance, alternating with a white one and with darkness—might arise from the presence or absence of one or other, or both, above the horizon. Insulated stars of a red color, almost as deep as that of blood, occur in many parts of the heavens, but no green or blue star (of any decided hue) has, we believe, ever been noticed unassociated with a companion brighter than itself.

Another very interesting subject of inquiry, in the physical history of the stars, is their proper motion. It might be expected that apparent motions of some kind or other should be detected among so great a multitude of individuals scattered through space, and with nothing to keep them fixed. Their mutual attractions even, however inconceivably enfeebled by distance, and counteracted by opposing attractions from opposite quarters, must, in the lapse of countless ages, produce *some* movements, some change of internal arrangement, resulting from the difference of the opposing actions. And it is a fact, that such apparent motions do exist, not only among single, but in many of the double stars; which, besides revolving round each other, or round their common centre of gravity, are transferred, without parting company, by a progressive motion common to both, towards some determinate region. For example, the two stars of 61 Cygni, which are nearly equal, have remained constantly at the same, or very nearly the same, distance, of 15″ for at least fifty years past. Meanwhile they have shifted their local situation in the heavens, in this interval of time, through no less than 4′ 23″, the annual proper motion of each star being 5″.3; by which quantity (exceeding a third of their interval) this system is every year carried bodily along in some unknown path, by a motion which, for many centuries, must be regarded as uniform and rectilinear. Among stars not double, and no way differing from the rest in any other obvious particular, Mu Cassiopeiæ is to be remarked as having the greatest proper motion of any yet ascertained, amounting to 3″.74 of annual displacement. And a great many others have been observed to be thus constantly carried away from their places by smaller, but not less unequivocal motions.

Motions which require whole centuries to accumulate before they produce changes of arrangement, such as the naked eye can detect, though quite sufficient to destroy that idea of mathematical fixity which precludes speculation, are yet too trifling, as far as practical applications go, to induce a change of language, and lead us to speak of the stars in common parlance as otherwise than fixed. Too little is yet known of their amount and directions, to allow of any attempt at referring them to definite laws. It may, however, be stated generally, that their apparent directions are various, and seem to have no marked common tendency to one point more than to another of the heavens. It was, indeed, supposed by Sir William Herschel, that such a common tendency could be made out; and that, allowing for individual deviations, a general recess could be perceived in the principal stars, *from* that point occupied by the star Zeta Herculis, *towards* a point diametrically opposite. This general tendency was referred by him to a motion of the sun and solar system in the opposite direction. No one, who reflects with due attention on the subject, will be inclined to deny the high probability, nay certainty, that the sun *has* a proper motion in *some* direction; and the inevitable consequence of such a motion, unparticipated by the rest, must be a slow *average* apparent tendency of all the stars to the vanishing point of lines parallel to that direction, and to the region which he is leaving. This is the necessary effect of perspective; and it is certain that it must be detected by such observations, if we knew accurately the apparent proper motions of all the stars, and if we were sure that they were independent, i. e. that the whole firmament, or at least all that part which we see in our own neighborhood, were not drifting along together, by a general *set*, as it were, in one direction, the result of unknown processes and slow internal changes going on in the sidereal stratum to which our system belongs, as we see motes sailing in a current of air, and keeping nearly the same relative situation with respect to one another. But it seems to be the general opinion of astronomers, at present, that their science is not yet matured enough to afford data for any secure conclusions of this kind one way or other. Meanwhile, a very ingenious idea has been suggested, viz. that a solar motion, if it exist, and have a velocity at all comparable to that of light, must necessarily produce a *solar aberration;* in consequence of which we do not see the stars disposed as they really are, but too much crowded in the region the sun is leaving, too open in that he is approaching. Now this, so long as the solar velocity continues the same, must be a constant effect, which observation cannot detect; but *should it vary*, in the course of ages, by a quantity at all commensurate to the velocity of the earth in its orbit, the fact would be detected by a general apparent *rush* of all the stars to the one or other quarter of the heavens, according as the sun's motion were accelerated or retarded; which observation would not fail to indicate, even if it should amount to no more than a very few seconds. This consideration, refined and remote as it is, may serve to give some idea of the delicacy and intricacy of any inquiry into the matter of proper motion; since the last mentioned effect would necessarily be mixed up with the systematic parallax, and could only be separated from it by considering that the nearer stars would be affected more than the distant ones by the one cause, but both near and distant alike by the other.

When we cast our eyes over the concave of the heavens in a clear night, we do not fail to observe that there are here and there groups of stars which seem to be compressed together in a more condensed manner than in the neighboring parts, forming bright patches and clusters, which attract attention, as if they were there brought together by some general cause other than casual distribution. There is a group, called the Pleiades, in which six or seven stars may be noticed, if the eye be directed full upon it; and many more if *the eye* be turned carelessly aside, while *the attention* is kept directed* upon the group. Telescopes show fifty or sixty large stars thus crowded together in a very moderate space, comparatively insulated from the rest of the heavens. The constellation called Coma Berenices is another such group, more diffused, and consisting of much larger stars.

In the constellation Cancer there is a somewhat similar, but less definite, luminous spot, called Præsepe, or the bee-hive, which a very moderate telescope—an ordinary night-glass, for instance—resolves entirely into stars. In the sword-handle of Perseus, also, is another such spot, crowded with stars, which requires rather a better telescope to resolve into individuals separated from each other. These are called clusters of stars; and, whatever be their nature, it is certain that other laws of aggregation subsist in these spots, than those which have determined the scattering of stars over the general surface of the sky. This conclusion is still more strongly pressed upon us, when we come to bring very powerful telescopes to bear on these and similar spots. There are a great number of objects which have been mistaken for comets, and, in fact, have very much the appearance of comets without tails: small round or oval nebulous specks, which telescopes of moderate power only show as such. Messier has given, in the *Connois. des Temps* for 1784, a list of the places of 103 objects of this sort; which all those who search for comets ought to be familiar with, to avoid being misled by their similarity of appearance. That they are not, however, comets, their fixity sufficiently proves; and when we come to examine them with instruments of great power, such as reflectors of eighteen inches, two feet or more in aperture, any such idea is completely destroyed. They are then, for the most part, perceived to consist entirely of stars crowded together so as to occupy almost a definite outline, and to run up to a blaze of light in the centre, where their condensation is usually the greatest. The figure represents the thirteenth nebula of Messier's list, as seen in the twenty feet reflector at Slough.* Many of them, indeed, are of an exactly round figure, and convey the complete idea of a globular space filled full of stars, insulated in the heavens, and constituting in itself a family or society apart from the rest, and subject only to its own internal laws. It would be a vain task to attempt to count the stars in one of these *globular clusters*. They are not to be reckoned by hundreds: and on a rough calculation, grounded on the apparent intervals between them at the borders, (where they are seen not projected on each other,) and the angular diameter of the



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*It is a very remarkable fact, that the centre of the visual area is by far less sensible to feeble impressions of light, than the exterior portions of the retina. Few persons are aware of the extent to which this comparative insensibility extends, previous to trial. To appreciate it, let the reader look alternately full at a star of the fifth magnitude, and beside it; or choose two equally bright, and about three or four degrees apart, and look full at one of them, the probability is, he will see *only the other*. The fact accounts for the multitude of stars with which we are impressed by a general view of the heavens; their paucity when we come to count them.

* This beautiful object was first noticed by Halley in 1714. It is visible to the naked eye, between the stars Mu and Zeta Herculis. In a night-glass it appears exactly like a small round comet.

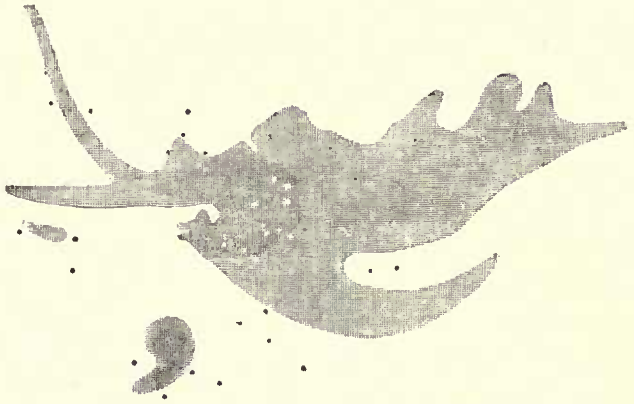
whole group, it would appear that many clusters of this description must contain, at least, ten or twenty thousand stars, compacted and wedged together in a round space, whose angular diameter does not exceed eight or ten minutes; that is to say, in an area not more than a tenth part of that covered by the moon.

Perhaps it may be thought to savor of the gigantesque to look upon the individuals of such a group as suns like our own, and their mutual distances as equal to those which separate our sun from the nearest fixed star; yet, when we consider that their *united* lustre affects the eye with a less impression of light than a star of the fifth or sixth magnitude, (for the largest of these clusters is barely visible to the naked eye,) the idea we are thus compelled to form of their *distance* from us may render even such an estimate of their dimensions familiar to our imagination; at all events, we can hardly look upon a group thus insulated, thus perfect in itself, as not forming a system of a peculiar and definite character. Their round figure clearly indicates the existence of some general bond of union in the nature of an attractive force; and in many of them there is an evident acceleration in the rate of condensation as we approach the centre, which is not referable to a merely uniform distribution of equidistant stars through a globular space, but marks an intrinsic *density* in their state of aggregation greater at the centre than at the surface of the mass. It is difficult to form any conception of the dynamical state of such a system. On the one hand, without a rotary motion and a centrifugal force, it is hardly possible not to regard them as in a state of progressive collapse. On the other, granting such a motion and such a force, we find it no less difficult to reconcile the apparent sphericity of their form with a rotation of the whole system round any single axis, without which internal collisions would appear to be inevitable.

It is to Sir William Herschel that we owe the most complete analysis of the great variety of those objects which are generally classed under the common head of nebulæ, but which have been separated by him into—1st, Clusters of stars, in which the stars are clearly distinguishable; and these, again, into globular and irregular clusters; 2d, Resolvable nebulæ, or such as excite a suspicion that they consist of stars, and which any increase of the optical power of the telescope may be expected to resolve into distinct stars; 3d, Nebulæ properly so called, in which there is no appearance whatever of stars; which, again, have been subdivided into subordinate classes, according to their brightness and size; 4th, Planetary nebulæ; 5th, Stellar nebulæ; and, 6th, Nebulous stars. The great power of his telescopes has disclosed to us the existence of an immense number of these objects, and shown them to be distributed over the heavens, not by any means uniformly, but, generally speaking, with a marked preference to a broad zone crossing the milky-way nearly at right angles. In some parts of this zone, indeed,—especially where it crosses the constellations Virgo, Coma Berenices, and the Great Bear,—they are assembled in great numbers; being, however, for the most part *telescopic*, and beyond the reach of any but the most powerful instruments.

Clusters of stars are either globular, such as we have already described, or of irregular figure. These latter are, generally speaking, less rich in stars, and especially less condensed towards the centre. They are also less definite in point of outline; so that it is often not easy to say where they terminate, or whether they are to be regarded otherwise than as merely richer parts of the heavens than those around them. In some of them the stars are nearly all of a size, in others extremely different; and it is no uncommon thing to find a very red star, much brighter than the rest, occupying a conspicuous situation in them. Sir William Herschel regards these as globular clusters in a less advanced state of condensation, conceiving all such groups as approaching, by their mutual attraction, to the globular figure, and assembling together from all the surrounding region, under laws of which we have no other proof than the observance of a gradation by which their characters shade into one another, so that it is impossible to say where one species ends and the other begins.

Resolvable nebulæ can, of course, only be considered as clusters either too remote, or consisting of stars intrinsically too faint to affect us by their individual light, unless where two or three happen to be close enough to make a joint impression, and give the idea of a point brighter than the rest. They are almost universally round or oval, their loose appendages, and irregularities of form, being as it were extinguished by the distance, and only the general figure of the more condensed parts being discernible. It is under the appearance of objects of this character that all the greater globular clusters exhibit themselves in telescopes of insufficient optical power to show them well; and the conclusion is obvious, that those which the most powerful can barely render *resolvable*, would be completely *resolved* by a further increase of instrumental force.



Of nebulæ, properly so called, the variety is again very great. By far the most remarkable are those represented in figures adjoining, the upper of which represents the nebulæ surrounding the quadruple (or rather sextuple) star Theta in the constellation Orion; the lower, that about Eta, in the southern constellation Robur Caroli: the one discovered by Huygens, in 1656, and figured as seen in the twenty feet reflector at Slough; the other by Lacaille, from a figure by Mr. Dunlop. The nebulous character of these objects, at least of the former, is very different from what might be supposed to arise from the congregation of an immense collection of small stars. It is formed of little flocky masses, like wisps of cloud; and such wisps seem to adhere to many small stars at its outskirts, and especially to one considerable star, (represented, in the figure, below the nebula,) which it envelopes with a nebulous atmosphere of considerable extent and singular figure. Several astronomers, on comparing this nebula with the figures of it handed down to us by its discoverer, Huygens, have concluded that its form has undergone a perceptible change. But when it is considered how difficult it is to represent such an object duly, and how entirely its appearance will differ, even in the same telescope, according to the clearness of the air, or other temporary causes, we shall readily admit that we have no evidence of change that can be relied on.

The next figure represents a nebula of a quite different character. The original of this figure is in the constellation Andromeda, near the star Nu. It is visible to the naked eye, and is continually mistaken for a comet, by those unacquainted with the heavens. Simon Marius, who noticed it in 1612, describes its appearance as that of a candle shining through horn, and the resemblance is not inapt. Its form is a pretty long oval, increasing by insensible gradations of brightness, at first very gradually, but at last more rapidly, up to a central point, which, though very much brighter than the rest, is yet evidently not stellar, but only nebula in a high state of condensation. It has in it a few small stars; but they are obviously casual, and the nebula itself offers not the slightest appearance to give ground for a suspicion of its consisting of stars. It is very large, being nearly half a degree long, and fifteen or twenty minutes broad.

This may be considered as a type, on a large scale, of a very numerous class of nebulæ, of a round or oval figure, increasing more or less in density towards the central point: they differ extremely, however, in this respect. In some, the condensation is slight and gradual; in others great and sudden: so sudden, indeed, that they present the appearance of a dull and blotted star, or of a star with a slight burr round it, in which case they are called stellar nebulæ; while others, again, offer the singularly beautiful and striking phenomenon of a sharp and brilliant star surrounded by a perfectly circular disc, or atmosphere, of faint light in some cases, dying away on all sides by insensible gradations; in others, almost suddenly terminated. These are *nebulous stars.* A very fine example of such a star is 55 Andromedæ. Eta Orionis and Iota of the same constellation are also nebulous; but the nebula is not to be seen without a very powerful telescope. In the extent of deviation, too, from the spherical form, which oval nebulæ affect, a great diversity is observed: some are only slightly elliptic; others much extended in length; and in some the extension so great as to give the nebula the character of a long, narrow, spindle-shaped ray, tapering away at both ends to points.

Annular nebulæ also exist, but are among the rarest objects in the heavens. The most conspicuous of this class is to be found exactly half way between the stars Beta and Gamma Lyræ, and may be seen with a telescope of moderate power. It is small, and particularly well defined, so as in fact to have much more the appearance of a flat, oval, solid ring than of a nebula. The axes of the ellipse are to each other in the proportion of about four to five, and the opening occupies about half its diameter: its light is not quite uniform, but has something of a curdled appearance, particularly at the exterior edge; the central opening is not entirely dark, but is filled up with a faint, hazy light, uniformly spread over it, like a fine gauze stretched over a hoop.

Planetary nebulæ are very extraordinary objects. They have, as their name imports, exactly the appearance of planets; round or slightly oval discs, in some instances quite sharply terminated, in others a little hazy at the borders, and of a light exactly equable or only a very little mottled, which, in some of them, approaches in vividness to that of actual planets. Whatever be their nature, they must be of enormous magnitude. One of them is to be found in the parallel of Nu Aquarii, and about five minutes preceding that star. Its apparent diameter is about 20″. Another, in the constellation Andromeda, presents a visible disc of 12″, perfectly defined and round. Granting these objects to be equally distant from us with the stars, their real dimensions must be such as would fill, on the lowest computation, the whole orbit of Uranus. It is no less evident that, if they be solid bodies of a solar nature, the intrinsic splendor of their surfaces must be almost infinitely inferior to that of the sun's. A circular portion of the sun's disc, subtending an angle of 20″, would give a light equal to 100 *full moons;* while the objects in question are hardly, if at all, discernible with the naked eye. The uniformity of their discs, and their want of apparent central condensation, would certainly augur their light to be merely superficial, and in the nature of a hollow spherical shell: but whether filled with solid or gaseous matter, or altogether empty, it would be a waste of time to conjecture.

Among the nebulæ which possess an evident symmetry of form, and seem clearly entitled to be regarded as systems of a definite nature, however mysterious their structure and destination, the most remarkable are the 51st and 27th of Messier's catalogue. The former consists of a large and bright globular nebula surrounded by a double ring, at a considerable distance from the globe, or rather a single ring divided through about two fifths of its circumference into two laminæ, and having one portion, as it were, turned up out of the plane of the rest. The latter consists of two bright and highly condensed round or slightly oval nebulæ, united by a short neck of nearly the same density. A faint nebulous atmosphere completes the figure, enveloping them both, and filling up the outline of a circumscribed ellipse, whose shorter axis is the axis of symmetry of the system about which it may be supposed to revolve, or the line passing through the centres of both the nebulous masses. These objects have never been properly described, the instruments with which they were originally discovered having been quite inadequate to show the peculiarities above mentioned, which seem to place them in a class apart from all others. The one offers obvious analogies either with the structure of Saturn or with that of our own sidereal firmament and milky way. The other has little or no resemblance to any other known object.

The nebulæ furnish, in every point of view, an inexhaustible field of speculation and conjecture. That by far the larger share of them consists of stars there can be little doubt; and in the interminable range of system upon system, and firmament upon firmament, which we thus catch a glimpse of, the imagination is bewildered and lost. On the other hand, if it be true, as, to say the least, it seems extremely probable, that a phosphorescent or self-luminous matter also exists, disseminated through extensive regions of space, in the manner of a cloud or fog—now assuming capricious shapes, like actual clouds drifted by the wind, and now concentrating itself like a cometic atmosphere around particular stars; what, we naturally ask, is the nature and destination of this nebulous matter? Is it absorbed by the stars in whose neighborhood it is found, to furnish, by its condensation, their supply of light and heat? or is it progressively concentrating itself by the effect of its own gravity into masses, and so laying the foundation of new sidereal systems or of insulated stars? It is easier to propound such questions than to offer any probable reply to them. Meanwhile an appeal to facts, by the method of constant and diligent observation, is open to us; and, as the double stars have yielded to this style of questioning, and disclosed a series of relations of the most intelligible and interesting description, we may reasonably hope that the assiduous study of the nebulæ will, ere long, lead to some clearer understanding of their intimate nature.

We shall conclude this section by calling the reader's attention to a fact, which, if he now learn for the first time, will not fail to surprise him, viz. that the stars continue visible through telescopes during the day as well as the night; and that, in proportion to the power of the instrument, not only the largest and brightest of them, but even those of inferior lustre, such as scarcely strike the eye at night as at all conspicuous, are readily found and followed even at noonday,—unless in that part of the sky which is very near the sun,—by those who possess the means of pointing a telescope accurately to the proper places. Indeed, from the bottoms of deep narrow pits, such as a well, or the shaft of a mine, such bright stars as pass the zenith may even be discerned by the naked eye; and it was stated by a celebrated optician, that the earliest circumstance which drew his attention to astronomy was the regular appearance, at a certain hour, for several successive days, of a considerable star, through the shaft of a chimney.

SECTION III.

Astronomy of the Ancients—Their method of dividing the stars into constellations—Constellations easily distinguished—The division arbitrary, yet convenient—Anciently was important to the husbandman—Reason of the names of the constellations—The twelve signs of the zodiac—The origin of their hieroglyphic characters—Signs and constellations of the same name not coincident—Method of studying the stars—Fables, and descriptions of the constellations—Remarks—The heavenly bodies unequally distant from the earth—Earth comparatively but an atom.

Astronomy seems to have been cultivated as a science at a very early age of the world. The sons of Seth employed themselves in its study; and it has been asserted on the authority of Berosus that Abraham was adroit in celestial observations. In Babylon, after its capture by Alexander the Great, were found observations on record, that had been made by the Chaldeans about one thousand nine hundred years previous, which extends back to the confusion of tongues. It is probable, therefore, that the Chaldeans were the first that cultivated the science of astronomy to any great extent. At what time they divided the heaven into constellations is not known. The method was as follows: they fixed one vessel containing water over another that was empty, and at the moment a certain star appeared in the eastern horizon, they opened a small passage for the liquid, so that it might run through slowly and be caught in the vessel beneath: at the moment the same star again appeared in the eastern horizon they stopped the flow of the water. This quantity of water was then to be divided into twenty-four equal parts, and the time one of these portions should take to run out was the time allowed between the rising of the first and last star in any constellation.

To some of these they gave the names of celebrated individuals, whose memory they wished to perpetuate; to others such birds, beasts, fishes, insects, as (if delineated) would occupy the space allotted to the constellation.

If we thus consider a few stars to form a group, we may observe this group night after night and its shape and appearance will be always the same. There are not anywhere in the heavens different groups, of considerable extent, so resembling each other that an observer can be in any danger of mistaking one for the other. And as the groups cannot be mistaken, the individual stars composing them may thus be certainly recognised, however any single stars in each may resemble each other in magnitude, color, and brightness. Being thus able to recognise a star which we have once observed, we may prosecute our observations upon it night after night, and year after year. For the immediate observations of an individual no more than this is requisite; but when he wants to register their results, or to inform others of their nature, it is evident that he can no longer be satisfied with this mere power of identifying to his own satisfaction the particular star which he observes at different times, but he must have some means of distinguishing between the different stars which he has himself observed, and of announcing to others which it is, among all the heavenly bodies, to which he has especially applied his attention. For this purpose we again have recourse to those groups by which we originally distinguished each particular star from every other. These groups, when divided for the convenience of reference, are called *constellations*, (i. e. *collections of stars*,) a name which is also applied to those portions of the heavens which they respectively occupy; and the whole surface of the heavens has been long divided in this manner. The divisions are arbitrary in themselves, and often, perhaps, ill chosen; but as the only real use of them is for the convenience of reference, the one important object is to have a single received standard; and it would consequently be very undesirable to alter them, even for the purpose of making what would originally have been a simpler and more distinct division. The surface of the heavens being thus divided into constellations, consisting each of a moderate number of stars, those in each are catalogued, and are arranged nearly in the order of their apparent brightness. Stars thus registered on maps or globes, or their places defined, become known bodies, and any astronomer, making observations on a particular star, may communicate it to any other, who will at once know the star in question, and be able to compare the results with his own. Besides, some of the brighter and most remarkable stars have been distinguished by particular names, which will be given hereafter.

The number of stars of each magnitude increases as their brilliancy diminishes. In the catalogue of the Astronomical Society in London, consisting of 2881 stars, there are but twenty-one above the second magnitude; (three of which are considered between the first and second;) about fifty of the second, or between the second and third; and about eighty of the third, or between the third and fourth magnitudes.

The division of the starry heavens served to distinguish the seasons of the year, and consequently the proper periods for the various operations of agriculture. Thus the spring signs, or constellations, were distinguished by those animals which were then held in most esteem at that season of the year. The first sign they called Aries; because the ram was considered the father of the fleecy flock, which afforded them both food and raiment. The next sign was named Taurus, because the bull was looked upon as being the pride and strength of their numerous herds. The last of the spring signs was called Gemini, being emblematical of the goats bringing forth twins about the season of the year that the sun got so high in the zodiac as to enter into this constellation.

The first of the summer signs was called Cancer; because, when the sun entered that constellation, he was observed to have attained his greatest northern distance from the equinoctial, and then began to assume a retrograde motion. This motion the ancients represented under the figure of a Crab, because of its creeping backwards. The next constellation was called Leo, because of the parching heat which usually attended the sun's entrance into this sign; and also because the lion, impelled by thirst, would frequently quit the sandy desert of Zaharah, and make his appearance on the banks of the Nile about that time. The last of the summer signs was called Virgo; this constellation the ancients represented under the figure of a virgin, or female reaper, holding an ear of corn in her hand; as being emblematical of the harvest time.

The first of the autumnal signs was called Libra; because when the sun entered into this constellation he seemed to hold the days and nights in equilibrio, giving the same proportion of light and darkness to the inhabitants of all parts of the globe. The second sign was called Scorpio; because when the sun entered this constellation a great variety of fruit was ripened, the immoderate use of which was found to be productive of much evil, and generally a predisposing cause of fever and a numerous train of diseases. Hence the ancients represented this sign under the figure of a scorpion; because that reptile gives a poisonous wound with its tail to the person who makes too free with it. The last of the autumnal signs was called Sagittarius; because when the sun entered it the trees were nearly divested of their clothing or leaves. This they considered as emblematical of the fit season for hunting; and hence represented the constellation under the figure of an archer with his bow and arrows.

The first of the winter signs was called Capricornus, because of the goat, who delighted in climbing up high and craggy places; and also as an emblem of the winter solstice; for when the sun enters this sign he begins to ascend or climb higher in the zodiac. The next sign was called Aquarius, because they observed that when the sun entered into this constellation it was always about the wet and dreary season of the year; hence it was represented under the figure of a man pouring out water from an urn. The next and last of the winter signs was called Pisces; this the ancients represented under the figure of two fishes tied back to back, as an emblem of the fishing season.

The constellations thus alluded to are those lying in the sun's track, commonly called the twelve houses, or signs of the zodiac; and which bear an evident correspondence with the division of the year into the twelve parts, called the calendar months.

Besides the above-mentioned twelve, there are eighty-one other constellations in the heavens; thirty-four of which are on the north side of the equinoctial, and forty-seven on its south side; making in the whole ninety-three constellations.

Instead of writing the name of the sign of the zodiac every time there is occasion to speak of it, astronomers use a hieroglyphic or symbol for this purpose; thus ♈ signifies the Ram; ♉ the Bull; ♊ the Twins; ♋ the Crab; ♌ the Lion; ♍ the Virgin; ♎ the Balance; ♏ the Scorpion; ♐ the Archer; ♑ the Capricorn; ♒ the Water-Bearer; ♓ the Fishes. These symbols were probably adopted from some resemblance, fancied or real, to the whole or to a part of the animal whose name was given to the sign. This may appear the more credible on an inspection of the accompanying plate.

Thus the horns of the ram have quite a similarity in appearance to the symbol ♈ appropriated to that sign in the zodiac. The same resemblance may be traced between the head of the bull; the twins as a whole; the beam of the balance; the archer's weapon; the whole of the capricorn; the stream of the water-bearer; the fishes; and the hieroglyphics used to denote the respective signs named for these animals or things. The others, it is true, are not so evident, but we may readily suppose that in the lapse of many centuries the symbols might be somewhat changed from their original form, or we might suppose that they originated in the imagination of some one whose fancy might be more vivid than his eyesight. At any rate the origin thus attributed to these characters may serve to amuse the reader and to gratify the minds of those who are curious on such subjects.

Hipparchus, who has transmitted us a catalogue of the stars known in his time, reckons forty-nine constellations, twelve in the zodiac, twenty-two to the north of the zodiac, and fifteen to the south. And here we would remark that it is necessary to distinguish the *constellations* from the *signs* of the zodiac that have the same name.

The signs occupy, along the ecliptic, spaces of a determinate length, viz. thirty degrees each, while the constellations are, on the contrary, scattered, in the celestial globe, through regions of very variable extent. Besides, owing to the precession of the equinoxes, the constellations have moved forward and are now 30° from the signs of the same name.

The constellation of the Ram, for instance, was two thousand years ago in the sign which bears its name, or in the first part of the ecliptic, but the equinoxes having moved backward about 50″ yearly, the sun is now in the *constellation* of the Fishes when it crosses the equator coming north, that is, when it is in the *sign* of the Ram.

We have seen that space is filled with an infinite multitude of stars at an immense distance. These myriads of heavenly bodies, which appear to us like so many twinkling points, are suns, luminous in themselves, the sources of light and heat. It is distance alone that renders them so small to our imperfect visions.

We have supposed that the earth is immovable in the middle of space; that the heaven like a sphere turns around with a motion rigorously uniform in twenty-three hours fifty-six minutes and four seconds upon an imaginary axis nearly invariable: half of this sphere the horizon conceals from our view.

The constellations or asterisms have their proper names; whether appropriate or not is nothing to the present purpose. We shall give them as we find them. It would be almost impossible and altogether useless to have given proper names to each of the stars. The astronomy of the early observers was very rude, as it could not but have been. They were satisfied with naming the most beautiful stars; and we have preserved their names. But when astronomers wished to study the subject with more care, and to distinguish the less brilliant of the stars, they could not but perceive the imperfection of the earlier method. They followed the course of the naturalist who distributes under certain classes a number of individuals. Astronomers have distributed the stars into groups, around which they have made the outline of some animal or fabulous being. Such is, then, the system adopted for classing and naming the stars. A lion is drawn as an outline for a group; one star is in the neck, another in the back; this is in the tail; that is in the heart; and these parts serve to point out and distinguish particular stars.

Next to a beautiful day, what is more imposing than a beautiful night? when the heaven without a cloud discovers to us its azure plains, on which gold seems to mingle its brightness with the diamonds that are scattered over it! How rich and glorious is the mantle of night. In this view she is nothing frightful; she is a goddess: she scatters in her path a beneficent dew, that is drank by the flowers, the leaves, and the plants, dried by the heat of the day; she mingles with the breezes that mild humidity so requisite for vegetation. She measures the slumber of nature and spreads a veil over man and animals in their repose, which she surrounds with a majestic silence. Observe the heavens through the whole of a clear night; those of autumn and winter are preferable, because of their length. Two clear nights in the months of October and March will be sufficient to make you acquainted with all the constellations visible at this latitude. You will distinguish at first only the most brilliant of the stars; their brightness renders them remarkable even when the moon shines. After learning these, they will serve as so many marks by which to find the rest.

Straighten a thread and place it in such a manner as to be in a line, or nearly, with three stars, two of which are known. On the chart form a similar alignment; this will serve to point out and make known to you the unknown star. We must remember, however, that lines on the chart will not answer exactly to those in the heavens. We cannot draw a projection of the sphere which shall not have disadvantages as well as advantages. Again, in consequence of the rotation of the sphere, the stars, though they preserve their mutual distances and relations, turn with the sphere. The ideal lines, therefore, which join them, take different directions, that cannot be drawn on the charts. Such lines as we imagine to pass through two stars are sometimes vertical, at others inclining, and at others horizontal. The circumpolar constellations especially present remarkable variations of this kind. Let the observer place himself in an open spot; let him turn his back to the south; then, having the east on his right and the west on his left, he will have before him the northern pole, distinguished by a star that appears to be immovable; it is almost the only star of the second magnitude in that region, and we shall easily learn to recognise it. It is sufficient at present to say that all the constellations revolve about this point, and in the course of twenty-four hours take almost all positions: now high, now low; now on this side, now on that. At the same hour of the night the aspect of the heavens is different at different seasons of the year. The horary circle of a star advances, day by day, towards the west and towards the sun. We could not indicate the place of a star without having regard to the daily variations; for its position changes at every instant of the night, and it does not return to the same position in less than twenty-four hours.

The figures and the names of the constellations, though arbitrary, are connected with each other, and with chronology, physics, and mythology. It is not without interest to go back to the origin of these symbols, and to read in the heavens the history of the civil and religious customs of the ancients, who have consecrated their memory in these poetic fictions, despised by those only who cannot comprehend them. Still it is difficult to give to explanations of these figures that character of certainty which belongs to positive truth. Many celebrated men have deceived themselves on this subject; many opinions have been adopted lightly and defended obstinately. It is more particularly important to explain the constellations of the zodiac, since they have come to us unchanged through so many ages. Their connection with religion and history gives them a still greater importance.

Marks of the same principles are to be found also in the other constellations; but they have suffered, in the lapse of centuries, changes, which render their interpretation doubtful. It has been well remarked that every thing in Greece is adapted to encourage the lover of the arts and to discourage the philosopher. It is in the East that we must seek the key of those fictions which are based upon astronomy. We must study the civil and religious usages of that time and place, the natural phenomena, the seasons devoted to agriculture, &c. We should regard as the work of a people that which belongs to them and to them only; that which had at a particular epoch a meaning for them, and which could have none at any other time or to any other nation.

The heavens have at all times received the homage of the people, and the stars, according to their importance, have participated in this homage. As men always preferred the marvellous to the true, the priests took advantage of this disposition to rivet their chains, by making science serve as the basis of the mysterious emblems they invented. It is thus that the truths of nature are bound to fictions which disgrace them.

THE BULL.

In this cluster are two remarkable groups, the Pleiades and the Hyades. According to Hebrew authorities this constellation is ascribed to Joseph. According to the Greeks it represents the animal that carried Europa over the sea from Asia. While Europa was gathering flowers, a snow-white bull approached her train; she caressed the beautiful animal, and had the courage to sit upon his back. He immediately made for the shore, crossed the sea, and with the lady arrived safely in Crete. The carrying off of Europa and Io by Jupiter is probably an allusion to the new year, the sun and moon in spring being in the sign Taurus; and in Virgil we find

> The milk-white Bull with golden horns
> Leads on the new-born year.

The Pleiades were the seven daughters of Atlas (the heaven) and of Pleione, (the sea,) or Hesperia, (the evening.) Their name seems to be derived from a Greek word meaning plurality, they being seven; viz. Electra, Maia, Taygeta, Alcyone, Celeno, Sterope, and Merope; the last of whom married a mortal, and her star accordingly became dim. Orion was the persecutor of the Pleiades, but to save them from his fury Jupiter placed them in the heaven, where that giant still pursues them, but in vain.

The Pleiades are sometimes called Virgins of the Spring, because the sun enters this cluster in May.

The Hyades were nymphs of Dodona, daughters of Ocean; they are five in number. Their name signifies to rain, because their return announced the approach of the rainy season among the ancients.

The Bull is one of the constellations of the zodiac. The head and shoulders of the animal are the only parts to be seen; these are very distinctly marked. Its declination is about sixteen degrees north. It has the *Twins* on the east, the *Ram* on the west, Orion and the River *Po* on the south, *Perseus* and the *Charioteer* on the north. It includes one hundred and forty-one stars. In the Pleiades there are but seven stars visible to the naked eye, and one of these is so dim that it has been called the "*Lost Pleiad*," and has been the cause of many beautiful strains of poetry.

The Pleiades are principally of the fourth and fifth magnitudes; they are situated in the neck of the Bull, and form a very conspicuous group, such that they cannot be mistaken. The brightest star in the group is sometimes called *The Light of the Pleiades*. With a telescope, *two hundred* stars have been discovered in this cluster.

The Hyades are south-east of the Pleiades, in the forehead of the Bull. The five stars of this group are so placed as to form the letter V, and the most brilliant of these is called Aldebaran; a most important star to navigators, since it is one of the nine from which the moon's distance is computed in the Nautical Almanac.

ORION.

Orion was a giant of prodigious size, and an intrepid hunter. His rising in the evening and presence during the nights in winter cause to be attributed to him the power of troubling the ocean.

> Stormy Orion rises.
> Virg.

Orion surpassed the rest of mankind in fleetness, and boasted that he could overcome all animals. A scorpion was sent out of the earth as a punishment for his boast, and, biting his foot, caused his death. He has been called the son of Neptune, who gave him power to walk on the water; others have said that he was given by Jupiter, Neptune, and Mercury to an inhabitant of Bœotia in the skin of a bull; whence he was placed near that constellation when advanced to the heavens, and as far as possible from the Scorpion. Some suppose the fable of Orion intends Abraham entertaining the three angels, who foretold the birth of his son Isaac.

Orion is situated to the southward of the Bull. It is the most beautiful of all the constellations for its extent and the number of its brilliant stars, situated in an oblong, four-sided figure, whose diagonals are formed by two stars of the first and two of the second magnitude. At the north-east angle, or in the right shoulder, is *Betelgeux*, a star of the first magnitude. At the south-west angle, or in the left foot, is Rigel, of the first magnitude, a splendid star. In the middle of the oblong are situated three stars of the second magnitude, in an oblique line. They have been called *The Shoulder-belt*, *The Girdle*, *The Three Kings*, *The Rake*, *Jacob's Staff*, *The Three Stars*, because there are no other three that resemble them exactly. In Scripture they are spoken of as the *bands of Orion*: "Canst thou loose the bands of Orion?" To the southward of these are several stars of the fourth and fifth magnitudes, called *The Sword*. Both of these were named *Napoleon* in 1807 by the university at Leipsic, but they are more commonly known as the *Yard and Ell*. The three in the belt forming the yard measure three degrees in length, divided by each star into equal parts. *The Ell* is once and a quarter the length of the belt. Orion is represented by the figure of a man, with a club in his right hand, and the skin of a lion on his left for a shield; in the attitude of assaulting the Bull. Orion is easily discovered during the beautiful nights of winter. It is placed in a part of the heaven which is filled with bright stars. About nine or ten o'clock in the evening, in February or March, there can be seen at the same time as many as twelve stars of the first magnitude; viz. Sirius, Procyon, Capella, Spica Virginis, Aldebaran, Arcturus, Betelgeux, Rigel, Regulus, Denebola, Castor, and Alphard, without mentioning a greater number of the second magnitude.

The whole number visible to the naked eye in this constellation is seventy-eight; with the telescope upwards of two thousand have been seen.

THE HARE.

This was an animal which Orion delighted to hunt, and its swiftness was one of his attributes; it was therefore placed near him in the skies. It is in fact directly against his right leg. It may be easily known by means of four stars of the third magnitude which form an irregular four-sided figure, distinguishing it at once. These stars are in the legs and feet of the animal. The principal star, marked Alpha, bears about south from the middle star in Orion's belt, from which it is distant nearly seventeen degrees; it also bears about west from the dogstar, (*Sirius*,) distance seventeen degrees. The dogstar, Alpha of the Hare, and the middle star in Orion's belt form nearly a right-angled triangle, Alpha of the Hare being at the right angle.

NOAH'S DOVE.

This constellation, as is evident from its name, commemorates the messenger sent forth by Noah from the ark to see if the waters of the deluge had abated; "and the dove returned with an olive branch in her mouth."

> "A dove sent forth once and again to spy
> Green tree or ground, whereon his foot may light;
> The second time returning, in his bill
> An olive branch he brings, pacific sign."

The Dove is south of the Hare about sixteen degrees, and is nearly on the same meridian with the most eastern star in the belt of Orion, distant thirty-two degrees, and south-west by south of Sirius, distant twenty-three degrees nearly. It contains one star of the second, one of the third, and two of the fourth magnitude.

THE RIVER PO.

This river was celebrated by the poets on account of the fabled fall of Phäeton, the son of Phœbus, from whom he obtained a rash promise that whatever boon he asked should be granted. No sooner was the promise spoken, than the reckless youth, as if bent on his own destruction and that of the world, demanded to drive for one day the chariot of his father. It was all in vain to represent to him the danger of such an attempt. The terrible oath, (by the river Styx,) which even the gods could not break, had bound the father; and the son was not to be moved from his purpose. Phœbus gave him the reins, which he had no sooner received than he betrayed his ignorance and incapacity to manage them. He had nearly set the world on fire, when Jupiter struck him with lightning and tumbled him headlong from his aerial flight into the river Po. Some call this constellation the Nile, or the River of Orion.

It is a narrow line of stars of the third and fourth magnitudes, curving through various parts of the heavens. It commences near the left foot of Orion, passes westward towards the Whale, where it makes a circuit, passes south-east, and again trends to the south-west, passing between the *Chemical Furnace* and the *Phœnix* on the west, and *the Clock* on the east, and finally terminates in the bright star *Achernar*, of the first magnitude; its entire length being about one hundred and thirty degrees. It contains eighty-four stars, among which one is of the first, one of the second, and eleven of the third magnitude.

THE CHARIOTEER.

Some suppose that this constellation owes its name to Ericthonius, the son of Vulcan and Minerva, who was the fourth king of Athens. He was of monstrous shape, having the tails of serpents instead of legs. Being anxious to conceal his deformity, he invented chariots and the manner of harnessing horses to draw them. Others think this constellation represents Phäeton, an account of whom has been given under the River Po. Others think it is Belerophon; others, Absyrtus, the brother of Medea; others, Myrtilus, driver of Œnomaus. It announces by its heliacal rising the entrance of the sun into the *Bull.*

The *Charioteer* is represented by the figure of a man in a bending attitude, one foot upon a horn of the Bull, with a bridle in his right hand and a goat in his left. It is situated eastward of *Perseus*, and north of *Orion* and the Bull. A line drawn through the two most northerly stars in the square of the *Great Bear* will lead to Capella, the principal star in the Charioteer. Capella is not only the brightest in this constellation, but one of the brightest in the heavens. The two stars in the shoulders of *Auriga*, with the two in the shoulders of *Orion*, make an oblong, whose length (running north and south) is five times its breadth. Also these and the star in the right horn of the *Bull* form two similar and nearly equal triangles, the last star being at their common vertex. The whole number of stars in this constellation is sixty-six.

THE CAMELOPARD.

This constellation was so called from an animal peculiar to Ethiopia. This animal is very tractable, and has the natural properties of the camel, except that its body is spotted, whence its name. It was made out of the unformed stars which lay between *Perseus*, the *Charioteer*, the head of the *Great Bear*, and *Alruccabah*, the north polar star. It contains fifty-eight stars, all small.

THE LYNX

was made out of forty-four unformed stars lying between the *Charioteer* and the *Great Bear*. None of them are above the third magnitude, and but three belong to that order; the remainder, being quite small and scattered, present us nothing very interesting or worthy of notice.

THE TWINS.

This constellation is a symbol of friendship. Some call it Amphion and Zethus; others, Triptolemus and Jasius; or Appollo and Hercules; or, lastly, the most common opinion, Castor and Pollux. These last were the twin sons of Jupiter and Leda. The manner of their birth was remarkable. As soon as they had arrived at years of discretion, they embarked with Jason in quest of the golden fleece. In this expedition both conducted with great courage. After their return they cleared the sea from pirates; therefore they have ever since been considered the friends of navigation. Castor was finally killed in battle. Pollux was immortal, and as he loved his brother tenderly he entreated Jupiter to restore him to life, or take from himself immortality. Jupiter so far granted the prayer as to allow them to share the immortality. This act of fraternal love Jupiter rewarded by placing them both in heaven under the name of the *Twins.*

This constellation is situated to the eastward of the *Bull*, and represents in a sitting posture twin brothers, the one holding a lyre in his right hand and an arrow in his left, and his head encircled with beams of light; the other holds a club. This is the fourth constellation in the zodiac. The sun is in the *Twins* in July. This constellation contains eighty-five stars, one (Castor) of the first, and one (Pollux) of the second magnitude, in the heads, about four and a half degrees asunder; four of the third magnitude, and seven of the fourth. It is easily known by means of the two first mentioned. Castor is the northernmost and the brightest of the two. Pollux is one from which the moon's distance is given in the Nautical Almanac. Castor and Aldebaran form the base of an isosceles triangle, Capella being at the vertex. The constellation forms almost an oblique parallelogram. The relative magnitude of the two principal stars has undergone changes at different periods, and some astronomers have thought that Pollux must vary from the first to the third magnitude; but Herschel ascribes the variation to Castor, which he found to consist of two stars close together, the less revolving about the other in three hundred and forty-two years.

THE LITTLE DOG.

This is supposed to be one of Orion's hounds turned into a constellation, and of course placed near him in the heavens. It is sometimes called *Antecanis*, from its rising before the *Great Dog.*

Some suppose this constellation represents Anubis, an Egyptian deity, who had the body of a man and the head of a dog. Others say that it is one of Actæon's hounds, that devoured their own master, he having been changed into a stag by Diana.

The Little Dog is south of the *Twins.* Its principal star is Procyon, of the first magnitude. This star is situated to the southward of Pollux, distant twenty-three degrees, and to the eastward of Betelgeux, distant twenty-six degrees. Pollux, Procyon and Betelgeux, form a right-angled triangle, Procyon being at the right angle.

Procyon is often used for the name of the whole constellation, as Sirius is for that of the *Great Dog.*

THE UNICORN.

This represents an animal about the size and shape of the horse, with one white horn growing out of the middle of its forehead. It is fabled to have existed in Ethiopia. The unformed stars which lay between *Orion* and the *Little Dog* were made into a constellation with this name. It lies on both sides of the equator. It contains thirty-one stars, a few of them being as large as the fourth magnitude; these form a very oblique V, whose northerly branch is in a line with the star *Xi* in one foot of the Twins. The remaining stars of this constellation are very small and scattered.

THE GREAT DOG

Was, with the Dragon, set to watch Europa after she had been carried off by Jupiter. It afterward was given to Minos, and at different times belonged to Procris, Cephalus and Aurora, and finally to Orion.

Anciently the summer solstice happened while the sun was in *Capricorn* or the *Lion.* The rising of Sirius in the evening or morning announced to Egypt the rise of the river Nile, and gave men notice, like a faithful dog, to prepare themselves against the coming inundation. His name Sirius or Siris is derived from Osiris, which means the sun and the fertilizing river.

But the precession of the equinoctial points has deprived Sirius of the power of predicting the inundation. He rose heliacally, that is, before the sun, about the 21st of June, fifteen days previous to the swelling of the water. It is not visible now in that country until the 10th of August. About the year 300 of our era, it rose heliacally towards the middle of July, and thus announced the season of great heat and sicknesses consequent, which were accordingly attributed to its influence under the name of the Dogstar. This was the origin of the name dog days, which continue from the 22d of July to the 23d of August, during which the sun was describing the *sign* of the Lion or the *constellation* of Cancer.

The Great Dog is to the southward and eastward of Orion, and may be easily known by the brilliancy of its principal star Sirius, which is the brightest and *apparently* the largest in the heavens, and can never be mistaken for any other star. Light, which comes from the sun to the earth in eight minutes thirteen seconds, or at the rate of *two hundred thousand miles a second*, would require three years and eighty-two days to pass from Sirius to the earth; so that if that star were destroyed, we should still continue to see it more than three years; and this too is considered as one of the nearest of the fixed stars.

Sirius in the Great Dog, Procyon in the *Little Dog*, and Betelgeux in *Orion* form an equilateral triangle. A line drawn from the Pleiades by the easternmost star in Orion's belt will lead directly to Sirius, which is distant from the belt twenty-two degrees nearly.

THE SHIP ARGO.

Some think this represents the ship that carried Jason and his companions, when they sailed for Colchis in quest of the golden fleece. This *ship* had fifty oars, and could not have been much larger than our boats; for it is said that the crew carried it on their backs from the Danube to the Adriatic. When the expedition was completed, Jason drew the ship on shore and consecrated her to Neptune; the poets turned her into a constellation.

Others imagine this constellation to have been formed by the Egyptians, owing its existence to the numberless boats of bark which were in use during the time of an inundation. The heliacal rising of the star *Canopus* was a precursor of this phenomenon, since this star rose with the first of the *Lion* at the summer solstice.

The ship is situated south of the equator, to the eastward of the *Great Dog*. It may be known by the stars in the prow and deck. If a straight line joining Sirius and Delta in the *Great Dog* be produced it will reach Zeta in the rowlock. The principal star in the constellation is called *Canopus*, which is of the first magnitude, but it never rises above our horizon, being in fifty-three degrees south declination. There are in the constellation sixty-four stars, most of which have so great a southern declination that they cannot be seen in the United States.

THE CRAB.

While Hercules was engaged in destroying the famous Lernean monster, Juno sent a sea-crab to bite the hero's foot; this new enemy was soon despatched, but Juno, to reward its services, placed it among the constellations. Sometimes two asses are placed in this division of the zodiac, because they were the animals Bacchus used to ride, or because they assisted Jupiter to overcome the giants, terrifying them with their noise. This is the least apparent of any constellation in the zodiac, in which it is the fifth, lying between the *Twins* and the *Lion*. *Acubens*, of the third magnitude, is its principal star. A line drawn from Capella through Pollux will lead to Acubens; it is also situated in a right line drawn from Bellatrix in *Orion* to Regulus in the *Lion*. The Crab contains eighty-three stars.

Tegmine, the last in the back, is a treble star, which requires very favorable circumstances to be seen distinctly.

Præsepe, the stall, is a small *nebula* in the breast of the *Crab*, containing five or six stars.

THE LION.

The lion was a symbol of strength and power; therefore he was placed where the sun was in midsummer, thereby signifying the intense heat at that time. The Egyptians were annoyed by lions during the heat of the summer, as they then left the desert and loved to roam by the cool waters of the Nile. It was natural, therefore, that they should place the lion where we find him. The Greeks supposed this constellation to be the Nemæan lion, that Hercules slew and Jupiter placed among the stars to commemorate the dreadful conflict. The principal star took its name from the Roman consul, whose valor and virtue have rendered his name immortal. In this constellation four stars form an irregular four-sided figure. The star in the heart is called *Regulus* or the Lion's Heart, that in the tail *Denebola*. There are ninety-five visible stars in the constellation. The south-westernmost is in, or nearly in the ecliptic, and may be distinguished by its brilliancy. A line drawn from the north pole-star through the Pointers passes about twelve degrees east of Regulus. It is one of the nine stars from which the distance of the moon is measured, to obtain the longitude at sea. To the northward of Regulus, eight degrees distant, is a star of the second magnitude; near these are five other stars of the third magnitude; the whole forming a cluster resembling a sickle, Regulus being in the extremity of the handle. The other stars will be easily found in the heavens after one has found Regulus and Denebola, and observed their relative situation to the rest on the map. These two are important, being often used to point out other clusters in their neighborhood.

THE LITTLE LION.

This constellation was made by Hevelius out of the unformed stars situated between the *Lion* on the south and the *Great Bear* on the north. It contains fifty-three stars, all of them small; the principal one, being of the second magnitude, is situated in the body of the animal.

THE SEXTANT

Was formed out of the stars unformed by the ancients, situated between the *Lion* on the north and the *Water Snake* on the south. It contains forty-one small stars. It was formed in honor of the nautical instrument called Hadley's quadrant.

THE WATER-SNAKE AND THE CUP.

This Cup is said to be the same from which Jupiter, Neptune, and Mercury drank when they were kindly entertained by a peasant of Bœotia. The gods were so pleased with his hospitality, that they placed his cup as a constellation in the heavens. The *Water Snake* was a monster that infested the vicinity of lake Lerna. It had a hundred heads, and as soon as one was cut off two grew out in its place, unless hot iron were applied to the wound. It was one of the labors of Hercules to destroy this monster.

The Cup contains thirty-one stars, one being of the third magnitude and called Alkes, distant from Alphard twenty-five degrees in an east-south-east direction, and from Denebola south by west thirty degrees. It may be known by a crescent formed by several stars of the fourth magnitude.

The *Water-snake* contains sixty stars, most of them small. It trends to the eastward in a serpentine manner from the *Little Dog* to the *Balance*, lying south of the *Crab*, the *Lion* and the *Virgin*. Its principal star is Alphard, called also the Heart, which is twenty-three degrees distant from Regulus, south-south-west. It may be distinguished by its dark reddish appearance. The head of the Snake may be recognised by four stars of which the upper three form an arch. When the head is on the meridian the tail is far below the horizon; and its whole length cannot be traced out in the heavens until the *Cup* is on or near the meridian.

THE GREAT BEAR.

Calisto, an attendant and favorite nymph of Diana, was changed into a bear by Juno. To prevent her being injured by the hunters Jupiter transferred her to heaven, placing her among the constellations. Juno, furious, besought Thetis to forbid the Bear dipping into the ocean, which it never does in our latitude.

According to another account, the two Bears are the nymphs who fed Jupiter on mount Ida. They are called Helices, because of their motion round the pole. The ancients represented this constellation by a wagon; hence it has been called *Charles' Wain* or *Wagon*. This constellation never sets in our latitude, and consequently takes all positions in passing round the pole. It is formed principally of seven beautiful stars, four of which form an oblong; the other three are in a curved line; of these, the two first are in the continuation of the diagonal. These seven stars are sometimes called the *Dipper* and sometimes the *Plough*. When on the meridian above the pole, the bottom of the Dipper lies toward us, the handle on the right. The two stars most distant from the tail are called *the Pointers*, because a straight line drawn through them and continued would strike the pole-star nearly. The distance of the nearest Pointer, called Dubhe, from the pole is twenty-nine degrees; the distance between the Pointers is five degrees.

The right fore-paw and the two hind-paws are severally distinguished by a couple of stars of the fourth magnitude; these six are the only stars in this constellation that ever set in this latitude. On the side opposite the tail, there are six or seven stars of the fourth magnitude, placed in a semicircle convex toward the oblong; these, with three or four of the *Lynx*, form an S, and are in the head of the Bear. This constellation has always been an object of observation, being so conspicuous and constantly visible. All nations seem to have been equally attracted by its appearance. It is even asserted that the Iroquois Indians have given it the same name as the ancients did; though there is really no resemblance to a bear in the constellation. The star near the root of the tail, called Megrez, is in the equinoctial colure.

The whole number of stars in this constellation is eighty-seven. One is of the first, three are of the second, seven of the third magnitude.

BERENICE'S HAIR.

Berenice was the daughter of Philadelphus and Arsinoe. She married Ptolemy Euergetes and loved him with much tenderness. He went on an expedition against his enemies, and Berenice, being anxious for his safety, vowed to dedicate her hair to the goddess of Beauty if her husband should return safe. She performed her vow on the victorious return of Euergetes, but the day after the locks had disappeared from the temple. Conon an astrologer was sent for; and when the king expressed great regret for the loss of what he so much valued, and inquired of Conon what had become of them, the astrologer, to make his court to the monarch, artfully pointed to some unformed stars and exclaimed " there are the queen's locks." The king was pleased and the queen's vanity flattered by this reply, and Conon publicly reported that Jupiter had taken the queen's hair from the temple and placed it among the constellations.

It is a beautiful constellation of very small stars, situated quite near each other, and between Denebola and Charles' Heart. It contains forty-three stars, one being of the fourth magnitude. The stars are so small that it is not always easy to perceive them. Yet it is not possible to mistake any other group for them.

THE CROW.

Apollo had occasion for the services of the crow. He performed his part so faithfully, that as a reward, he was transferred to a place among the stars by the god of day.

Some say that this cluster took its name from the daughter of Coronœus, who was changed into a crow for her own safety. This constellation is situated to the southward of *the Virgin* and to the eastward of the *Cup*, and is distinguished by means of four stars of the third magnitude which form a trapezium. Its principal star is called Algorab, distant from Alkes in the Cup twenty-two degrees in a direction north-easterly, and from the Sheaf of the Virgin fifteen degrees south-westerly. It includes nine visible stars, four being of the third, and one of the fourth magnitude.

THE VIRGIN.

The Virgin, an emblem of justice and law, represented Themis, whose balance is at her feet, or Astræa, the daughter of Jupiter and Themis, whom the crimes of men obliged to abandon earth for heaven at the end of the golden age.

> Faith flies and piety in exile mourns,
> And justice, *here* oppressed, to heaven returns.

Astræa was placed among the constellations of the zodiac under the name of Virgo.

Some consider Virgo as Ceres and the emblem of harvest; or Diana of Ephesus; or Isis of Egypt; or the great goddess of Syria, Atergatis; or Fortune; or Cybele, drawn by lions; or Minerva, the mother of Bacchus; or the sibyl of Virgil, who with a golden branch in her hand conducted Eneas into the lower regions; or Erigone, the death of whose father by the hands of some intoxicated peasants caused her so much grief, that in a fit of despair she hung herself, and was placed among the constellations of the zodiac. Her faithful dog Mœra, afterward placed in the heavens, directed her to the spot where her father was buried. The Virgin is the seventh constellation of the zodiac; it is east of the *Lion*, and between the *Crow* and *Berenice's Hair.* It is of considerable extent, and contains one hundred and ten stars, one being of the first, one of the second, five of the third, and ten of the fourth magnitude. The longest diagonal of the trapezium of the *Great Bear* being produced toward the south will strike a star of the first magnitude in the Virgin; this is the *Sheaf of Wheat*, (Spica Virginis.) It forms also an equilateral triangle with Arcturus and the star in the tail of the *Lion*. A right line from this last to the Sheaf would nearly bisect a right angle formed by five stars of the third magnitude in the Virgin, one side of which angle is directed toward Regulus and lies along the ecliptic, the other side is directed toward the last star in the tail of the *Great Bear.* Spica may be known by its solitary splendor, there being no star very near it of any magnitude. The situation of this star in the heavens has been determined very accurately for the assistance of seamen. The moon's distance from it is taken to determine the longitude. It lies within the moon's path, and two degrees south of the earth's orbit. A star of the second magnitude, called Vindemiatrix, is situated in the right arm, half way between Spica and Berenice's Hair. Regulus, Vindemiatrix and Charles' Heart, form nearly a right-angled triangle, Vindemiatrix being at the right angle. Two stars, Eta and Zeta, of this constellation point out the direction of the equator. Several other stars of the third magnitude lie scattered about in this constellation, which may be easily traced on the map.

BOOTES AND THE GREYHOUNDS.

Bootes or the *Bear-driver* represents Arcas, the son of Jupiter and Calisto. Juno, jealous of Jupiter for his partiality to Calisto, transformed her to a bear, and Arcas, who was a famous hunter, one day started a bear in the chase, and not knowing that it was Calisto, his mother, was on the point of killing her, when Jupiter, to prevent the deed, transported them both to heaven and made constellations of them.

Bootes has also been considered as Icarus, whom Bacchus taught the art of making wine. He imprudently gave some to the peasants, who, thinking it pleasant, drank it to excess and became intoxicated; then conceiving they had been poisoned by Icarus, they killed him. Some say, however, that it is Atlas, who supports the world, because formerly its head was near the pole. Volney thought that Bootes was Osiris.

The Greyhounds, named Asterion and Chara, according to fable, are the hounds with which Bootes, through mistake, hunted his mother Calisto; they are represented as being in pursuit of the *Great Bear*, which Bootes is hunting round the north pole, he holding in his right hand the leash with which the hounds are fastened together.

The *Bear-driver* is represented as a huntsman grasping a club in his left hand. It is situated to the eastward of *Charles' Heart* and west of the *Northern Crown.* It contains fifty-four stars, of which one is of the first and seven of the third magnitude.

This constellation may be found by means of its principal star, Arcturus, which shines with a lustre and hue very much like Mars. Arcturus is near the right knee, and is about the same distance east as Capella is west of the southernmost Pointer. It is also in a straight line which passes through the two last in the tail of the *Great Bear*, and in the upper base of the trapezium of the *Lion* produced. In Bootes is a pentagon north-east of Arcturus. The upper hand of the figure, formed by several stars of the fourth magnitude, is near the tail of the *Great Bear.*

The Greyhounds, a constellation formed by Hevelius out of stars left unformed by the ancients, lies between Bootes and the Great Bear, and contains twenty-five stars, most of which are of the fifth and sixth magnitude. Charles' Heart, the principal star, of the third magnitude, in the neck of the southern Hound, *Chara*, was so named in memory of Charles the first, by Scarborough. This star, with Alioth in the *Bear* and the southernmost Pointer, forms a right-angled triangle, the vertex of the right angle being at *Charles' Heart*. A line drawn through it and Alioth will lead to the pole-star. When Alioth and Charles' Heart are in the same vertical circle, they will be on or near the meridian.

THE CENTAUR AND THE CROSS.

An imaginary existence, half man and half horse. Under the reign of Ixion, of Thessaly, a herd of wild bulls laid waste that country and rendered the mountains inaccessible. The king promised a reward to whomsoever would destroy or drive them from his kingdom. Some young men, having found means to break and ride horses, pursued and destroyed the bulls. The peasants, seeing them at a distance, conceived, as the Mexicans did in later times, that the men and the horses were one animal, or rather monsters of a dreadful form. The celebrated Chiron was one of the centaurs.

This constellation is south of the *Virgin*, and the whole of it does not rise in this latitude; it is far south, occupying a large space in that hemisphere. In it are thirty-five stars, two being of the first and one of the second magnitude. The principal of these are not visible in this latitude. The star in the east shoulder may be seen in June about twelve or fourteen degrees above the horizon. There is no other star of equal brightness in its vicinity; it may therefore be easily distinguished. It is nearly on the same meridian with Arcturus. In the other shoulder, and almost exactly south of the Sheaf, is a star of the fourth or fifth magnitude. A few degrees north of these two, in the shoulders, are four small stars in the head of the constellation, resembling those in the head and shoulders of Orion, in their relative position.

Between the legs of the Centaur is that beautiful constellation, which has been so much celebrated and admired by those who have visited a southern latitude, *The Cross*. It is said to represent the cross which Constantine the Great saw in the sky when going to give battle to Maxentius, whom he totally defeated, near Rome. Yet this constellation is not visible at Rome, its declination being too far south to allow it to rise above the horizon in that latitude. It is formed of four stars situated in the milky-way. The bright star in the top of the cross is nearly south of Algorab in the *Crow*, and distant from it about forty-one degrees, and south-west of the *Sheaf*, distant forty-seven degrees.

THE WOLF.

This constellation is said to have been Lycaon, an Arcadian monarch, celebrated for his wickedness and inhumanity. The sins of mankind had become so enormous, that Jupiter visited the earth to punish impiety. He came to Arcadia, where the people began to pay adoration to his divinity. Lycaon, however, to try him, served up human flesh on his table. For this wickedness Jupiter immediately destroyed Lycaon's house and turned its owner into a wolf. This animal is represented as pierced with an arrow from the bow of the *Centaur*. The ancients regarded the constellation of the Wolf as an unlucky presage, as they also did the *Serpent* and the *Scorpion*, which occupy neighboring regions of the heavens, and are symbols of the winter. There is another origin given to this constellation, viz. Romulus and Remus being thrown into the Tiber, and floating ashore, were found and protected by a wolf, until Faustulus carried them away and educated them as his own.

The Wolf is situated eastward of the *Centaur* and south of the *Balance*, and has such a high southern declination that but few of its stars are visible in this latitude.

It contains twenty-four stars, three being of the third and three of the fourth magnitude, the brightest of which may be seen in a clear evening just above the horizon.

THE BALANCE.

Two thousand years ago the sun at the time of the autumnal equinox was in the Balance, which was represented as placed either in the hands of the *Virgin* or the claws of the *Scorpion.* The Greeks, whose sphere was like that of the Chaldeans, had but eleven constellations in the zodiac. They gave the *Scorpion* an extent equal to two signs, by prolonging the claws into what is now the *Balance.* The sign filled by the claws was called *Chelæ.* The Balance was formed first by the Egyptians, as their monuments prove. As Augustus was born in September, flattery leagued with astrology to celebrate the blessing promised to the world by his birth. They replaced the *Balance,* the symbol of justice, in heaven. Bearing this in mind, the following lines from Virgil, addressed to Augustus, will be easy to interpret.

> And seated near the Balance, poise the days
> Where in the void of heaven a space is free,
> Between the Scorpion and the Maid, for thee;
> The Scorpion, ready to receive thy laws,
> Yields half his region and contracts his claws.

The Balance is the eighth constellation in the zodiac from the vernal equinox, and is east of the *Virgin.* It may be known by means of four bright stars, forming a four-sided figure; the most southwesterly of these is in the ecliptic. Three other stars in this cluster form an isosceles triangle, the two brighter of which distinguish the two scales of the Balance. In the cluster are found fifty-one stars, two of the second, two of the third, and twelve of the fourth magnitude.

THE SERPENT-BEARER AND THE SERPENT.

The Serpent-bearer was so named by the ancients, who represented it under the figure of a man with a large beard, holding in his hand a staff, around which was wreathed a serpent; or as holding with both his hands a serpent, which is writhing under the power of his grasp. The serpent was sacred to Ophiucus, and was the symbol of medicine, and of the god who presided over it. Ophiucus is but another name for Æsculapius, the son of Apollo and Coronis, or Arsinoe, one of the Hyades; this fable alludes to the circumstance of the Serpent-bearer's rising when the sun, being in the Bull, sets. Some add that the Serpent-bearer was fed by a goat and brought up by Chiron, the centaur; and in reality the *Centaur* rises just before the Serpent-bearer, which happens at the setting of Capella, (the Goat.) Ophiucus is considered by some as Jason; by others as Tantalus. The River Po sets at the rising of Ophiucus; and from this circumstance the fable had its origin, that the water constantly flies before the thirsty Tantalus. The serpent placed in the hands of Ophiucus is an emblem of his wisdom and sagacity, or, as some think, of his skill in curing the bite of the serpent. Again, *the Serpent* is said to be Cadmus, who implored the gods to change him into that reptile, to save him from the constant and malignant persecutions of Juno.

The Serpent-bearer occupies a considerable space in the heavens. It is situated to the southward of Hercules, and contains seventy-four stars. In the head is Ras Alhague, the principal star, of the second magnitude; it is situated to the left and south of the star in the head of Hercules. Farther south are two stars of the third magnitude, very near each other, forming the eastern shoulder. In the western shoulder are also two stars near together, of the fourth magnitude; these are to the right of the heads of *Hercules* and *Ophiucus;* which being connected, together with those in the shoulders, by right lines, will make a trapezium, at the southern point of which is a thick cluster of little stars forming the letter V, open toward the north. This beautiful cluster is the head of the *Royal Bull,* or the *Bull of Poniatowski.* South of the trapezium may be seen in the folds of the Serpent a quadrilateral, formed by stars of the fourth magnitude. The tail of the *Serpent* is between two trapezia, those of *Ophiucus,* and *Antinous,* near the *Eagle.* North-west of the head of Ophiucus, and south of the *Crown,* is the head of the *Serpent,* which forms a letter Y placed obliquely, the tail of which is broken, as it were, and curved. In this curve is situated the principal star of the Serpent, Unukalhay, or the Heart, being of the second magnitude.

This may also be known by means of a small star, just north of it. The tail of the Y is prolonged by a row of stars of the third magnitude, which extends far below the equator. The serpent terminates near the constellation of the *Eagle.*

THE NORTHERN CROWN.

This cluster represents a crown presented by Bacchus to Ariadne, the daughter of Minos, king of Crete. Bacchus loved her with much tenderness, and after her death transferred the crown to the heavens, placing it among the constellations.

> He bids her crown among the stars be placed,
> As an eternal constellation graced.
> The golden circlet mounts, and as it flies
> Its diamonds twinkle in the northern skies.

This constellation may be easily known by means of its circular form, which resembles a wreath, consisting of six stars. It is situated to the eastward of *Bootes* and north of the *Serpent's Head,* and contains one star of the third magnitude, called Alphacca, which is in the middle of the diadem, eleven degrees east of Mirac in Bootes. A line drawn from Vindemiatrix through Arcturus will lead close to Alphacca. The two last, with Seginus, form an isosceles triangle, whose vertex is at Arcturus. In this cluster there are twenty-one stars, of which only six or eight are visible to the naked eye.

THE LITTLE BEAR.

As the *Great Bear* represents Calisto, so does the *Little Bear* her dog. But it is more probable that the latter was named long after the former, and took its name from the general similarity discoverable in the appearance of the two.

This constellation, though not remarkable in its appearance, and containing but few conspicuous stars, is justly distinguished from all others for the peculiar advantages which its position in the heavens is well known to afford to nautical astronomy, and especially to navigation and surveying.

Situated near the celestial pole, the stars in this group appear to revolve about it, very slowly, and in circles so small as never to descend below the horizon.

In all ages of the world, this constellation has been more universally observed, and more carefully noticed, than any other, on account of the importance which mankind early attached to the position of its principal star.

This star, which is so near the true pole of the heavens, has, from time immemorial, and, as it were, by common consent, been denominated the NORTH POLAR STAR.

The Little Bear contains twenty-four stars, including three of the third magnitude and four of the fourth. The seven principal stars in this constellation are so situated as to form a figure very much resembling that in the Great Bear, only that the *Dipper* is reversed, and about one half the size of the larger one.

The first of these, in the handle, called *Cynosure,* or *Alruccaba,* is the polar star, round which the rest are constantly revolving. The two last in the bowl of the Dipper, corresponding to the *Pointers* in the Great Bear, are of the third magnitude, situated about fifteen degrees from the pole, the brightest of which is called *Kochab,* which signifies an axle or hinge, probably in reference to its moving so near the axis of the earth.

Kochab may easily be known by its being the brightest and middle one of three conspicuous stars forming a row, one of which is about two degrees from Kochab, and the other three degrees. The two brightest of these are situated in the breast and shoulder of the animal, about three degrees apart, and are called the *Guards* or *Pointers* of the Little Bear. They may be seen at all hours of the night.

Of the four stars which form the bowl of the Dipper, one is so small as hardly to be seen. They lie in a direction towards Gamma in Cepheus; but as they are continually changing their position in the heavens, they may be much better traced out from the map than from description.

Kochab is distant from Benetnasch about twenty-five degrees, and from Dubhe about twenty-four, and hence forms with these two very nearly an equilateral triangle.

THE SCORPION.

The Scorpion was the symbol of maladies and destructive plagues. When the sun entered this constellation a great variety of fruit was ripe, by an immoderate use of which sickness was brought on, a predisposition to fever and a numerous train of diseases. Hence the ancients represented this sign under the figure of a scorpion, because that reptile inflicts a poisonous wound. It was the terror of *Orion*, Phäeton, and Hyppolitus. This constellation was anciently represented by other symbols, but most commonly by a Scorpion.

Ovid says that this is the Scorpion that at Juno's command appeared (rising from the earth) and stung Orion, who died of the bite. They were removed to the heavens, but placed as far as possible from each other.

The Scorpion is a beautiful group of stars, and easily found; it contains forty-four stars, one being of the first, one of the second and eleven of the third magnitude, and is distinguished for the peculiar lustre and position of its principal stars. It is situated to the eastward of the *Balance.* Its principal star is Antares, the heart of the Scorpion. This is a remarkable star, being of a reddish hue, and the most brilliant of any in that region of the heaven. It forms, with two others of the fourth magnitude, a very obtuse angle, (say one hundred and seventy degrees,) Antares being at the vertex. This star is distant from the Sheaf of the Virgin forty-six degrees, direction east-south-east. It is one of the stars from which the moon's distance is measured, to find the longitude. It is distant from Zubenelgin, the north scale of the *Balance*, about twenty-five degrees, in a south-easterly direction. The tail of the Scorpion trends to the southward till it reaches the fourth star from Antares; here it turns to the eastward, continuing to the sixth star, whence it trends northward; thus forming a circular line of stars, of the third and fourth magnitudes, in which the principal is named Lesath, in the extremity, distant eighteen degrees from Antares, in a south-east by south direction. This circular line of stars, forming the tail of the Scorpion, is very conspicuous, and may be easily traced.

HERCULES AND CERBERUS.

Hercules was the son of Jupiter and Alcmene, and one of the most renowned heroes of antiquity. He performed many wonderful exploits, commonly called the "labors of Hercules." He put on a poisoned tunic, which had been presented him, through the treachery of the centaur Nessus; no sooner had he done so, than he felt a fatal fire through all his bones and the blood boil in his veins. As the distemper was incurable, he built a funeral pyre, laid upon it his club and the skin of the Nemæan lion, and setting fire to it, he was consumed. Jupiter looked from heaven and promised the surrounding gods that he would raise to the skies the immortal parts of a hero who had cleared the earth from so many monsters and tyrants.

> High o'er the hollow clouds the coursers fly,
> And lodge the hero in the starry sky.

The twelfth, last, and most difficult of his labors was to bring upon earth the three-headed dog *Cerberus*, stationed by Pluto at the mouth of hell to prevent the living from entrance and the dead from escape. Hercules dragged off the treble-headed monster, and Jupiter placed him in the same constellation with Hercules.

This constellation is represented by a man partly covered with a lion's skin, in a kneeling posture, the feet toward the north pole, the head to the south, and near that of the *Serpent-bearer.* The three-headed dog, Cerberus, is in his left hand, and a club in his right. The cluster is situated south of the *Dragon* and west of the *Harp.* It occupies a large space in the heaven, and the figure is in an inverted position. The principal star is Ras Algethi, in the head. A line drawn from Vega in the *Harp* to Alpha in the *Crown* traverses a quadrilateral in the body of Hercules, one of whose diagonals continued will reach Ras Algethi, which may be also known by its proximity to Ras Alhague, in the head of the *Serpent-bearer*, being five degrees west-north-west of it. About half way from Ras Algethi to the *Crown* are two stars of the third magnitude, three degrees apart, in the west shoulder. The most northerly of these is named Rutilicus. In the east shoulder are also two stars of the fourth magnitude. These pairs, with Ras Algethi, form a triangle nearly equilateral.

THE DRAGON.

Some affirm to be the monster that Cadmus slew, when he was in search of his sister Europa. His father Agenor, king of Phenicia, ordered him to bring his daughter home or never return himself. Having sent his companions to a neighboring grove to bring water, their long delay either wearied or alarmed him. He therefore went to the spot and found a dragon feeding on their remains. He instantly attacked, and with the assistance of Minerva, overcame the monster. Others assert that in a war with the giants this dragon was brought into the combat and opposed to Minerva, who seized it in her hand and hurled it into heaven, around the axis of the sphere, before it could unwind its folds, and that it sleeps there to this day.

But the more commonly received fable was, that this constellation represented the dreadful monster that guarded the golden apples in the garden of the Hesperides. Hercules killed the dragon and carried away the fruit; but Juno, as a reward for its faithful services, changed the monster into a constellation.

This important group is of the number of those which do not set in our latitude. It is easily recognised by a line of stars with three coils. The tail commences near the back of the *Great Bear;* the third star from its extremity is of the second magnitude, and is between the guards of the Little and the tail of the Great Bear. This star is called by navigators the Dragon's Tail. It was also once the Polar star, having been nearer the pole than even the Cynosure is now. Following their line of stars, we soon reach a curve at Theta; then a coil, containing Eta and Zeta; then come two stars and another coil, in which are three stars of the third magnitude; now, taking a direction toward *Hercules*, another coil and the head may be found. In this coil are five or six stars, one being of the fourth magnitude. The head may be distinguished by means of five stars, forming an angle, (the vertex being in the nose,) or the letter V, the point toward the west, the opening toward the east. The brighter star in the head is called Rastaben. It is nearly east from the last star in the tail of the Great Bear. Rastaben is interesting from its connection with the discovery of a new law in physical science.

THE HARP.

This small cluster takes its name from the instrument which Apollo, the god of music, gave Orpheus. With this the musician played in such a masterly manner that the most rapid rivers stayed their course, the savage beasts were overcome, the mountains moved and forests bent to listen to the melody. After his death Orpheus received divine honors, the muses gave an honorable burial to his remains, and his lyre became one of the constellations. This cluster of stars has been sometimes represented as an eagle flying downward; also called the Falling Vulture.

It is situated south-easterly from the head of the Dragon. It contains the most brilliant star in the northern hemisphere, called Vega. This, with Arcturus and the pole star, forms a large triangle, Vega being at the vertex of its right angle. As regards the pole, Vega is opposite Capella. A little south of Vega are three stars of the third magnitude, which form an isosceles triangle. Vega is south-east of Rastaben about fifteen degrees. The Harp contains twenty-one stars, one being of the first and three of the third magnitude.

THE ARCHER.

Chiron, a centaur, son of Saturn, was famous for his knowledge of music, medicine and shooting. He instructed the greatest heroes of his age. To Æsculapius he taught medicine, to Apollo music, to Hercules astronomy. He was wounded in the knee by an arrow from the bow of Hercules, when he pursued the centaurs and they fled for protection to Chiron. The arrow had been dipped in the blood of the Lernean hydra, and consequently the wound was incurable; he therefore implored Jupiter to take away his immortality, that death might free him from the excruciating torments he endured.

His prayers were heard, and Jupiter turned him into the constellation of the *Archer*. This constellation is situated to the eastward of the *Scorpion*, and is easily distinguished by means of several stars of the fourth magnitude, which form a figure bearing some resemblance to the Plough in the Great Bear. This, being on the confines of the milky-way, is sometimes called the Milk-dipper. The constellation occupies a considerable space in the southern hemisphere, containing a number of conspicuous stars. The whole number of its visible stars is sixty-nine, five being of the third and ten of the fourth magnitude. There is also a curve line of stars like a bow, convex toward the Scorpion; the arrow is formed by these stars. Of the two stars close together in the upper end of the bow, the brightest, which is of the fourth magnitude, serves to point out the winter solstice, being about two degrees north of the tropic of Capricorn, and less than one east of the colure.

THE EAGLE AND ANTINOUS.

This was originally one constellation, the *Eagle* or *Egyptian Hawk*, who carried the thunderbolts of Jupiter, as a reward for having nourished him in a cave of Crete, where he was concealed to prevent his becoming the food of his father Saturn. By others it is supposed to be Merops, king of the island of Cos, this monarch having been transformed into an eagle and placed among the stars.

The dismemberment of this constellation was the work of the emperor Adrian. Antinous was a young man from Bythynia, of whom the emperor was so fond that at his death he built a temple to his memory, and endeavored to propagate a belief that his favorite had become a constellation and was placed near the Eagle. Antinous is also called Ganymede, a beautiful youth, who was carried off by Jupiter under the shape of an eagle and made his cupbearer.

South of the *Fox and Goose*, and north of the *Archer*, may be seen three stars near each other, and in an oblique line. Of these the middle is Altair, in the Eagle, of the first magnitude; the most southerly is in the head of Antinous, and the most northerly in the back of the bird. These two last are of the third magnitude. There are two stars of the third magnitude in the tail and two in the southern wing. South of the Eagle are four stars which form a quadrilateral; this is the upper part of Antinous. One of them, that in the shoulder, is the variable star Eta. It is about eight degrees southerly from Altair, and is one of those stars which often change their appearance. Altair in the Eagle is an important star, being one of those from which the moon's distance is given. By the situation and brilliancy of this star the constellation may easily be found. It contains seventy-one stars; one of the first, nine of the third, and seven of the fourth magnitude.

THE DOLPHIN.

Bacchus when young was found asleep in the island of Naxos by some pirates of Tuscany, who captured and carried him off. Finding himself their prisoner when he awoke, he soon made them repent of their rashness. He first filled the boat with ivy, and afterward drove them into the sea and changed them to dolphins, transferring to heaven, as a constellation, Acestes, the pilot, because he alone had expressed some sympathy for the prisoner.

Another account is, that this cluster represents the Dolphin who persuaded Amphitrite to become the bride of Neptune, though she had previously made a vow of perpetual singleness. For his services on this occasion the Dolphin was placed by Neptune among the stars.

A small lozenge or rhombus, formed of four stars, of the third magnitude, very near together, makes it easy to find this constellation, which is situated about fourteen degrees north-east by east of the *Eagle*, and exactly south of the principal star in the Swan, called Deneb, of the first magnitude, and distant from it about thirty degrees. The rhombus is called by many "Job's Coffin," without any known reason for the name. There is a fifth star in the body of the Dolphin, a little south of the rhombus. There are beside several very small stars in the cluster, only visible under favorable circumstances.

THE SWAN.

As of many other constellations, so of this, several fables are told respecting its origin. Orpheus, when torn in pieces by Bacchanalians, was transformed to a Swan and placed in heaven near the Harp. Jupiter changed himself to a swan on an occasion when it suited his purpose. According to some this constellation took its name from Cycnus, a son of Neptune, who was invulnerable, so that, to destroy him in battle, Achilles threw him and attempted to smother him, but he was suddenly changed to a swan. Ovid says that Cycnus, a relative of Phäeton, who deeply lamented the fate of that insensate, and of his sisters, who wept themselves to death, was changed into a swan.

> Forth from his sides the wings and feathers grow;
> Forth from his mouth proceeds the blunted beak;
> And Cycnus now into a swan is turned.

The Swan is situated to the eastward of the Harp, and is remarkable for forming a large cross in the milky-way, down which the bird is flying with outspread wings. As regards the pole, this cluster is opposite that of the Twins. The *cross* in the cluster is formed by stars of the third magnitude in the head, body, and wings of the bird; one of them is, however, of the first magnitude, called Deneb. It is at the top of the cross, in the body of the bird; the beak being the foot of the cross, where there is a star of the third magnitude, named *Albireo*. This constellation contains eighty-one stars, one being of the first, six of the third, and twelve of the fourth magnitude. There have been discovered in the Swan three *variable stars*. One of these, situated about midway of the neck, was first observed to be variable in 1686. Its changes are completed in a little more than a year. The star near the junction of the neck with the body varies from the third to the sixth magnitude. Its changes are not regular; they seem to require ten years or more for their completion. The third variable star is in the head. It was seen in the summer of 1670, appearing then of the third magnitude, was scarcely visible in October, became brighter than ever in the spring of 1671, and disappeared finally in the spring of 1672.

CAPRICORN.

This is said to be a goat, that was brought up with Jupiter on mount Ida. He discovered the conch shell and blew upon it; thus carrying terror into the ranks of the Titans in their war against heaven. In one attack the gods, affrighted, concealed themselves under the forms of different animals; Mercury became an ibis, Apollo a crane, Diana a cat, Jove a ram, Juno a cow, and finally Pan, plunging into the Nile, became a capricorn; that is, the part of his body above the water took the form of a goat, that beneath the form of a fish. Or this constellation may represent Amalthæa, who fed Jupiter on goats' milk, and who was rewarded for her kindness by being placed among the stars. Jupiter gave a horn to one of the nymphs that had taken care of his helpless years. This was the *horn of plenty*, a talisman to give the possessor whatever she might desire. Capricorn is situated to the eastward of the *Archer*. A line, drawn from Vega to Altair, and produced, will reach two stars very near together in the head of this constellation. Of these the more northerly is a double star, and is distant from Altair twenty-three degrees nearly, in a south-south-east direction. To the southward of this, and distant about two and a half degrees, is a star marked Beta; this at sea is called the *south head* of Capricorn. Both are of the third magnitude. Nearly east from these is another pair of the third magnitude; these are in the tail. The whole number of stars is fifty-one, most of them small and inconspicuous.

ANDROMEDA.

Was the daughter of *Cepheus* and *Cassiopeia*. Cassiopeia had the vanity to boast that she was more beautiful than the Nereids, who were so piqued at the boast that they persuaded Neptune to send a sea-monster to lay waste the country. To free himself from this monster Cepheus was obliged to expose his daughter, which he accordingly did by chaining her to a rock on the sea-shore. The gods, struck with the sufferings of so much innocence and beauty, sent Perseus to deliver her. Perseus, possessing the head of Medusa, which was fabled to change into stone any living thing that looked upon it, delivered the lady and married her.

This constellation is situated to the southward of *Cassiopeia*, and to the westward of *Perseus*. It is represented by a woman having her arms extended and chained to a rock. In the head of Andromeda is a star of the second magnitude, named Alpheratz. This star is on an imaginary line drawn from the north-eastward in the square of the Great Bear through the north polar star, and distant from the latter about sixty-one degrees. In a north-easterly direction from Alpheratz, at the distance of about fifteen degrees, is *Mirach*, a star in the girdle of Andromeda. In the same direction nearly, and distant about thirteen degrees from Mirach, is Almaach, a star in the foot. From this last Algol, in the head of Medusa, is about thirteen degrees, and in an easterly direction. *Almaach*, *Algol*, and *Algenib* (in Perseus) form very nearly a right-angled triangle, the right angle being at Algol. Mirach, Almaach, and Algol divide into three equal parts the space between the head of Andromeda and the centre of Perseus. Andromeda when on the meridian is directly over our heads. It contains sixty-six stars, three being of the second and two of the third magnitude.

THE FISHES,

According to some, are those whose form Venus and Cupid assumed to escape the giant Typhon. Others say that two fishes, having found an egg, rolled it on shore, where it was warmed by a dove, and from it there arose Astarte, the Venus of Assyria. From that time the Assyrians abstained from eating fish. According to Theon the *Fishes* are the children of the *Southern* Fish, after whom they always rise.

This constellation occupies much space in the heavens. It is represented by two fishes tied together, yet quite distant from each other, the connecting cord being long and undulating. Both of the fishes join the *Flying Horse*, one being east and the other south, quite close to the wing. The first, which may be called the *Eastern Fish*, is exactly south of Merach in Andromeda. The cord may be traced in a south-easterly direction till we reach *Alpha*, which is in the knot. From Alpha the cord runs north-westerly, until it reaches the *Western Fish*, between which and Alpha in the knot are three stars of the fourth or fifth magnitudes, nearly equidistant from each other. The *Fishes* contain one hundred and thirteen stars, most of which are very small.

CEPHEUS,

A king of Ethiopia and one of the Argonauts, made a constellation after death. Although he had promised Andromeda to Phineas, yet when Neptune flooded the country and Andromeda was devoted as food for a sea-monster, Cepheus was ready to comply with the demand of Perseus, who promised to save the lady if she would marry him. Their nuptials were opposed by Phineas, but his opposition ceased when Perseus held before his eyes the Gorgon's head.

Cepheus is represented with a crown on his head and a sceptre in his hand. He is opposite the Great Bear with regard to the pole. His head is in the milky-way, and may be known by three stars of the fourth magnitude in the crown, forming a little triangle. The principal star in the constellation is named Alderamin; it is of the third magnitude, situated in the west shoulder, forming a quadrilateral, that may be readily distinguished, with three other stars of the fourth magnitude, of which one is in the girdle, one in the east arm, and one in the east knee. Alderamin bears east by north from Rastaben in the Dragon, being distant about twenty-nine degrees. It is about twenty-eight degrees from the pole star, and twenty-six from Schedir, a bright star in Cassiopeia, in a west-north-west direction.

CASSIOPEIA,

Or *the lady in her chair*, was the wife of Cepheus and mother of Andromeda. As a reward for her hard-wrung consent to sacrifice her daughter for the good of the country, she was carried to heaven after death and placed among the constellations by Minerva.

Cassiopeia holds in her hand a branch of the palm tree. Her head and body are in the milky-way, and her foot rests upon the polar circle. She is surrounded by her husband, daughter, and son-in-law. This constellation is midway between Andromeda and the pole. It is visible at all hours of the night in our latitude, being in such high northern declination that it never sets. It contains fifty-five stars, five being of the third magnitude, which form (as many persons imagine) the figure of an inverted chair. *Beta* is in the back of the chair. It is the western star of the bright cluster. The uppermost of these is in the breast, and is named *Schedir*. The situation of Beta is important to mariners; it is used for finding the latitude, and for determining the variation of the needle of the compass from the true north. Beta also serves to mark a spot memorable as the situation of a lost star.

In November, 1572, a star was seen about five degrees from Beta, which became suddenly so brilliant that it surpassed the planets in brightness, and could be seen in the daytime. This brilliancy diminished until 1573, when it became entirely invisible. Its color exhibited the appearances of flame. It was first of a dazzling white, then of a reddish yellow, and lastly of an ashy paleness, in which its light expired. Some imagined that it would reappear after one hundred and fifty years, but it has not been seen since. Vince, one of the most learned astronomers of the age, has remarked, that the disappearance of stars may be the destruction of that system, at the time appointed for the probation of its inhabitants; and the appearance of new stars may be the formation of new systems for new races of beings, then called into existence to adore their Creator. The conflagration (if so it were) was visible for sixteen months. How tremendous must it have been to be visible so far! La Place says "that the supposition of such a conflagration on the surfaces of some of the stars is confirmed by their change of color."

THE FLYING HORSE AND THE LITTLE HORSE.

The flying horse is Pegasus, who sprung from the blood of Medusa, when Perseus cut off her head. Pegasus fixed his residence on mount Helicon, where, by striking the earth with his hoof, he produced the famous fountain called Hippocrene. Pegasus was long the favorite of the muses, but, being tamed by Neptune, he was given to Bellerophon to assist him in subduing the fiery monster Chimæra.

After the destruction of Chimæra, Bellerophon attempted to fly to heaven on Pegasus, which so incensed Jupiter that he sent a fly to sting the horse; this occasioned the fall of the rider, but the horse continued his upward flight and became a constellation.

The *Little Horse* was named by the ancients, who supposed that it was the brother of Pegasus, named Celeris, a horse given to Castor, who was skilful in the management of those animals. The head only of the Little Horse is visible in the heavens.

The Flying Horse is situated between the *Swan*, the *Dolphin*, and the *Eagle* on the west, *Andromeda* and the *Eastern Fish* on the east, and occupies a large space in the heavens. It may be known by means of four stars of the second magnitude, forming a large four-sided figure, called the square of Pegasus. Alpheratz, the north-easternmost star of the square, is in the head of Andromeda; to the southward of this, and distant about fourteen degrees, is the star Algenib; to the westward of Algenib, distant about sixteen degrees, is the star Markab; to the northward of Markab, distant about thirteen degrees, is Scheat, from which to Alpheratz is about fifteen degrees, direction westerly. These are the four stars that form the square of Pegasus. Markab is one of the nine stars from which navigators measure the distance of the moon. In Pegasus there are eighty-nine stars; most of them, however, are small. We see but a part of the Flying Horse; the poets imagined that the rest was hid in the clouds.

About twenty degrees from Markab, in a westerly direction, is a star in the nose of the *Little Horse*, named *Enif*. The cluster contains ten stars, of which the four principal are of the fourth magnitude, rather noticeable on account of the figure they form than for their brilliancy. They form a long irregular square, the two in the nose being much nearer together than those in the eyes. This horse, like Pegasus, is in an inverted position.

THE WATER-BEARER.

This is Ganymede, whom Jupiter, under the form of an eagle, carried off to be the cupbearer of the gods. The hoof of Pegasus rises just before the stream of the Bearer. The water represents the fountain Hippocrene, which Pegasus produced by a blow of his hoof. The nine stars of the Dolphin are the nine muses who drink at the fountain. Some consider the Water-bearer as Deucalion, who, escaping with his wife Pyrrha from the flood, landed on mount Parnassus, the abode of the muses, of Pegasus, and of Hippocrene.

The *Water-bearer* is situated to the southward of Pegasus. Within it are four stars, so situated as to form the figure of a Y, very plainly visible; these stars are in the hand of the Bearer and the handle of the Urn. This figure is distant from Markab in Pegasus about eighteen degrees, in a direction south-west by south, and with the Dolphin and the head of the Capricorn forms an isosceles triangle. To the westward of the Y and distant about four and a half degrees, is a star of the third magnitude, named Alpha, in the east shoulder of the Bearer; it is the principal star in the constellation. A line drawn from Alpheratz, in the head of Andromeda, through Markab, will lead directly to Alpha. Two stars, one in the east hand, the other in the west shoulder, form with Alpha a triangle, the largest angle being at Alpha. About eighteen degrees from the Y, in a south by east direction, is Scheat, of the third magnitude, in the right leg. This cluster contains one hundred and eight stars, four being of the third magnitude. The stream or cascade terminates in the mouth of the *Southern* Fish, which is thirty degrees south of the Y.

THE SOUTHERN FISH

Is said by the Assyrians to have saved the life of Derceto, and by the Egyptians the life of Isis. Fomalhaut, its principal star, by its rising at night indicated that the sun was in the solstitial Lion, as Sirius did by rising heliacally. These two stars were worshipped by the Egyptians, who considered them as the causes of the Nile's inundations. Fomalhaut was honored under the name of Phagrus, or of Dagon. His presence above the horizon at that time showed the shortest night of the year; for it rose at evening and set in the morning at the summer solstice.

This constellation lies south of the *Water-bearer;* it is represented as a fish drinking the water flowing from the urn. There is in it one beautiful star of the first magnitude, Fomalhaut, in the mouth. A line drawn from Scheat and passing through Markab (both in Pegasus) will lead to Fomalhaut. It is one of the stars from which the moon's distance is measured, and consequently its place has been determined with great precision. The cluster contains twenty-four stars, one being of the first, two of the third, and five of the fourth magnitude.

PERSEUS AND THE HEAD OF MEDUSA.

Perseus was the son of Jupiter and Danae. Polydectes, king of one of the Cyclades, where Perseus lived, ordered him to cut off the head of Medusa and bring it to the palace. Vulcan gave the hero a casque that rendered him invisible, and a famous sword, Mercury lent him his wings and talaria, and Minerva a shield. He attacked the Gorgons, whose hair was stiff with snakes, and cut off the head of Medusa. As he flew off with this trophy of success, the blood that dropped from it on the sandy deserts of Lybia become serpents innumerable, which have infested that desolate country ever since.

> The gory drops distilled, as swift he flew,
> And from each drop envenomed serpents grew.

Perseus after death became a constellation, and the head of Medusa was placed near him.

This constellation is principally in the milky-way. It is represented by a man having wings to his feet, a sword in his right hand, and a trunkless head in his left. It is situated north of the Pleiades, west of the *Wagoner*, and east of *Andromeda*. Perseus is easily known by means of three stars of the second and third magnitudes, which form an arc of a circle, the concave being toward the Great Bear. The middle star is Algenib, of the second magnitude. South of this arc is Algol, in the head of Medusa, surrounded by a group of very small stars; west from Algol are two stars near together; these are in the leg of Perseus, near the knee; south of these is one in the foot; these three form a curve. Algol is the only star at all remarkable in the head of Medusa. It is usually very bright, but changes from the second to the fourth magnitude in three and a half hours, and back again in the same time; then it remains visibly the same for two days, when the same changes begin again.

This constellation contains fifty-nine stars, of which number about a dozen are in the head of Medusa. When Algenib and Algol are near the meridian the most beautiful part of the heaven is visible. Its glories are magnificent beyond description, and he who looks upward at this time can scarcely fail "to reverence the Being who made the seven stars and Orion."

THE RAM.

Phryxus and Helle, obliged to fly from their stepmother's cruelty, were carried on a winged ram with a golden fleece across the Hellespont, in which Helle fell and perished. Phryxus arrived at Colchis, and sacrificed the animal to Mars. The story of the expedition of the Argonauts relates to the sun (at the equinox) in the Bull. From Thrace, the country of Jason, they saw the sun rise in the direction of Colchis. The Ram, rising just before it, was an emblem of a golden fleece, guarded by a monster, (Cetus,) and by a Bull, that vomited flame. At evening, Ophiucus, that is, Jason, rises from the spot whence the Ram rose in the morning. The hero then has carried off this precious fleece. His companions, Hercules, Castor, Pollux, and Cepheus are at the horizon.

The Ram is the second constellation in the zodiac, being situated next east of Pisces It is north of the head of the *Sea Monster*, (Cetus,) and west of the *Bull*. It may be distinguished by the stars in the head. Of these there are three; the two brightest being of the second and third magnitudes, four degrees apart, one in each horn. That in the right horn is named Arietis, and is the principal star, and an important one, being of the number of those from which the moon's distance is measured at sea; that in the left horn is called Beta. To the southward of this is a star in the ear, named Mesarthim, of the fourth magnitude. The other stars are small. The cluster contains sixty-six stars, one being of the second, one of the third, and two of the fourth magnitude.

THE SEA MONSTER.

The delineation of this constellation being as little like a whale as Pollonius' cloud, it may be better to call it as above. It represents the monster sent to devour Hesione, which was killed by Hercules, or that sent to destroy Andromeda, which was killed by Perseus.

South of the Ram we shall find a star of the second magnitude; it is Menkar, in the jaw of the monster. It forms an equal sided triangle with the Ram and the Pleiades. The five stars in the head form a pentagon. South-west of this pentagon is a star in the lower jaw, and six degrees farther, in nearly the same direction, is the *wonderful star* of 1596, named Mira, which changes from a star of the second magnitude so as to become invisible in about three hundred and thirty-two days; though Hevelius is certain that it once disappeared for four years. From Mira south-east we shall find a quadrilateral formed by four stars of the third magnitude. Still farther south-east is Deneb, in the tail, of the second magnitude. South-west of the quadrilateral we find in the fore paw another very small quadrilateral.

We have thus endeavored to describe the most important of the constellations, their position and that of their individual stars, that no one may be at a loss to find them in the heaven, should his taste fortunately lead him to the study of so important and interesting a subject. We have given the fables of the ancients respecting them, in hope to attract those who are not yet interested, and, in a few instances, given explanations of the origin and even reasonableness of these fables; being of the number of those who think that the stories of antiquity, which appear to some the productions of childish folly or imbecile superstition, were replete with meaning, hidden, to be sure, from the common people, but full of wisdom to the sage, although the signification of most of them has been lost. The meaning of the few may teach us what to think of the rest.

In the serious contemplation of so many splendid luminaries, the mind will have its reasoning faculties expanded and filled with more sublime ideas of the grandeur, the magnificence, and the unlimited extent of creation; nor can it fail to be inspired with reverential delight in reflecting on the wisdom of those immutable laws that govern the stupendous whole, and preserve such wonderful harmony, connection, and order throughout so many systems of systems. It will wander beyond the reach of contracted prejudice, and, rising above this orb on which the body rests, feel conscious of the existence of other suns, and soar, unfettered by the chains of superstition, through thousands of millions of revolving worlds.

The stars appear to be fixed in the concave of a large sphere. This appearance is not caused by the stars being situated at equal distances from us, but is an illusion of vision; the narrowness of human sight not permitting us to see, in their true places, objects that are very remote.

This will appear evident when we consider that the sun and the moon appear to be placed in the same concave and equidistant, while in fact the sun is four hundred times farther off than the moon, and the stars at a distance infinitely greater than the sun; we know not how far! It may be inferred from this that the stars are at unequal distances, and that there may be as great a distance between two that *appear* to us close to each other, as between our sun and that star which is nearest him.

The rays of light reflected by the atmosphere produce that bluish tint, which forms the beautiful celestial shade commonly called the azure sky. If this were not an appearance only, but a reality, and the stars were attached to it, they would not be more than forty-five miles distant; for beyond this it is probable the atmosphere is too rare to reflect the rays. Instead of this being the distance of the stars, it is so great as to be entirely beyond the comprehension of the human mind; so great that all other considerations of remote or high seem to vanish from the mind in its endeavors to contemplate it. We may think of space as

> Without bound,
> Without dimensions, where length, and breadth, and height,
> And time, and place are lost.

Our earth then, compared to the whole of creation, is less than an atom floating in a sunbeam. This must be granted when it is understood, that comets travel millions upon millions of miles from the farthest of our planets, and at such immense distances, must be still nearer to the sun than to any of the stars; otherwise would they be attracted by those stars and return not again to our system.

> Take thy boldest flight
> Amid those sovereign glories of the skies,
> Of independent native lustre, proud,
> The souls of systems! What behold'st thou now?
> A wilderness of wonders burning round;
> Where larger suns inhabit higher spheres!
> And ask for Him who gave these orbs to roll.

CHAPTER II.

SECTION I.

Erroneous notions derived from appearances—Why the stars are not visible to the naked eye in the day-time—Fictions of poetry respecting the universe—Is the earth its centre?—Does the earth rotate?—Different constellations visible at different regions—Rotation of the earth consistent with appearances—Permanence of its axis—Precision of the ancients—Discovery by Copernicus—Causes of erroneous impressions—Consequences of considering the earth immovable—Centrifugal and centripetal forces—Pendulum a means of finding the force of attraction—Measures of gravity—Attraction not a simple force—Effects of the earth's rotation—Trade winds—Proofs of wisdom in the rotation of the earth—Consequences of a changeable axis—Advantages of the existing law of attraction—Perturbations periodical.

Man, misled by appearances, regarded for a long time the earth as nearly a plain, situated in the middle of the universe; the sun, the moon, and the stars were all in motion around it.

As evident as this hypothesis may appear to the untutored eye, we shall see by an attentive observation of various phenomena that it is altogether erroneous.

If one of our senses is strongly affected it ceases to be sensible to slight impressions. A low sound cannot be readily heard in the midst of loud and confused noises. The eyes, acted upon by a brilliant light, can perceive nothing situated in a dark corner. But by degrees they become accustomed to the shade, and recover slowly the faculty of distinguishing objects.

The cause is similar that deprives us of the sight of the stars during the brightness of day. They are as much within view as ever, but it is only by twilight that they successively become visible, beginning with the most brilliant and the most easterly. The moon produces the same effect upon the *small* stars near it as the sun does upon all of them. Some appear to describe small circles without ever setting or going beneath the horizon, and are lost to our sight only because morning approaches to diminish their splendor; but the greater number describe more extended curves; they disappear beneath the horizon, and after some hours reappear in the opposite region of the heavens. They must therefore, while below our horizon, continue the curves which they describe while above it.

It has been found that the stars apparently describe around the earth circumferences parallel to each other and oblique to our horizon, by a rotation that is uniform and accomplished in the same time by each. These appearances lead men to regard the earth as immovable in the centre of a celestial sphere, whilst this sphere turns round with a uniform motion, carrying with it all the stars, fixed, like so many twinkling points. We shall by and by come to explain the falseness of this supposition, which, however false it is, will give us some good idea of the movements of the heavens.

Placed upon the earth, it does not seem to us as a sphere isolated in space. An attentive observation, however, will convince us that if we had the power of removing to a distance from the globe, it would present to our sight the same form as the sun and moon present, with apparent dimensions differing at different distances. Reason has dissipated the mist of ancient physics, and with it have vanished the fictions and brilliant illusions of poesy.

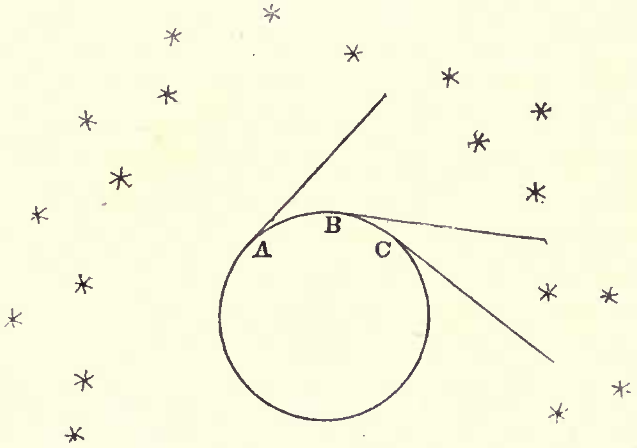
The earth is no longer "a plain, supporting a celestial dome;" Phebus no longer "extinguishes his brilliant fire in the waves;" Sol rises without "Aurora's opening the gates for his flaming chariot;" and, finally, Olympus is no longer a "small mountain of Thessaly, inhabited by the fabled god of thunder."

This first step it was not very difficult to take. But is the earth fixed in the centre of the universe? Does the universe revolve about it? Are the multitude of heavenly bodies attached to the surface of a sphere turning on one of its diameters? It is not always the first step that is the most difficult. Observations did not correct this opinion. The sport of deceitful appearance, it was necessary, if we would escape this error, to put aside prejudices born with us, and which our eyes confirmed at every look, instead of removing. The philosopher who first affirmed that the celestial sphere was motionless, and that on the contrary the earth turned round, dared to contradict the testimony of the senses. It was by the comparison of different phenomena, by studying their consequences, that he discovered those great natural laws, whose impress is upon every thing around us.

First, it was observed that the moon, and the planets Venus and Mercury, sometimes passed over the sun; all these heavenly bodies at times covered the stars in the same way as a cloud conceals them. They are then at unequal distances from the earth. It is also probable that the stars are at unequal distances, since they have very different degrees of splendor and apparent magnitude, for "one star differeth from another in glory." There are myriads which are not visible to the naked eye, and of whose existence we should be wholly ignorant but for the telescope. Is it not probable that these are more distant than the others?

We are under the necessity of choosing between two suppositions, either of which explains well enough the facts observed. One (that which agrees better with the testimony of our senses) supposes the heavens to revolve around us with a general and equable motion; the other, which is the only reasonable one, supposes the earth to revolve on its axis, while the celestial sphere remains motionless.

A traveller, shifting his locality on our globe, will obtain a view of celestial objects invisible from his original station, in a way which may be not inaptly illustrated by comparing him to a person standing in a park close to a large tree. The massive obstacle presented by its trunk cuts off his view of all those parts of the landscape which it occupies as an object; but by walking round it a complete successive view of the whole panorama may be obtained. Just in the same way, if we set off from any station, and travel southward, we shall not fail to notice that many celestial objects which are never seen from that station come successively into view, as if rising up above the horizon, night after night, from the south, although it is in reality our horizon, which, travelling with us southward round the sphere, sinks in succession beneath them. The novelty and splendor of fresh constellations thus gradually brought into view in the clear calm nights of tropical climates, in long voyages to the south, is dwelt upon by all who have enjoyed this spectacle, and never fails to impress itself on the recollection among the most delightful and interesting of the associations connected with extensive travel. A glance at the accompanying figure, exhibiting three successive stations of a traveller, A, B, C, with the horizon corresponding to each, will place this process in clearer evidence than any description.



Suppose the earth itself to have a motion of rotation on its centre. It is evident that a spectator at rest (as it appears to him) on any part of it, will, unperceived by himself, be carried round with it: unperceived, we say, because his horizon will constantly contain, and be limited by, the same terrestrial objects. He will have the same landscape constantly before his eyes, in which all the familiar objects in it, that serve him for landmarks and directions, retain, with respect to himself or to each other, the same invariable situations. The perfect smoothness and equality of the motion of so vast a mass, in which every object he sees around him participates alike, will prevent his entertaining any suspicion of his actual change of place. Yet, with respect to external objects,—that is to say, all celestial ones which do not participate in the supposed rotation of the earth,—his horizon will have been all the while shifting in its relation to them, precisely as in the case of our traveller. Recurring to the figure, it is evidently the same thing, so far as their visibility is concerned, whether he has been carried by the earth's rotation successively into the situations A, B, C ; or whether, the earth remaining at rest, he has transferred himself personally along its surface to those stations. Our spectator in the park will obtain precisely the same view of the landscape, whether he walk round the tree, or whether we suppose it sawed off, and made to turn on an upright pivot, while he stands on a projecting step attached to it, and allows himself to be carried round by its motion. The only difference will be in his view of the tree itself, of which, in the former case, he will see every part, but, in the latter, only that portion of it which remains constantly opposite to him, and immediately under his eye.

By such a rotation of the earth, then, as we have supposed, the horizon of a stationary spectator will be constantly depressing itself below those objects which lie in that region of space towards which the rotation is carrying him, and elevating itself above those in the opposite quarter ; admitting into view the former, and successively hiding the latter. As the horizon of every such spectator, however, appears *to him* motionless, all such changes will be referred by him to a motion in the objects themselves so successively disclosed and concealed. In place of his horizon approaching the stars, therefore, he will judge the stars to approach his horizon ; and when it passes over and hides any of them, he will consider them as having sunk below it or *set;* while those it has just disclosed, and from which it is receding, will seem to be rising above it.

If we suppose this rotation of the earth to continue in one and the same direction,—that is to say, to be performed round one and the same *axis*, till it has completed an entire revolution, and come back to the position from which it set out when the spectator began his observations,—it is manifest that every thing will then be in precisely the same relative position as at the outset: all the heavenly bodies will appear to occupy the same places in the concave of the sky which they did at that instant, except such as may have actually moved in the interim ; and if the rotation still continue, the same phenomena of their successive rising and setting, and return to the same places, will continue to be repeated in the same order, and (if the velocity of rotation be uniform) in equal intervals of time.

Now, in this we have a lively picture of that grand phenomenon, the most important, beyond all comparison, which nature presents, the daily rising and setting of the sun and stars, their progress through the vault of the heavens, and their return to the same apparent places at the same hours of the day and night. The accomplishment of this revolution in the regular interval of twenty-four hours, is the first instance we encounter of that great law of *periodicity*, which, as we shall see, pervades all astronomy ; by which expression we understand the continual reproduction of the same phenomena, in the same order, at equal intervals of time.

A free rotation of the earth round its centre, if it exist and be performed in consonance with the same mechanical laws which obtain in the motions of masses of matter under our immediate control, and within our ordinary experience, must be such as to satisfy two essential conditions. It must be invariable in its direction *with respect to the sphere itself*, and uniform in its velocity. The rotation must be performed *round an axis* or diameter of the sphere, whose *poles*, or extremities, where it meets the surface, correspond always to the same points on the sphere. Modes of rotation of a solid body under the influence of external agency are conceivable, in which the poles of the imaginary line or axis about which it is at any moment revolving shall hold no fixed places on the surface, but shift upon it every moment. Such changes, however, are inconsistent with the idea of a rotation of a body of regular figure about its axis of symmetry, performed in free space, and without resistance or obstruction from any surrounding medium. The complete absence of such obstructions draws with it, of necessity, the strict fulfilment of the two conditions above mentioned.

Now, these conditions are in perfect accordance with what we observe, and what recorded observation teaches us in respect of the diurnal motions of the heavenly bodies. We have no reason to believe, from history, that any sensible change has taken place since the earliest ages in the interval of time elapsing between two successive returns of the same star to the same point of the sky; or, rather, it is demonstrable from astronomical records that no such change *has* taken place. And with respect to the other condition,—*the permanence of the axis of rotation*,—the appearances which any alteration in that respect must produce, would be marked by a corresponding change of a very obvious kind in the apparent motions of the stars; which, again, history decidedly declares them *not* to have undergone.

Such general views of the nocturnal heavens, which every common observer may take, have a tendency to expand the mind, and to elevate it to the contemplation of an Invisible Power, by which such mighty movements are conducted. Whether we consider the vast concave, with all its radiant orbs, moving in majestic grandeur around our globe, or the earth itself whirling round its inhabitants in an opposite direction—an idea of sublimity, and of Almighty energy, irresistibly forces itself upon the mind, which throws completely into the shade the mightiest efforts of human power. The most powerful mechanical engines that were ever constructed by the agency of man, can scarcely afford us the least assistance in forming a conception of that incomprehensible Power, which, with unceasing energy, communicates motion to revolving worlds. And yet, such is the apathy with which the heavens are viewed by the greater part of mankind, that there are thousands who have occasionally gazed at the stars, for the space of fifty years, who are still ignorant of the fact, that they perform an *apparent* diurnal revolution round our globe.

Again, if we contemplate the heavens with some attention, for a number of successive nights, we shall find, that by far the greater part of the stars never vary their positions with respect to each other. If we observe two stars at a certain apparent distance from each other, either north or south, or in any other direction, they will appear at the same distance, and in the same relative position to each other, the next evening, the next month, and the next year. The stars, for instance, which form the *sword* and *belt* of *Orion*, present to our eye the same figure and relative aspect during the whole period they are visible in winter, and from one year to another; and the same is the case with all the fixed stars in the firmament. On examining the sky a little more minutely, however, we perceive certain bodies which regularly shift their positions. Sometimes they appear to move towards the east, sometimes towards the west, and at other times seem to remain in a stationary position. These bodies have obtained the name of *planets*, or wandering stars; and, in our latitude, are most frequently seen either in the eastern and western, or in the southern parts of the heavens. Ten of these planetary orbs have been discovered; six of which are, for the most part, invisible to the naked eye. By a careful examination of the motions of these bodies, and their different aspects, astronomers have determined that they all move round the sun as a centre, and form, with the earth, one grand and harmonious system.

If the results at which we arrive in this age, in consequence of the great progress of the physical sciences, were unknown to the ancients, still it must be admitted that they were not without some idea of their existence; and we are often surprised to find a precision, that we should be far from expecting of them, if we considered sufficiently how much patience and reflection were requisite to enable them to attain what they have, with the aid of their rude methods. However this may be, there was nothing better than doubts concerning the motions of the heavenly bodies, until the illustrious *Copernicus* appeared. He was undoubtedly the first who displaced the earth from the centre of the celestial motions, and subjected it to the laws, followed by the other planets, by making it revolve around the sun; and thus destroyed that proud pretension of man, that considered the abode he possessed as a spot upon which a beneficent Creator had poured out all his blessings, and to which he had given, as it were, the sovereignty of the universe.

Some have wished to take from Copernicus the immortal glory of such a discovery, by asserting that his theory had been already held by certain of the ancients. They have mentioned Pythagoras, Empedocles, and others. But wise men know how to value justly this assertion, and despise the common accusation of plagiarism, which so many are ever ready to make against those who are guilty of having acquired a great reputation.

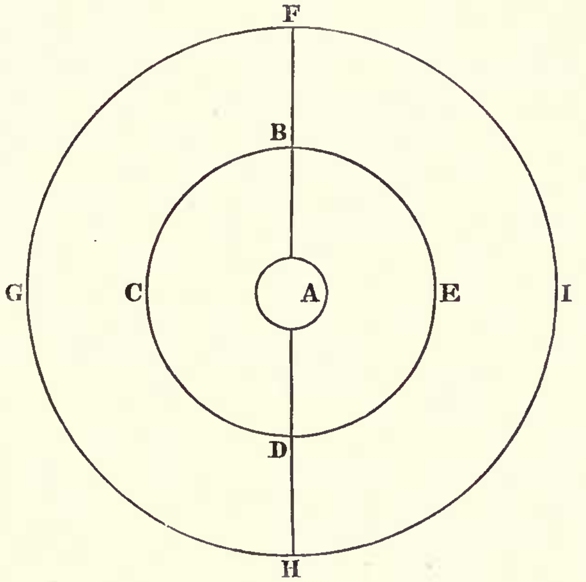
The numerous arguments furnished by Copernicus in support of his theory, caused it to be adopted by almost all the astronomers who succeeded him; and those which Kepler, Galileo and Newton added, have served to establish it forever. Let us consider now what are the phenomena that should result from the rotation of the earth on its axis. And first, what induces one ignorant of the subject to attribute to a motion of the heaven what is really a consequence of our own rotation? Experience offers to us daily examples of a similar illusion. Placed in a boat that is descending a river, if we direct our sight toward the bank, do not the hills, the mountains, the trees, all objects seem to move in a direction contrary to our own motion, and with a rapidity proportioned to their proximity to us? Do not all objects which are presented to his vision seem equally to be flying backward from the traveller in his coach? and does not the illusion become stronger in proportion to the rapidity of his own motion?

These effects, and many others similar to them, are owing to various causes, the explanation of which may be found by examining the sensations that affect us in such cases. The motion which carries us onward not being the result of the voluntary action of our organs, and our relations to the objects about us being unchanged thereby, we are affected in a manner entirely passive, and the cause is not attributed to ourselves. This is so true, that, notwithstanding the strong conviction we are under that we are subject to a deceitful appearance, we cannot at first prevent ourselves from believing the erroneous testimony of our senses. The circumstances are the same which happen to one situated on the surface of the earth. All the objects nearest him participate in the same motions that are performed so unconsciously by himself, and consequently their motion is unobserved. He believes that he and they are motionless, and attributes to other objects with which his relations are changed a motion in a direction contrary to the real motion of himself and those objects that move with him. Thus we at first sight should suppose that the course of the heavenly bodies was from east to west, while in reality it is directly the reverse. The observer, accompanying the earth in its rotation, perceives that the heavenly bodies become more and more elevated above his horizon, and then apparently descend until they are concealed by the earth, whose opacity prevents the passage of luminous rays to the eye of the observer.

Before coming to the direct and unanswerable proofs of the rotation of the earth,—proofs drawn from the laws of attraction and from the many phenomena going on about us,—let us reflect a moment on the consequences which would result from admitting its immobility in space.

The distance of the sun is about ninety-five millions of miles; consequently, the diameter of the circle he would describe around the earth would be 190 millions, and its circumference 597,142,857, which forms the extent of the circuit through which he would move in twenty-four hours, if the earth were at rest. This number divided by twenty-four gives 24,880,952, the number of miles he would move in an hour; and this last number divided by sixty gives 414,682, the number of miles he would move in a minute. The nearest star is reckoned to be at least 20,000,000,000,000, or twenty billions of miles distant from the earth; consequently, its daily circuit round our globe would measure more than 125,000,000,000,000, miles. This sum divided by 86,400, the number of seconds in a day, would give 1,454,861,111, or somewhat more than one thousand four hundred millions of miles, for its rate of motion in a second of time: a motion which, were it actually existing, would, in all probability, shatter the universe to atoms.

The reader may, perhaps, acquire a more distinct idea of this explanation from the following figure.



Let the small circle, A, in the centre, represent the earth, and the circle B C D E the orbit of the sun, on the supposition that he moves round the earth every twenty-four hours. The line A B will represent the distance of the sun from the earth, or ninety-five millions of miles; the line B D the *diameter* of the orbit he would describe; and the circle B C D E the circumference along which he would move every day, or 597 millions of miles, which is somewhat more than three times the diameter. If the line A F represent the distance of the nearest star, the circle F G H I will represent the circuit through which it would move every twenty-four hours, if the earth were at rest. It is obvious, from the figure, that since the stars are at a greater distance from the earth than the sun, the circle they would describe around the earth would be larger in proportion, and, consequently, their velocities would be proportionably more rapid; since they would move through their larger circles in the same time in which the sun moved through his narrower sphere. But the supposition that the earth is the centre of all the celestial motions, and that the different stars are daily moving around it with different velocities, and the slowest of these motions is so inconceivably rapid, is so wild and extravagant that it appears altogether inconsistent with the harmony of the universe, with the wisdom and intelligence of the Deity, and with all the other arrangements he has made in the system of nature.

How then can we reasonably believe that the heavenly bodies, scattered in such numbers through the dome of heaven, placed at such different distances, so variable in volume and mass, should perform their daily revolutions in exactly the same time? And what other probabilities could we not bring forward against such a theory, if we would seek with care for all that could be found?

If it be not proved satisfactorily that the stars are at unequal distances from the earth, at least this truth is evident with regard to the sun, the moon, and the planets. It would be requisite that these bodies should have velocities proportioned to their respective distances, in order to produce the same appearances as would be presented by the rotation of the earth. This concert of motion seems the more impossible to admit when reflecting upon the comets; they move in all directions and with all velocities, and yet make this apparent revolution about the earth in twenty-four hours; a revolution affected only by the small quantity of their own proper motion. And if this unanimity of motion, so constant in the midst of so many regular variations, present some trifling differences, still the equality may be taken as perfect, and the diurnal motion considered as the only instance of uniformity in existence. How can we believe that the earth, this insensible point of matter, is the only one immovable in the midst of bodies so immense and so rapidly moving?

The sentiment of self-love, which would refer every thing to ourselves, tempts us to believe our earth the centre of the motions of the universe. It is the part of philosophy to remove such a cause; or, rather, does not religion remove it? Is it not attacking the majesty of the Creator to make the creation of all these myriads of bodies have for its sole or chief object the lighting up or enlivening of this earth, a mere atom in space?

When we whirl a sling, the hand that holds the cord feels that some effort is required to retain it. As soon as this effort ceases, the stone, released from its confinement, escapes. The power that causes the tension of the string is called *centrifugal force*, (tendency from the centre.) Every body, thus revolving round a point, has a tendency to escape from that centre, in a right line, which is tangent to the circle made by the revolving body; while the cord which confines it represents the *centripetal force* (tendency toward the centre) exercised to retain the body. Calculations show that this force increases as the mass of the body and as the squares of the velocity of its motion. How immense then would be the power required to keep the sun and the stars in their respective orbits round the earth. Thus all things seem to conspire to prove to us that *the earth has a motion of rotation on its axis from west to east, while the stars remain fixed.*

Since the earth revolves, it must, like all bodies that have a similar motion, possess a centrifugal force, which (according to experience and calculation) increases as the squares of the velocities of the motion. The equator being the largest circle of the earth, the centrifugal force must be greatest there. It will, on the contrary, be nothing at the poles. And as the centrifugal force varies with the distance from the centre of the globe, it follows that the force of attraction acts upon bodies on different parts of the surface with a varying intensity.

To be convinced of this fact it was only necessary to carry a pendulum from the equator toward the pole, and as the number of oscillations increase with its weight we have a very simple method of finding the force of attraction.

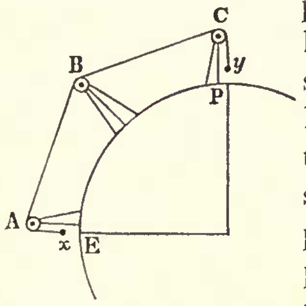
But there are two things to be considered in the difference of results with which we should be thus furnished; viz. the greater distance of the body from the centre of attraction, and the greater centrifugal force at the equator. These two circumstances conspire to make the weight of bodies at the equator less than they would be at the poles; weight being an effect of attraction which the earth exercises on bodies. It is found that the weight decreases as we ascend high mountains, and we know that the equatorial diameter is the longest; therefore there is nothing unreasonable in supposing that the cause of the diminution of weight is the same in both cases, viz., the greater distance from the centre. The other conspiring cause of the diminution of weight will hardly need an argument, viz. the greater rapidity of motion at the equator.

The attraction of the globe also varies with the density of its internal strata, which is unknown. It would be scarcely possible to admit that the earth were homogeneous, even if observations on the length of the pendulum did not contradict the idea; while we find an admirable consistency in the theory that *the density of the earth increases from the surface to the centre.*

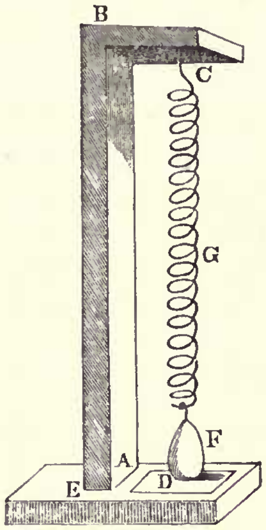
A pendulum, then, at the same time that it helps to prove the rotation of the earth, introduces us, as it were, into the interior of the globe, and permits us to appreciate the strata which compose it. It has been usual to regard the diminution of weight at the equator as $\frac{1}{289}$; that is, bodies lose at the equator $\frac{1}{289}$ of the weight they have at the poles. As 289 is the square of seventeen, and as the centrifugal force increases as the square of the velocity, it follows that if the rotation of the earth should become seventeen times more rapid than it is, a body at the equator would lose the whole of its weight. If a still greater velocity were imparted to it, bodies would fly off from the earth's surface, as stones rise from the crater of a volcano.

The reader will naturally inquire what is *meant* by speaking of the same body as having different weights at different stations; and how such a fact, if true, can be ascertained. When we weigh a body by a balance or a steelyard we do but counteract its weight by the equal weight of another body under the very same circumstances; and if both the body weighed and its counterpoise be removed to another station, their gravity, if changed at all, will be changed equally, so that they will still continue to counterbalance each other. A difference in the intensity of gravity could, therefore, never be detected by these means; nor is it in *this* sense that we assert that a body weighing 194 pounds at the equator will weigh 195 at the pole. If counterbalanced in a scale or steelyard at the former station, an additional pound placed in one or other scale at the latter would inevitably sink the beam.

The meaning of the proposition may be thus explained: conceive a weight, x, suspended at the equator by a string without weight passing over a pulley, A, and conducted (supposing such a thing possible) over other pulleys, such as B, round the earth's convexity, till the other end hung down at the pole, and there sustained the weight y. If, then, the weights x and y were such as, at any one station, equatorial or polar, would exactly counterpoise each other on a balance or when suspended side by side over a single pulley, they would not counterbalance each other in this supposed situation, but the polar weight, y, would preponderate; and to restore the equipoise the weight x must be increased by $\frac{1}{194}$th part of its quantity.



The means by which this variation of gravity may be shown to exist, and its amount measured, are twofold, (like all estimations of mechanical power,) statical and dynamical. The former consists in putting the gravity of a weight in equilibrium, not with that of another weight, but with a natural power of a different kind not liable to be affected by local situation. Such a power is the elastic force of a spring. Let A B C be a strong support of brass, standing on the foot A E D, cast in one piece with it, into which is let a smooth plate of agate, D, which can be adjusted to perfect horizontality by a level. At C let a spiral spring, G, be attached, which carries at its lower end a weight, F, polished and convex below. The length and strength of the spring must be so adjusted that the weight F shall be sustained by it just to swing clear of contact with the agate plate in the highest latitude at which it is intended to use the instrument. Then, if small weights be added cautiously, it may be made to descend till it *just grazes* the agate, a contact which can be made with the utmost imaginable delicacy. Let these weights be noted; the weight F detached; the spring G carefully lifted off its hook, and secured, for travelling, from rust, strain, or disturbance; and the whole apparatus conveyed to a station in a lower latitude. It will then be found, on remounting it, that, although loaded with the same additional weights as before, the weight F will no longer have power enough to stretch the spring to the extent required for producing a similar contact. More weights will require to be added; and the additional quantity necessary will, it is evident, measure the difference of gravity between the two stations, as exerted on the whole quantity of pendent matter, i. e. the sum of the weight of F and *half* that of the spiral spring itself. Granting that a spiral spring can be constructed of such strength and dimensions that a weight of 10,000 grains, including its own, shall produce an elongation of ten inches without permanently straining it, one additional grain will produce a further extension of $\frac{1}{1000}$th of an inch,—a quantity which cannot possibly be mistaken in such a contact as that in question. Thus we should be provided with the means of measuring the power of gravity, at any station, to within $\frac{1}{10000}$th of its whole quantity.



The other or dynamical process, by which the force urging any given weight to the earth may be determined, consists in ascertaining the velocity imparted by it to the weight when suffered to fall freely in a given time, as one second. This velocity cannot, indeed, be directly measured; but, indirectly, the principles of mechanics furnish an easy and certain means of deducing it, and, consequently, the intensity of gravity, by observing the oscillations of a pendulum. It is proved in mechanics that, if one and the same pendulum be made to oscillate at different stations, or under the influence of different forces, and the numbers of oscillations made in the same time in each case be counted, the intensities of the forces will be to each other inversely as the squares of the numbers of oscillations made, and thus their proportion becomes known. For instance, it is found that, under the equator, a pendulum of a certain form and length makes 86,400 vibrations in a mean solar day; and that when transported to fifty-one and a half degrees north, the same pendulum makes 86,535 vibrations in the same time. Hence we conclude, that the intensity of the force urging the pendulum downwards at the equator is to that at fifty-one and a half degrees north as 86,400 to 86,535, or as 1 to 1·00315; or, in other words, that a mass of matter at the equator weighing 10,000 pounds exerts the same pressure on the ground, and the same effort to crush a body placed below it, that 10,031½ of *the same pounds*, transported to fifty-one and a half degrees north, would exert there.

Experiments of this kind have been made, as above stated, with the utmost care and minutest precaution, to insure exactness in all accessible latitudes; and their general and final result has been, to give $\frac{1}{194}$ for the fraction expressing the difference of gravity at the equator and poles. Now, it will not fail to be noticed by the reader, and will, probably, occur to him as an objection against the explanation here given of the fact by the earth's rotation, that this differs materially from the fraction $\frac{1}{289}$, expressing the centrifugal force at the equator. The difference by which the former fraction exceeds the latter is $\frac{1}{590}$,—a small quantity in itself, but still far too large, compared with the others in question, not to be distinctly accounted for, and not to prove fatal to this explanation, if it will not render a strict account of it.

The mode in which this difference arises affords a curious and instructive example of the indirect influence which mechanical causes often exercise, and of which astronomy furnishes innumerable instances. The rotation of the earth gives rise to the centrifugal force; the centrifugal force produces an ellipticity in the form of the earth itself; and this very ellipticity of form modifies its power of attraction on bodies placed at its surface, and thus gives rise to the difference in question. Here, then, we have the same cause exercising at once a direct and an indirect influence. The amount of the former is easily calculated, that of the latter with far more difficulty, by an intricate and profound application of geometry, whose steps we cannot pretend to trace in a work like the present, and can only state its nature and result.

The weight of a body (considered as undiminished by a centrifugal force) is the effect of the earth's attraction on it. The attraction of the earth, then, on a body placed on its surface, is not a simple but a complex force, resulting from the separate attractions of all its parts. Now, it is evident, that if the earth were a perfect sphere, the attraction exerted by it on a body anywhere placed on its surface, whether at its equator or pole, must be exactly alike, for the simple reason of the exact symmetry of the sphere in every direction. It is not less evident that, the earth being elliptical, and this symmetry or similitude of all its parts not existing, the same result cannot be expected. A body placed at the equator, and a similar one at the pole of a flattened ellipsoid, stand in a different geometrical relation to the mass as a whole. This difference, without entering further into particulars, may be expected to draw with it a difference in its forces of attraction on the two bodies. Calculation confirms this idea. It is a question of purely mathematical investigation, and has been treated with perfect clearness and precision by Newton, Maclaurin, Clairaut, and many other eminent geometers; and the result of their investigations is to show that, owing to the elliptic form of the earth alone, and independent of the centrifugal force, its attraction ought to increase the weight of a body in going from the equator to the pole by almost exactly $\frac{1}{590}$th part; which, together with $\frac{1}{289}$th due to the centrifugal force, make up the whole quantity, $\frac{1}{194}$th, observed.

We shall next proceed to state some of the remarkable effects resulting from the diurnal rotation of the earth.

When we abandon a body to the action of gravity it falls; its direction would be vertical if the earth were at rest. And if the point whence we let it fall be not far from the surface of the earth, the direction of its descent would not be appreciably out of the vertical, on the supposition that the earth revolves. But let a body be carried to a very high summit, is it not evident that it would acquire a velocity of rotation proportioned to the height of the summit, that is, to its distance from the axis of motion? It will therefore acquire a velocity in a horizontal direction greater than the base of the edifice or mountain. But this swiftness of motion from the west towards the east, that is, in the direction of the earth's rotation, it retains when left to itself, and acquires another from gravity, in the direction of the vertical. Being thus acted upon by two forces, it would fall in the resultant of the two, and strike the ground a little to the east of the tower. This experiment is a very delicate one, for a fall of two hundred feet causes but very slight deviation from the vertical; yet it has often been tried, and has always agreed with the theory. Although such an experiment would be unsatisfactory by itself, because of the small scale on which it can be tried, it may make one link in the great chain of evidence that so irresistibly proves the rotation of the earth on its axis.

Another effect of the revolution of the earth is the displacement of the air in the equatorial regions. The air, heated by the action of the sun, expands, and, rising, passes toward the poles, while the denser air at the poles rushes, in different directions, to fill up the void under the equator. In their contact with the earth the particles acquire the same velocity of rotation as the zone they occupy. When, therefore, they reach the equator, they would receive an increase of rapidity if they could remain long enough in contact with that part of the globe; but as the air is constantly expanding and rising there, it never acquires a velocity equal to that of the equator. Wherefore the trees, houses, mountains, ships, turning with the rapidity of the earth, strike with force upon the air, producing the same effect and appearance as if they were still and the air in motion.

The following on this subject is from "Arnott's Physics."

If our globe were at rest, and the sun were always acting over the same part, the earth and air directly under him would become exceedingly heated, and the air would be constantly rising, like oil in water, or like the smoke from a great fire; while currents or winds below would be pouring towards the central spot from all directions. But the earth is constantly turning round under the sun, so that the whole middle region or equatorial belt may be called the sun's place; and therefore, according to the principle just laid down, there should be over it a constant rising of air, and constant currents from the two sides of it, on the north and south, to supply the ascent. Now this phenomenon is really going on, and has been going on ever since the beginning of the world, producing the steady winds of the northern and southern hemispheres, called the *trade winds*, on which, in most places within thirty degrees of the equator, mariners reckon almost as confidently as on the rising and setting of the sun himself.

The trade winds, however, although thus moving from the poles to the equator, do not appear on the earth to be directly north and south, for the eastward whirling, or diurnal rotation of the earth, causes a wind from the north to appear as if coming from the north-east, and a wind from the south as if coming from the south-east.

This fact is illustrated by the case of a man on a galloping horse, to whom a calm appears to be a strong wind in his face; and if he be riding eastward while the wind is directly north or south, such wind will appear to him to come from the north-east or south-east; or, again, by the case of a small globe made to turn upon a perpendicular axis, while a ball or some water is allowed to run from the top of it downwards; the ball will not immediately acquire the whirling motion of the globe, but will fall almost directly downwards; but the track, if marked upon the globe, will appear not as a direct line from the axis to the equator, that is, from north to south, but as a line falling obliquely. Thus, then, the whirling of the earth is the cause of the oblique and westward direction of the trade winds, and not, as has often been said, the sun drawing them after him.

The reason why the trade winds, at their external confines, which are about thirty degrees from the sun's place, appear almost directly *east*, and become more nearly *north* and *south* as they approach the central line, is, that at the confines they are like fluid coming from the axis of a turning wheel, and which has approached the circumference, but has not yet acquired the velocity of the circumference; while, nearer the line, they are like the fluid after it has for a considerable time been turning on the circumference, and has acquired its rotary motion; consequently appearing at rest as regards that motion, but still leaving sensible any motion in a cross direction.

While, in the lower regions of the atmosphere, air is thus constantly flowing towards the equator and forming the steady trade winds between the tropics, in the upper regions there must of course be a counter current, distributing the heated air over the globe. Accordingly, since reason led men to expect this, many striking proofs have been detected. At the summit of the Peak of Teneriffe, observations now show that there is always a strong wind blowing in a direction contrary to that of the trade wind on the face of the ocean below. Again, the trade winds among the West India islands are constant, yet volcanic dust thrown aloft from the island of St. Vincent, in the year 1812, was found, to the astonishment of the inhabitants of Barbadoes, hovering over them in thick clouds, and falling, after coming more than one hundred miles directly against the strong trade wind, which ships must take a circuitous course to avoid. To persons sailing from the Cape of Good Hope to St. Helena the sun is often hidden for days together, by a stratum of dense clouds passing southward high in the atmosphere; which clouds consist of the moisture raised high near the equator with the heated air, and becoming condensed again as it approaches the colder regions of the south.

Beyond the tropics, where the heating influence of the sun is less, the winds occasionally obey other causes than those we have now been considering, which causes have not yet been fully investigated. The winds of temperate climates are in consequence much less regular, and are called *variable;* but still, as a general rule, wherever air is moving towards the equator from the north or south poles, where it was at rest, it must have the appearance of an east wind, or a wind moving in a contrary direction to the earth itself, until it has gradually acquired the whirling motion of that part of the surface of the earth on which it is found; and again, when air is moving from the equator, where it had at last acquired nearly the same motion as that part of the earth, on reaching nearer the poles, and which have less eastward motion, it continues to run faster than they, and becomes a westerly wind. In many situations beyond the tropics, the westerly winds, which are merely the upper equatorial current of air falling down, are almost as regular as the easterly winds within the tropics, and might also be called trade winds. Witness the usual shortness of the voyage from New York to Liverpool, and the length of those made in the contrary direction. North of the equator, then, on the earth, true north winds appear to be north-east, and true south winds appear to be south-west, which are the two winds that blow in England for three hundred days of every year. In southern climates the converse is true.

Among the many proofs of the wisdom and goodness of the Deity, one is drawn from the rotation of the earth, or rather from the situation of its axis of rotation. Among the possibilities out of which the choice was to be made, the number of those which were wrong bore an infinite proportion to the number of those which were right. We have already shown that the earth is an oblate spheroid, shaped something like an orange. Now the diameters upon which such a body may be made to turn round, or the axes of rotations, are as many as can be drawn through its centre to opposite points upon its whole surface; but of these axes none are permanent except either its shortest diameter, i. e. that which passes through the heart of the orange from the place where the stalk is inserted, and which is but one; or its longest diameters, (at right angles with the former,) which must all terminate in that circumference that goes round the thickest part of the fruit. The shortest diameter is that upon which the earth in fact turns, and it is, as the reader sees, what it ought to be, a permanent axis. Whereas, had blind chance, had a casual impulse, had a stroke or push at random, set the earth revolving, the odds were infinite but that they had sent it round on a wrong axis. And what would have been the consequence? When a spheroid, in a state of rotation, gets upon a permanent axis, it keeps there; it remains steady and faithful to its position; its poles preserve their direction with respect to the plane and to the centre of its orbit. But whilst it turns upon an axis which is not permanent, (and the number of these infinitely exceeds the number of the others,) it is always liable to shift and vacillate from one axis to another, with a corresponding change in the inclination of its poles. If therefore a planet once set off revolving upon any other than its shortest or one of its longest axes, the poles on its surface would be perpetually changing, and it would never attain a permanent axis of rotation. The effect of this instability would be, that the equatorial parts of the earth might become the polar, or the polar the equatorial, to the utter destruction of plants and animals, which are not capable of interchanging their situation, but are respectively adapted to their own. As to ourselves, instead of rejoicing in our temperate climate, and annually preparing for the moderate vicissitude, or rather the agreeable succession of seasons which we experience and expect, we might be suddenly locked up in the ice and darkness of the Arctic circle, with bodies neither inured to its rigors, nor provided with shelter or defence against them. Nor would it be much better if the trepidation of our pole, taking an opposite course, should place us under the heats of a vertical sun. But if it would fare so ill with the human inhabitant, who can live under greater varieties of latitude than any other animal, still more noxious would it prove to the rest of creation, the beasts and the plants. The habitable earth, with its beautiful variety, might have been destroyed by a simple mischance in the axis of rotation.

By virtue of the simplest law that can be imagined, viz. that a body *continues* in the state in which it is, whether of motion or rest; and if in motion that it goes on in the same line in which it was proceeding, and with the same velocity, *unless* there be some cause for change, it comes to pass that cases arise in which attraction, incessantly drawing a body toward a centre, never brings, nor ever will bring the body to that centre, but keep it in eternal circulation round it. If it were possible to fire off a cannon ball with the velocity of five miles a second, and the resistance of the air could be taken away, the ball would forever wheel round the earth, instead of falling upon it.

Attraction varies reciprocally as the square of the distance; that is, at double the distance it has a quarter of the force; at half the distance four times the force; and so on. Concerning this law of variation three things are to be observed:

I. That attraction, for any thing we know to the contrary, was originally indifferent to all laws of variation, or just as susceptible of one law as another. It might have been the same at all distances; it might have increased as the distance increased; it might have diminished with the increase of the distance; yet, amid ten thousand different proportions, it might have followed no stated law. If attraction be a primordial property of matter, then, by the very nature and definition of a primordial property, it stood indifferent to all laws. If it be the agency of something immaterial, then also, for any thing we know, it was indifferent to all laws. If the revolution of bodies round a centre depend upon vortices, neither are these limited to one law more than another. Attraction is sometimes ascribed to an *emanation* from the attracting body. But how is it possible that particles *streaming from* a centre should draw a body *toward* that centre? The impulse is all the other way. If we imagine particles incessantly flowing to the centre we are no better off; for by what source is the stream fed, or what becomes of the accumulation? There is nothing to support the theory of emanations excepting the one solitary circumstance, that the variation of the attracting force agrees with the variations of the density of the rays.

II. Out of an infinite number of possible laws, those which were *admissible*, i. e. consistent with the preservation of the system, lay within narrow limits. If the attracting force had varied according to any *direct* law of the distance, great destruction and confusion would have taken place. The direct simple proportion of the distance would have produced an ellipse, but then the perturbing forces would have so acted as to be continually changing the dimensions of this ellipse, in a manner inconsistent with our terrestrial creation. Of the *inverse* laws, if the centripetal force had varied with the cube of the distance, or in any higher proportion, i. e. if at double the distance the attractive force had diminished to an eighth part, or to less than that, the consequence would have been, that if the earth once began to approach the sun, it would fall into his body, or if it once, though ever so little, increased its distance from the centre, it would recede from it forever. The laws of attraction therefore, consistent with the safety of the universe, lie within narrow limits, compared with the possible laws.

We do not know, or rather we seldom reflect, how interested we are in this matter. Small irregularities may be endured, but (small changes excepted) the permanence of the ellipse is a question of life and death to the whole sensitive world.

III. Of the different laws that may be considered among the *admissible*, we say that the *best* has been chosen; that there are advantages in this particular law which do not belong to any of the rest.

While this law prevails between each particle of matter, the *united* attraction of a sphere, composed of matter, observes the same law. This property of the law is necessary to render it applicable to a system composed of spheres; yet it belongs to no other admissible law of attraction. If we go further, we shall more strikingly perceive that this regulation proceeded from a designing mind. A law both *admissible* and *convenient* was requisite. In what way is the law of the attracting globes attained? Observations and experiments show, that the attraction of the globes of the system is made up of the attraction of their parts. Here then are clearly shown regulation and design. A law admissible and convenient was to be obtained; the mode chosen for obtaining it was by making *each* particle of matter act. After this choice was made, one and one only particular law of action was to be assigned, and no other law but the one they have received would have answered the intended purpose.

All systems must be liable to *perturbations*. To guard against their running to destructive lengths, is perhaps the strongest evidence of care and foresight that can be given. It can be demonstrated of our law of attraction, and can be of no other, that the action of the parts of our system upon one another will not cause permanently increasing irregularities, but merely periodical or vibratory ones; that is, they will come to a limit and then go back again. To make this hold, several circumstances are necessary; viz.: the force must be inversely as the square of the distance; the masses of the revolving bodies must be small, compared with that of the body at the centre; the orbits not much inclined to each other, and their eccentricity small. In such a system the important points are secure. The mean distances and periodic times are constant; the eccentricities vary so slowly and to so small an extent as to produce no inconvenience. The same is true of the obliquity of the planes of the orbits. The inclination of the ecliptic to the equator will not change above two degrees, and that change requires many thousand years.

If it be said that the planets might have been sent round the sun in exact circles, in which case, no change of distance from the centre taking place, the law of variation of the attracting power would never have come in question, one law would have served as well as another; an answer to the scheme may be drawn from the consideration of these same perturbing forces. The system retaining in other respects its present constitution, though the planets had been sent round in exact circles, they could not have kept them: and if the law of attraction had not been what it is, or, at least, if the prevailing law had transgressed the limits above assigned, every movement would have been productive of fatal consequences. The planet once drawn (as it necessarily must have been) out of its course, would have wandered in endless error.

SECTION II.

Sun's apparent motion—Ecliptic—Celestial latitude and longitude—Tropics—Does the sun really move in the ecliptic?—Impulse requisite to produce the motions of the earth—Appearance of the motions of the planets as seen from the sun—System of Tycho Brahe—Proofs of the earth's double motion—Annual parallax—Axis of the earth always points to the same celestial poles—Its inclination to the ecliptic—Radius vector—Cause of the change of seasons—Zones—Winter at the poles—Illustration of the foregoing—Nature of the earth's orbit—Poetical rising and setting of the stars—Perihelion and aphelion—Designing wisdom apparent from the figure of the earth's orbit.

Beside the daily motion that has been mentioned, the earth has also another, which carries it in an elliptical orbit about the sun, the centre of our planetary system. In order to arrive at the knowledge of this motion, we shall examine the appearances that are presented to our senses.

At all times people have been struck with the alternate departure and approach of the sun, and with the variations of his height according to the seasons. If, in fact, we observe each day the right ascension and declination of this body, we shall find, that they are never twice the same; if we compare the sun's path with that of any star whatever, we shall find, that in relation to the star it advances daily about one degree towards the east. But one degree answers to four minutes of time. It arrives then four minutes later in the plane of the meridian than the star. These four minutes accumulating, it results, that after ninety days the distance to the same star will be about ninety degrees, or six hours. After one hundred and eighty days the star and the sun will be in the plane of the meridian at the same time; but the latter will pass the lower meridian while the first will be on the upper meridian. Finally, after three hundred and sixty-five days and a quarter, that is to say, one year, the two bodies will be found at the same time in the plane of the same meridian, the star having passed by this plane once more than the sun. And the same relative changes will be renewed the following year. If we have taken care to trace each day on a sphere the different points at which the sun is found at the same hour of the day, we shall thus have a curve which will be the track of its apparent motions during a whole year.

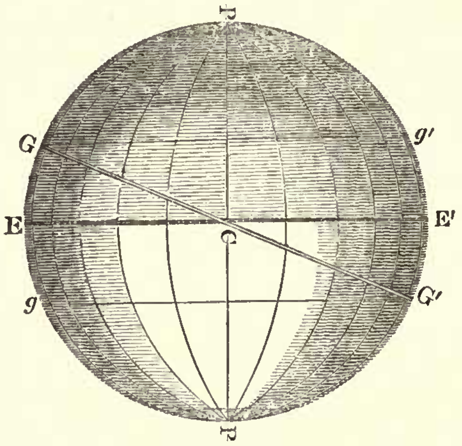
Observation has taught us that the plane of this curve, which has been called the *ecliptic*, (because the moon is always in or near it when she is eclipsed,) passes through the centre of the earth: its direction is oblique to the equator, and the angle that it makes with this great circle is equal to 23° 28′. This angle constitutes the obliquity of the ecliptic. It has for its complement the distance from the most northerly or southerly point of this curve to the pole, which is 66° 32′. The great circle of the celestial sphere, that corresponds to the track of the ecliptic on the earth, has received also the same name. The position of the stars, or of the different points of the heavens, are referred either to the horizon and the meridian, which are fixed for each terrestrial place, or to the celestial equator and a particular horary circle. The distance of any point from these last curves is called its declination and right ascension. A third method exists, which is of continual use in astronomy. A great part of the phenomena of the planetary system takes place near the plane of the ecliptic; it was therefore necessary to refer the heavenly bodies to this plane. For this purpose, we imagine, at each point of the heavens, a great circle perpendicular to the plane of the ecliptic. This is called a circle of latitude. Then the position of a star is determined by two elements: the first is the arc of a great circle, contained between the ecliptic and the star. This arc is called the *latitude* of the star.

The second is the arc of the ecliptic, contained between the vernal equinox and the circle of latitude. This arc is computed, like the right ascension, from west to east, in the direction of the sun's apparent motion, and is called the *longitude* of the star. The longitude and latitude of stars are not taken by immediate observation, but are deduced by trigonometrical calculations from their right ascension and declination.

The different positions of the sun in the ecliptic account for the variety of the seasons and the change in the length of the days. When it is in the plane of the equator, it apparently describes that circle in twenty-four hours; but as it departs from this plane, and advances (for example) in the northern hemisphere, it describes a series of parallels, which diminish each day, until it has reached its greatest distance from the equator, which is, as we have said above, 23° 28′. The parallel which it here describes has received the name of tropic, from a Greek word, which means return, because, when once this revolution is accomplished, it begins to return, again advancing toward the equator; and having passed it, approaches the most southerly point of the ecliptic in the opposite hemisphere, and returns again toward the equator; thus reproducing each year the phenomena of the preceding. It is evident that, on account of the continual motion of the sun in the ecliptic, the parallels that it describes each day will not be true circles, but spirals, such as we form when winding a ball of thread.

Let E E′ be the equator, G and G′ the most elevated points of the ecliptic, to which we give the name of *solstices*, because the sun seems to stop at these places; the parallels G g′ and g G′ will be the circles called *tropics*. When the sun is at one of the solstices, the countries which are near this point will have summer; those will have winter that are the most distant from this point. As to the days, the longest will be when the sun is in the summer solstice; the shortest, when the sun is at the winter solstice.

The time of the equinoxes, during which the days and nights are equal, happens always when the sun is in the plane of the equator. This is the case twice in each year; and for us it is spring when the sun comes toward the northern hemisphere, and autumn when it passes again into the southern hemisphere.



Such are the different appearances which the sun successively presents to us in its orbit, returning to the point whence it set out. The time required for its *apparent* revolution is called *a year.* But ought we to attribute to the sun himself the motions that we have noticed? We are already convinced that we must not always trust the evidence of our senses; and besides, if we reason according to the principles we have employed on the subject of the revolution of the earth about its axis, we shall soon be persuaded that it will be hazarding a supposition but little probable to regard as *real* an apparent motion. It would, in fact, be necessary to suppose the velocity of the sun so tremendous, that it is much more simple to think that the earth itself goes over the orbit of which we have above spoken. Calculation gives for the earth's motion eleven hundred and thirty-three miles as the space described in one minute, which is eighteen miles and three quarters a second. This swiftness of motion ought not to surprise us; for the more careful observation of the phenomena which the planets present will furnish us with similar movements; we shall see that, like our globe in form, they are also, like it, possessed of a double motion, one of translation in space, the other of rotation on their axes.

By the laws of mechanics, in order that a free body may be struck so as to turn on its axis, it is necessary that the impulse should not pass through the centre of gravity. Beside its revolution, it takes also a motion of translation, as if the force had acted on its centre, so that it is carried through space, while turning on its axis. If the force which moves a ball on the billiard table is not in the direction of the centre of this ball, it will revolve at the same time that it advances in the direction of the blow. In order that the rotation should exist alone, a second impulse, equal and opposite, must be impressed at the same time on the centre, capable of arresting its onward motion. We are assured that the earth has a motion of revolution in twenty-four hours; and that whatever be the cause of it, the globe could not have received this motion without another motion, viz. that of its centre being transported in space, unless an opposite force had prevented it. It is therefore more simple to suppose the earth possessed of this second motion, than to attribute it to the sun. In fact, there must be three impulses to produce the phenomena on the last supposition: one on the centre of the sun; the second on the earth, to make it turn on its axis; the third, equal and opposite to this, to arrest and fix it in space. We shall not speak here of the causes which make one of these bodies revolve about the other, or of the force which retains it in its orbit; these things being foreign to the part of the subject on which we are now occupied.

There are intermediate bodies between us and the stars, and which have, like the earth, a motion of their own. In observing these (which are called *planets*) with good telescopes, spots have been seen on their surfaces, the motion of which proves a revolution of these bodies on their axis, precisely similar to the rotation of the earth. All these bodies are opaque, like our globe, and are a little flattened at the poles, revolving about the sun, each in its own orbit, from west to east, like the earth. Some of them have their moons, as we have ours. A spectator placed on the sun, if the vivid light of that body did not deprive him of the view of the celestial bodies, would see the planets revolving about him, while turning on their own axes; the earth being subjected to the same general law as the rest.

The more distant the planets are from the sun, the slower is their motion around it: nor is the earth, any more than the other bodies of the system, free from the action of this general law. The analogy is complete. All things conspire to warrant us in classing this globe in the number of the planets. If we will believe that the sun has an annual motion in the ecliptic, we destroy the simplicity of this admirable system. Beside, it will be necessary to admit the revolution of the planets around the sun; the sun will thus carry off their orbits with it in space, compelling them to follow in its march about us:—a system very complicated. Yet such was the system of Tycho Brahé.

The rapidity of the earth's motion should not create any surprise, since that of Venus is much greater; for she describes twelve hundred miles in a minute. The size of this planet is nearly equal to that of the earth. And what a prodigious force must that be which moves Jupiter and Saturn, which are, one fifteen hundred, and the other nine hundred times greater than our globe! Why cannot the earth be moved like these bodies? An observer placed on Jupiter would suppose the sun, the earth, and the planets in motion about him: and the great size of his globe would render this illusion more probable to him than to us.

The annual motion of the earth or that of the sun are the two hypotheses between which we must choose. The first of these suppositions is the most simple, since it ascribes motion only to a point scarcely visible to a spectator placed on the sun; while we are obliged to acknowledge that other celestial bodies, of greater volume than our earth, are subjected to the same motion. Is it not natural to prefer a system which bears the character of truth, and respects the conditions of analogy, which we destroy by a contrary opinion?

And as to the two motions of the earth, its diurnal rotation on its axis and its annual motion in the ecliptic; far from regarding this double action as complicated, we should recollect that, besides the fact of their existing in the planets, where they offer nothing surprising, the motion in its orbit is a consequence, according to the principles of mechanics, of that force which causes the rotary motion. If the last existed alone, there must be more power to produce it, more effort of the mind to conceive it.

It is thus the toy we call a top, by a lateral impulse, turns rapidly on its axis, while its point describes a curve on the plane of the horizon. In other respects this comparison is very imperfect, since the air, the friction, the manner in which the top is thrown, tend to destroy its motion of transference in the beginning. That of the earth, which no resistance diminishes, seems, on the contrary, to be constant and unchangeable.

Let us admit therefore the theory of the double motion of the earth, and, far from considering it as lightly adopted, let us rather admire the great number of proofs it unites. In fact, this motion might not have been confirmed by the motion of the planets; for these bodies might not have existed at all, or they might not have had both their motions from west to east, or they might have been without moons, or, finally, they might have been smaller than the earth, and less distant from the sun. Yet there would still be, in the appearances of the sun alone, proofs enough to make us prefer the hypothesis of the motion of the earth to that of the sun.

But what gives the greatest weight to this opinion is the admirable agreement it establishes between observations and results. The most minute details, and the most delicate calculations, have not discovered any thing in their consequences inconsistent with the phenomena; any thing not agreeing rigorously with prediction. The proofs drawn from attraction and aberration cannot now be exhibited: and these are the only mathematical ones. Whatever is contained in the following part of this treatise, is, properly speaking, only a series of proofs of the double motion of the earth. This, which was at first only a supposition, (though infinitely more probable than the contrary opinion,) will become a truth demonstrated by more proofs than any theorem in physics, whether we consider the simplicity of the laws which result from it, or the analogy which it establishes in all parts of the system.

According to this, the centre of the earth will therefore describe about the sun, immovable in space, a continuous curve line in three hundred and sixty-five days and a quarter, from west to east, while, at the same time, it makes each day a revolution on its axis, in the same direction. Its axis remains parallel with itself in all its positions, forming with the plane of its orbit, which is the *ecliptic*, an angle of 66° 32′. A spectator, separated from the earth, who should follow it in the ecliptic, with his face turned toward the north pole, would have the sun constantly on his left, and would see our globe move in the course already mentioned, and at the same time turning on its axis, the disc visible to him passing from his left to his right.

A little after sunset, when the twilight begins to diminish, we perceive half of the celestial sphere. The heavens seem to us to turn slowly from east to west. The stars disappear on one side of the horizon, and on the opposite side others rise. This apparent revolution continues during the night, and the extent of the firmament which is successively exhibited to our view depends on the duration of the darkness. In one night in winter or autumn we may see, in this latitude, almost the whole heavens, except the part near the south pole, which never rises to us, and that which is near the point of the ecliptic where the sun appears, this last portion, rolling over our heads with the star of day, is concealed from us by its superior light. Such are the appearances produced by the rotation of the earth on its axis in twenty-four hours.

The sun *seems* to us to pass over the ecliptic in the same direction that the earth in reality describes this curve. If the earth is in the sign of the *Ram*, the sun will seem to us to occupy the opposite point, in the sign of the *Balance;* if the earth moves to the sign of the *Bull*, the sun will appear to us in the sign of the *Scorpion;* if the earth is in the *Twins*, we shall suppose the sun in the

Archer. Thus, while the earth passes over one half of the boundary line of the ellipse, the sun appears to be describing the other half and in the same direction, viz. from west to east.

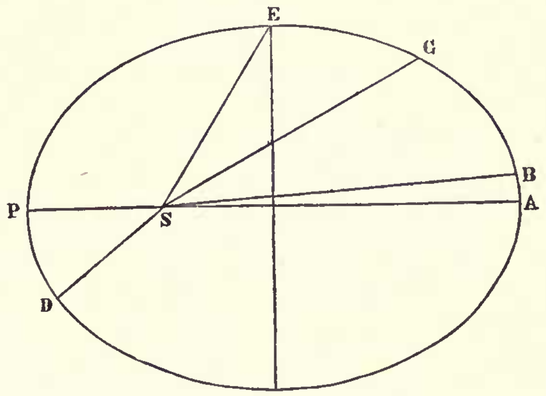
The largest base which at first could be used for a scale to measure considerable distances, was the diameter of the earth, which is nearly eight thousand miles. But when we have obtained with precision the solar parallax, and from it have determined the diameter of the ecliptic, we may take this for our base. It is by this means that we find with precision the distance of the planets from the sun. The motion of the earth, which, by the illusions it causes, for a long time retarded the knowledge of the real motions of the planets, makes them known to us with more precision than if we were fixed in the centre.

Since the axis of the earth continues parallel to itself, and makes with the plane of its orbit an angle of 66° 32′, we should suppose that the extremities of the axis must mark out, on the heavens and about the poles, two continuous curves, of an extent proportioned to that of the ecliptic, and to the radius of the celestial sphere. This is not so; but the axis, if prolonged, would reach two points invariably opposite. This results from the infinite distance of the stars. We have said that the dimensions of the earth are nothing compared to this distance. The same may be said of the diameter of the ecliptic itself, although this diameter is nearly two hundred millions of miles. Let us note with care the distance of a star on the ecliptic; after six months, the earth having passed over half of its orbit, if the annual parallax exists, this distance will vary gradually, in this time, the whole amount of that angle. But astronomers have never been able to observe the least change; and as they can measure with exactness an arc of two seconds, we must conclude that if the annual parallax were equal to two seconds it would have been discerned.

Some astronomers have thought they observed this parallax of two seconds in Sirius and Vega of the Harp. These, then, which, by reason of their brilliant light, seem to be the nearest of the stars, must be at least one hundred thousand times more distant than the sun. The diameter of the ecliptic is too small a base to enable us to measure the distance of the stars. The earth, having gone over three hundred millions of miles, must advance about one hundred thousand times farther in space to arrive at Sirius, which is more than 20,000,000,000,000 of miles distant from us; and perhaps must pass over another equal space to reach the stars of the second magnitude. What immensity! A spectator placed in Sirius will see the sun only under an angle of a hundredth part of a second at most, the orbit of the earth under an angle of scarcely four seconds, and the thickness of a thread of silk will be sufficient to hide the whole planetary system.

Thus the axis of the earth always points to the same celestial poles; for parallels meet when infinitely produced. The plane of the equator, carried onward with the annual motion, preserves a constant parallelism with itself, whilst it forms with the ecliptic an angle of twenty-three and a half degrees, and marks out in the heavens a circle bearing the same name, (celestial equator,) in the same manner as if the earth were without its motion of revolution. The movements of the earth in no way contradict the observation respecting the fixed place of the poles and of the celestial equator.

Let us now imagine ourselves transported to the sun, (its body being supposed transparent,) and let us thence direct our sight to the earth; we shall perceive that it is endowed with a rotation on its axis in twenty-four hours; and with another motion,

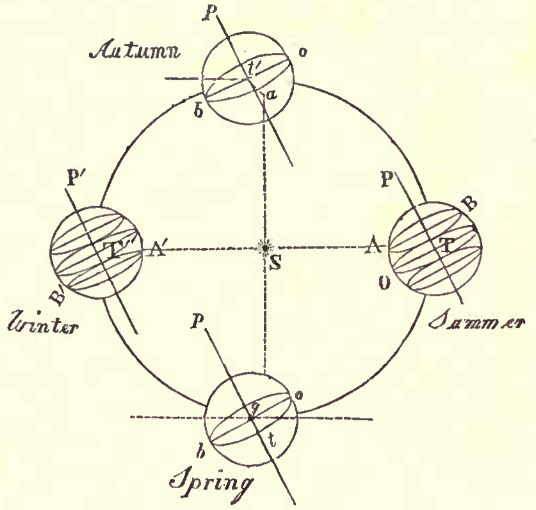


in which its centre describes a curved line in three hundred sixty-five and one fourth days nearly; the axis remaining parallel to itself all the while.

The line S E, that joins the centres of the sun and earth, is called the *radius vector*. This ideal line the earth carries with it through space, its length always varying with the earth's distance from the sun.

If we fasten a body to the end of an *elastic* cord, and whirl it around in such a way that its rapidity in various points of the curve would be different, the lengths would vary with the velocity of the motion, and would exactly represent what is called, in regard to the earth's annual motion, the radius vector. The orbit, which is also called the ecliptic, we shall see hereafter is not a circle; and while the diurnal rotation is uniform, the rapidity of the motion in the ecliptic is not so.

We shall, however, first show, that the change of seasons is owing to the maintenance of the same angle of inclination between the axis of the earth and its orbit at every point of that curve. Let T be our globe; the radius vector meets the surface at A. The plane A B, perpendicular to the axis P T, marks out the circle A B, each point of which comes in turn to A by reason of the diurnal rotation. The sun being supposed fixed at S, the inhabitants of the different points of the circle A B will in turn have the sun in their zenith: there will be no shadows at midday, and the image of the sun will be reflected from the bottom of the wells. If O T is the equator, A O designates the latitude of the places on the circle A B.



Suppose then the earth were at T, a position in which the projection of the axis P T on the plane of the orbit would coincide with the radius vector S T, or the plane P T A would be perpendicular to the plane of the ecliptic. The time when the earth is in this point is the *summer* solstice. The inhabitants of the zone A P B will not have the sun in their zenith, but this is the time when it rises nearest to that point. The circle B A will be the most northerly circle among those that the sun *appears* to describe in twenty-four hours, being distant from the equator twenty-three and a half degrees, and named the *tropic of Cancer*. When the earth has left this point and arrived at T′, diametrically opposite, the axis P′ T′ being parallel to P T, and its projection again falling on the radius vector, the inhabitants of that part of the earth that had midsummer in the situation first mentioned will now have *midwinter*.

At midday the sun is in the zenith to the inhabitants of the circle A′ B′, which is twenty-three and a half degrees south of the equator, and is named the *tropic* of *Capricorn*. The circle in the heavens directly over it has the same name, and is the most southerly of those circles that the sun *appears* to describe in twenty-four hours.

Let us examine now what happens between these opposite situations of the earth in its orbit. The angle formed by the radius vector and the axis of the earth varies incessantly, while that formed by the axis and the orbit remains the same. At the situation midway between T and T′, which we designate by *t′*, the angle formed by the radius vector and the axis is neither acute, as at T, nor obtuse, as at T′, but a right angle. Again, when the earth passes T′ this angle diminishes, and when at *t* it is again a right angle; and again becomes acute between *t* and T. When the earth is at *t′* or *t* the radius vector is perpendicular to the axis; and these epochs are called *the vernal equinox* and *the autumnal equinox*.

The constant inclination of the axis of the earth to the plane of the ecliptic makes the sun appear to us to describe a series of circles in passing from one tropic to another; circles that he moves over again on his return toward the equator. Each of these apparent circles is the effect of our daily rotation; and the passage from one circle to another, or the change in declination of the sun, is owing to our motion in the ecliptic. The time of the sun's meridian passage, or *noon*, *is not exactly the middle of the day*, *except at midsummer and midwinter*, i. e. at the solstices. By reason of the constant change of declination, the hour of the sun's rising and setting are not the same. At the vernal equinox the afternoon exceeds the forenoon by one and one fifth minutes; at the autumnal equinox the reverse takes place.

The inhabitants of the equator (as we before stated) have the poles of the heaven in their horizon. All the circles described by the heavenly bodies are vertical and bisected by the horizon. The days and nights are equal through the whole year. The sun passes through their zenith twice a year, and its meridian altitudes when at the solstices is 66° 32′,—equal to the inclination of the earth's axis to the ecliptic. These altitudes increase as the equinoxes draw near. In the course of the year the shadows take all possible positions, now on one side of the equator, now on the other, six months toward the north, six toward the south. The shadows at noon, being directed to the pole, grow shorter and shorter until the sun reaches the equinoxes; then *there are no shadows at noon*. During our summer and spring these shadows are cast toward the south; during our winter and autumn toward the north.

Properly speaking, they have no spring or autumn at the equator, but two summers and two winters. The first season is the most disagreeable, on account of the scorching heats and excessive rains.

On account of the great heat of the regions between the tropics, this belt of the earth has received the name of the *torrid zone*. Yet it would appear, from recent observations made by intrepid travellers, who some years since explored the interior of Africa, and have made interesting discoveries there, that the torrid zone is not exempt from a considerable degree of cold. They tell us that "one of their younger companions perished with the severity of the cold."

As we leave the tropics and advance toward the poles the phenomena change at every step. The length of the day increases in summer and shortens in winter in our latitude; the shadows of objects at noon being always toward the north. The zenith advances toward the poles as we advance, and the days of summer grow longer and longer, those of winter shorter and shorter. When we arrive at the distance of twenty-three and a half degrees from the north pole, we are on the *polar circle*, where the sun is above the horizon twenty-four hours at the summer solstice, and twenty-four hours below it, at the winter solstice. Nearer the pole it will remain longer above or below their horizon at the solstices; and finally, arrived at the pole, we shall have the sun six months above our horizon and six months below it; and the year will consist of one day and one night, of equal duration. The parts of the earth within the polar circles are called *frigid* or *frozen zones;* those between these circles and the tropics, *temperate zones*.

These divisions, though matters of convention, are not altogether arbitrary. Their general temperature was the origin of their names. The cold is of longer continuance and more severe as we approach the frigid zone during the time when the sun is describing the opposite tropic; but when it describes the nearer tropic, the weakness of the oblique ray is compensated by the long duration of its action, since the sun is a long time above the horizon, and the temperature is much raised.

Observers have found many causes that diminish a little the horror of the long night to which the Boreal inhabitants are exposed. From the nature of the atmosphere that surrounds the polar regions the slightest ray of light is refracted with a much greater intensity than in any other portion of the globe, and the day begins the moment the smallest portion of the sun's disc *appears* above the horizon: so that when the sun is below this plane, the polar regions may yet be lighted. The rapid decrease in the density of the air at small heights, owing to the constant congelation of the surface of the ground, is a cause which must tend to produce extraordinary refractions. This seems to be confirmed by the narration of three Hollanders. Having reached eighty-four degrees of north latitude, and being hemmed in by the ice, they were obliged to pass the winter at Nova Zembla. After three months of continual night, the cold having become extremely rigorous, the sun appeared an instant above the horizon at midday fourteen days sooner than they expected it in that latitude, and it continued after that day to rise higher and higher. If this narration be true, the refraction must have been equal to four degrees, which is enormous compared with its effects in our latitude, where it does not much exceed half a degree.

Beside, the long nights of these regions are frequently interrupted by a certain splendid light suddenly appearing in the heavens, which we call *Aurora Borealis.* Of the two hemispheres, the northern seems to be less cold than the southern. The ice that surrounds its pole does not extend more than ten degrees of latitude; while that of the antarctic pole extends twenty degrees. There are detached from the latter enormous *ice islands,* which float as far as sixty-five degrees, and even to fifty-five, which corresponds nearly with the latitude of the north of Ireland; and the most severe cold reigns in countries whose latitude differs but little from that of Scotland. Such is Terra del Fuego, which would seem to have been named in mockery the Land of Fire; placed at the extremity of South America, it is covered with eternal snow.

We shall now endeavor to illustrate what has been said by the following experiment and several plates, which, we trust, will make the subject plain to every reader.

Take about seven feet of strong wire, and bend it into a circular form, which, being viewed obliquely, will appear elliptical. Place a lighted candle on a table, and having fixed one end of a silk thread to the north pole of a small terrestrial globe about three inches diameter, cause another person to hold the wire circle, so that it may be parallel to the table, and as high as the flame of the candle, which should be in or near the centre. Then, having twisted the thread towards the left, that by untwisting it may turn the globe round eastward, or contrary to the way that the hands of a watch move, hang the globe by the thread within this circle, almost contiguous to it; and as the thread untwists, the globe (which is enlightened half round by the candle as the earth is by the sun) will turn round its axis, and the different places upon it will be carried through the light and dark hemispheres, and have the appearance of a regular succession of days and nights, as our earth has in reality by such a motion. As the globe turns, move your hand slowly, so as to carry the globe round the candle, keeping its centre even with the wire circle; and you will perceive that the candle, being still perpendicular to the equator, will enlighten the globe from pole to pole in its whole motion round the circle; and that every place on the globe goes equally through the light and the dark, as it turns round by the untwisting of the thread, and therefore has a perpetual equinox. The globe thus turning round represents the earth turning round its axis; and the motion of the globe round the candle represents the earth's annual motion round the sun, and shows, that if the earth's orbit had no inclination to its axis, all the days and nights of the year would be equally long, and there would be no different seasons. But now, desire the person who holds the wire to hold it obliquely, raising one side just as much as he depresses the other, that the flame may be still in the plane of the circle; and twisting the thread as before, that the globe may turn round its axis the same way as you carry it round the candle, that is, from west to east, let the globe down into the lowermost part of the wire circle, and if the circle be properly inclined, the candle will shine perpendicularly on the tropic of Cancer; and the *frigid zone,* lying within the *arctic* or *north polar circle,* will be all in the light, and will keep in the light, let the globe turn round its axis ever so often. From the equator to the north polar circle all the places have longer days and shorter nights; but from the equator to the south polar circle just the reverse. The sun does not set to any part of the north frigid zone, as shown by the candle's shining on it, so that the motion of the globe can carry no place of that zone into the dark: and at the same time the *south frigid zone* is involved in darkness, and the turning of the globe brings none of its places into the light. If the earth were to continue in the like part of its orbit, the sun would never set to the inhabitants of the north frigid zone, nor rise to those of the south. At the equator it would be always equal day and night; and as places are gradually more and more distant from the equator, towards the arctic circle, they would have longer days and shorter nights; whilst those on the south side of the equator would have their nights longer than their days. In this case there would be continual summer on the north side of the equator, and continual winter on the south side of it.

But as the globe turns round its axis, move your hand slowly forward, and the boundary of light and darkness will approach towards the north pole, and recede towards the south pole; the northern places will go through less and less of the light, and the southern places through more and more of it; showing how the northern days decrease in length, and the southern days increase, whilst the globe proceeds. When the globe is at a mean state between the lowest and highest parts of its orbit, and the candle is directly over the equator, the boundary of light and darkness just reaches to both the poles, and all places on the globe go equally through the light and dark hemispheres, showing that the days and nights are then equal at all places of the earth, the poles only excepted; for the sun is then setting to the north pole, and rising to the south pole.

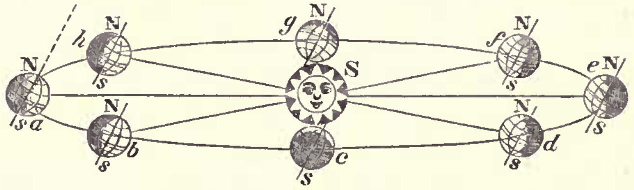
Continue moving the globe forward; the north pole recedes still farther into the dark hemisphere, and the south pole advances more into the light, and when the candle is directly over the tropic of Capricorn, the days are at the shortest, and nights at the longest, in the northern hemisphere, all the way from the equator to the arctic circle; and the reverse in the southern hemisphere, from the equator to the antarctic circle; within which circles it is dark to the north frigid zone, and light to the south.

Continue both motions; the north pole advances towards the light, and the south pole recedes towards the dark; the days lengthen in the northern hemisphere, and shorten in the southern; and when the candle is again over the equator the days and nights will again be equal, and the north pole will be just coming into the light, the south pole going out of it.

Thus we see the reason why the days lengthen and shorten from the equator to the polar circles every year; why there is no day or night for several rotations of the earth within the polar circles; why there is but one day and one night in the whole year at the poles; and why the days and nights are equally long all the year round at the equator, which is always equally cut by the circle bounding light and darkness.

The inclination of an axis or orbit is merely relative, because we compare it with some other axis or orbit which we consider as not inclined at all. Thus, our horizon being level to us, whatever place of the earth we are upon, we consider it as having no inclination; and yet, if we travel ninety degrees from that place, we shall then have a horizon perpendicular to the former; but it will still be level to us.

Let us now illustrate the annual course of the earth round the sun; its axis inclining twenty-three and a half degrees from a line perpendicular to the plane of its orbit, and keeping the same oblique direction in all parts of its annual course; or, as commonly termed, keeping always parallel to itself.



Let *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h* be the earth in eight different parts of its orbit, equidistant from one another; N *s* its axis, N the north pole, *s* the south pole, and S the sun, nearly in the centre of the earth's orbit. As the earth goes round the sun according to the order of the letters, *a b c d*, &c. its axis N *s* keeps the same obliquity. When the earth is at *a*, its north pole inclines towards the sun, S, and brings all the northern places more into the light than at any other time of the year. But when the earth is at *e*, in the opposite time of the year, the north pole declines from the sun, which occasions the northern places to be more in the dark than in the light; and the reverse at the southern places, as is evident by the figure. When the earth is either at *c* or *g*, its axis inclines neither to or from the sun, but lies sidewise to him; and then the poles are in the boundary of light and darkness; and the sun, being directly over the equator, makes equal day and night at all places. When the earth is at *b*, it is half way between the summer solstice and harvest equinox; when it is at *d*, it is half way from the harvest equinox to the winter solstice; at *f*, half way from the winter solstice to the spring equinox; and at *h*, half way from the spring equinox to the summer solstice.

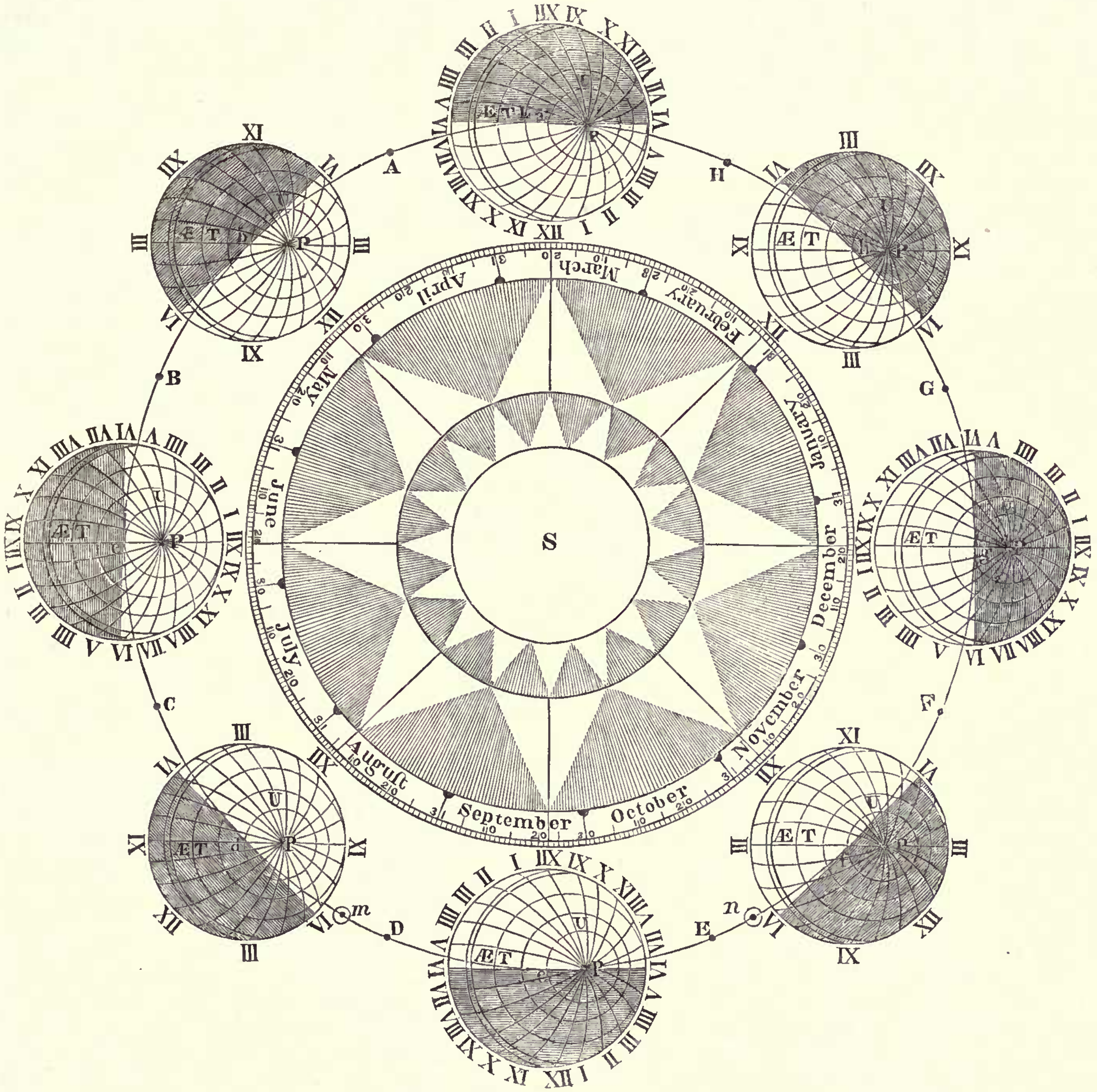
From this oblique view of the earth's orbit, let us suppose ourselves to be raised far above it, and placed just over its centre, S, looking down upon it from its north pole; and as the earth's orbit differs but very little from a circle, we shall have its figure in such a view represented by the circle A B C D E F G H. The earth is shown in eight different positions in this circle, and in each position Æ is the equator, T the tropic of Cancer, U the arctic or north polar circle, and P the north pole, where all the meridians or hour-circles meet. As the earth goes round the sun, the north pole keeps constantly towards one part of the heavens, as it keeps in the figure towards the right hand side of the plate. (See page 79.)

When the earth is at the beginning of the Balance, namely, on the 20th of *March*, the sun, S, as seen from the earth, appears in the opposite part of the heavens, the north pole is just coming into the light, and the sun is vertical to the equator; which, together with the tropic of Cancer and arctic circle, are equally cut by the circle bounding light and darkness, coinciding with the six o'clock hour circle, and therefore the days and nights are equally long at all places; for every part of the meridian Æ T L *a* comes into the light at six in the morning, and, revolving with the earth according to the order of the hour-letters, goes into the dark at six in the evening. There are twenty-four meridians or hour circles drawn on the earth in this figure, to show the time of sun rising and setting at different seasons of the year.

As the earth moves in the ecliptic according to the order of the letters A B C D, &c. the north pole comes more and more into the light; the days increase as the nights decrease in length, at all places north of the equator, Æ; which is plain by viewing the earth at *b* on the 5th of *May*. For then, the tropic of Cancer, T, is in the light from a little after five in the morning till almost seven in the evening; the polar circle, U, from three till nine; and a large track round the north pole, P, has day all the twenty-four hours, for many rotations of the earth on its axis.

When the earth comes to *c*, on the 21st of *June*, its north pole inclines towards the sun, so as to bring all the north frigid zone into the light, and the northern parallels of latitude more into the light than the dark from the equator to the polar circle; and the more so as they are farther from the equator. The tropic of Cancer is in the light from five in the morning till seven at night, and the polar circle just touches the dark, so that the sun has only the lower half of his disc hid from the inhabitants on that circle for a few minutes about midnight, supposing no inequalities in the horizon, and no refractions.

A bare view of the figure is enough to show, that as the earth advances, the north pole recedes towards the dark, which causes the days to decrease and the nights to increase in length, till the earth comes to the beginning of the Ram, and then they are equal, as before; for the boundary of light and darkness cuts the equator and all its parallels equally, or in halves. The north pole then goes into the dark, and continues therein until the earth goes half way round its orbit; or, from the 23d of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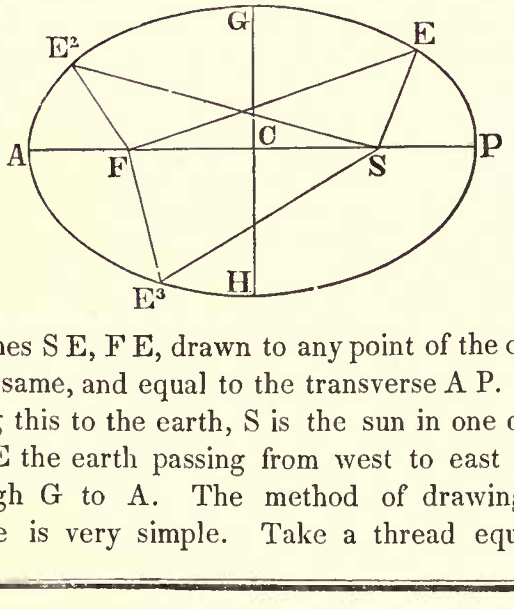
September till the 20th of *March*. In the middle between these times, viz. on the 22d of *December*, the north pole is as far as it can be in the dark, which is twenty-three and a half degrees, equal to the inclination of the earth's axis from a perpendicular to its orbit: and then the northern parallels are as much in the dark as they were in the light on the 21st of *June;* the winter nights being as long as the summer days, and the winter days as short as the summer nights.

We have already spoken of the orbit of the earth. We shall, however, dwell a little on the nature of this curve which the earth annually describes.

Mathematicians have proved that it is not a circle, as some have supposed, with the sun in its centre, but a curve, one of whose diameters is longer than the other, called an ellipse. The longest diameter we call the transverse or greater axis, which divides the figure into two equal parts in the direction of its greatest length. The diameter drawn at right angles to the greater axis is called the conjugate axis. This curve may be described by means of two points lying in the greater axis and equally distant from the central point; they are so situated that the sum of the lines drawn from each of them to any point of the curve is always the same, and is equal to the longer axis.



In the figure adjoining A P is the greater or transverse axis, C the central point, F and S are the *foci*, G H is the conjugate axis. The *sum* of the lines S E, F E, drawn to any point of the curve, is the same, and equal to the transverse A P. Applying this to the earth, S is the sun in one of the foci, E the earth passing from west to east along through G to A. The method of drawing the ellipse is very simple. Take a thread equal in length to the greater axis, and fasten its ends by two pins fixed in the points F, S. If now, with a pen or pencil, keeping the thread constantly stretched, we describe such a line as the confinement of the instrument allows, we shall form an elliptic curve. The distance of the foci from the central point C is called the *eccentricity* of the ellipse.

The orbit of the earth is a similar curve, having the sun situated in or near one of its foci. The arc that the earth describes in this curve is not of equal length every day, but longer the nearer it is to the sun.

By reason of this daily change of place to which the earth is subject, the *apparent* place of the sun is constantly changing. Thus, beside the change of declination which causes the seasons, it is apparently subject to a change in right ascension. It appears to remove a degree in the course of a day from the star with which it coincided at the beginning of that day. These retardations, accumulating every day, become at length so great, that the stars which passed the meridian with the sun at last pass this line long before, and the heavens appear entirely changed. When a star, which had for a time failed to be visible to us, appears in the east, in the morning twilight, it is said to rise *heliacally;* when it sets an hour after the sun it is said to set *heliacally*.

Those phenomena that happen at the instant of sunrise we distinguish by the epithet *cosmical*; and those that happen at the instant of sunset, *achronical*. A planet is said to rise *achronically* when it rises at sunset and is visible the whole night. It rises *cosmically* when it rises exactly with the sun. Then it is not visible to our naked eyes for the whole of its course.

As the heavenly bodies are not, in general, visible to the naked eye unless they are distant about fifteen degrees from the sun, it follows that their rising *cosmically* precedes, by about fifteen days, their *heliacal* rising; and that their heliacal setting precedes their achronical setting the same interval.

The *heliacal* rising of the stars is important to be observed. It once served the agriculturists to fix the time of their various labors. But the position of the equinoxes having changed, the rules would likewise require change.

The time in which the earth passes through the whole of its elliptical orbit, according to the most exact measure, is three hundred and sixty-five days five hours forty-eight minutes fifty-one seconds. We call this interval a *tropical year*, because it is determined by two successive passages of the sun over the same point of its *apparent* orbit; as, for instance, the *equinoctial* or *solstitial* points. In the preceding figure the point P, in which *the earth is nearest the sun*, is called the *perihelion;* the point A, diametrically opposite, in which *the earth is farthest from the sun*, is called the *aphelion. These two points taken together* are called the *apsides*. The line A P, which joins them, is called the *line of the apsides. In northern latitudes the earth is nearest the sun in winter and farthest from the sun in summer;*—a fact which one not versed in astronomy at all would be far from supposing.

What we have seen in the law of the centripetal force, viz. a choice guided by views of utility, and a choice of one law out of thousands which might equally have taken place, we see no less in the *figure* of the orbit. It was not enough to fix the law of centripetal force, though by the wisest choice; for even under that law it was still possible for the earth to have moved in a path possessing so great a degree of eccentricity, as in the course of every revolution to be brought very near the sun and carried off to an immense distance from him. The comets actually move in orbits of this sort; and had the earth done so, instead of going round in an orbit nearly circular, the change from one extremity of temperature to another must have destroyed every animal and plant on its surface. Now the distance from the centre at which the earth shall set off, and the absolute force of attraction at that distance, being fixed, the figure of its orbit (its being a longer or a rounder oval) depends upon two things, viz. the velocity with which, and the direction in which the earth were projected. And these, in order to produce a right result, must be both brought within certain narrow limits. One and only one velocity, united with one and only one direction, will produce a perfect circle. And the velocity must be nearly, but not exactly, the same, and the direction nearly, but not exactly, the same, to produce an orbit such as the earth has, viz. an ellipse with small eccentricity. The velocity and the direction must *both* be right. If the velocity were wrong, no direction can compensate for it; if the direction be in any considerable degree oblique, no velocity will produce the requisite orbit.

Take, for example, the attraction of gravity at the surface of the earth. The force of that attraction being what it is, out of all the degrees of velocity, swift and slow, with which a ball might be shot off, none would answer the purpose of which we are speaking but that which was nearly five miles a second. If it were less, the body would not get round, but fall to the earth; if much greater, the body would describe a very eccentric orbit, a long ellipse, the disadvantage of which we have mentioned above. If the velocity were equal to or exceeded seven miles a second, the ball would fly off from the earth and be never again heard of. In like manner with respect to the *direction;* out of the innumerable angles in which the ball might be sent off, (we mean angles formed with a line drawn to the centre,) none would serve but that which was nearly a right one; out of the various directions in which the cannon must be pointed upwards or downwards, every one would fail but that which was exactly or nearly horizontal. The same holds true of the earth. Why then did the projectile velocity and direction of the earth happen to be those which would retain it in nearly a *circular* orbit? Why not one of the infinite number of velocities, one of the infinite number of directions, which would have made it approach much nearer to or recede much farther from the sun? Such an exquisite arrangement could only arise from the contrivance and powerful influences of an intelligent, free, and most potent Agent, of a Being whose wisdom and power are infinite.

SECTION III.

The horizon and its dip—The earth at first supposed a limited plane—Early reasoning to the contrary—Proof furnished by navigation—Objections caused by our ideas of weight—Answered—Conical figure of the earth's shadow—Other proofs—Different aspects of the heaven according to the position of the observer—Time different in different places at the same absolute instant—Method of measuring an arc of the meridian—The earth an oblate spheroid—First meridian—Original constitution of the earth—Extent of the horizon proportioned to the height of the eye—Visible portion of the earth's surface—Temperature of the earth at its surface—Internal heat—Atmosphere—Reflections on the wisdom and knowledge of the Creator—Diversities of the globe.

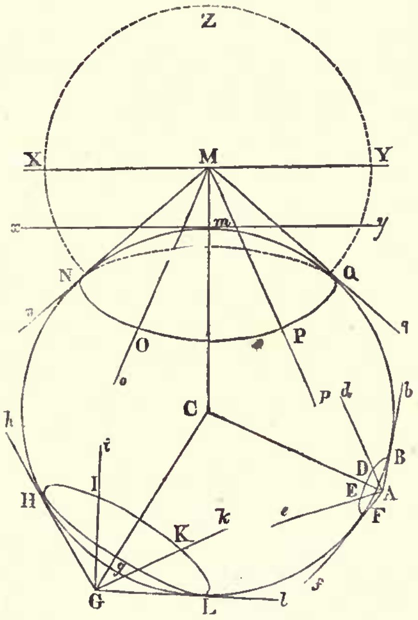
In studying the earth, we are desirous, among other things, to form a conception of *its shape and size.* Now, an object cannot have shape and size unless it is *limited* on all sides by some definite outline, so as to admit of our imagining it disconnected from other bodies, and existing insulated in space. The first rude notion we form of the earth is that of a flat surface, of indefinite extent in all directions from the spot where we stand, *above* which are *the air* and *sky;* below, to an indefinite profundity, solid matter. This is a prejudice to be got rid of, like that of the earth's immobility; but it is one much easier to rid ourselves of, inasmuch as it originates only in our own mental inactivity, in not questioning ourselves *where* we will place a limit to a thing we have been accustomed from infancy to regard as immensely large; and does not, like that, originate in the testimony of our senses unduly interpreted. On the contrary, the direct testimony of our senses lies the other way. When we see the sun set in the evening in the west, and rise again in the east, as we cannot doubt that it is the *same* sun we see after a temporary absence, we must do violence to all our notions of solid matter, to suppose it to have made its way *through* the substance of the earth. It must, therefore, have gone *under* it, and that not by a mere subterraneous *channel;* for if we notice the points where it sets and rises for many successive days, or for a whole year, we shall find them constantly shifting, round a very large extent of the horizon; and, besides, the moon and stars also set and rise again in *all* points of the visible horizon. The conclusion is plain: the earth cannot extend indefinitely in depth downwards, nor indefinitely in surface laterally; it must have not only bounds in a horizontal direction, but also an *under side,* round which the sun, moon, and stars can pass; and that side must, at least, be so far like what we see, that it must have a sky and sunshine, and a day when it is night to us, and *vice versa.*

Now, it is not on land (unless, indeed, on uncommonly level and extensive plains) that we can see any thing of the *general* figure of the earth;—the hills, trees, and other objects which roughen its surface, and break and elevate the line of the horizon, though obviously bearing a most minute proportion to the *whole* earth, are yet too considerable, with respect to ourselves and to that small portion of it which we can see at a single view, to allow of our forming any judgment of the form of the whole from that of a part so disfigured. But with the surface of the sea, or any vastly extended level plain, the case is otherwise. If we sail out of sight of land, whether we stand on the deck of the ship or climb the mast, we see the surface of the sea, not losing itself in distance and mist, but terminated by a sharp, clear, well defined line, or *offing,* as it is called, which runs all round us in a circle, having our station for its centre. That this line is really a circle, we conclude, first, from the perfect apparent similarity of all its parts; and, secondly, from the fact of all its parts appearing at the same distance from us, and that evidently a moderate one; and, thirdly, from this, that its *apparent diameter,* measured with an instrument called the *dip sector,* is the same (except under some singular atmospheric circumstances, which produce a temporary distortion of the outline) in whatever direction the measure is taken,—properties which belong only to the circle among geometrical figures. If we ascend a high eminence on a plain, (for instance, one of the Egyptian pyramids,) the same holds good.

Masts of ships, however, and the edifices erected by man, are trifling eminences compared to what nature itself affords; Ætna, Teneriffe, Mowna Roa, are eminences from which no contemptible *aliquot* part of the whole earth's surface can be seen; but from these again—in those few and rare occasions when the transparency of the air will permit the real boundary of the horizon, the true sea-line, to be seen—the very same appearances are witnessed, but with this remarkable addition, viz. that the angular *diameter* of the visible area, as measured by the dip sector, is materially *less* than at a lower level, or, in other words, that the *apparent size* of the earth has sensibly diminished as we have receded from its surface, while yet the *absolute quantity* of it seen at once has been increased.

The same appearances are observed universally, in every part of the earth's surface visited by man.

A diagram will elucidate this. Suppose the earth to be represented by the sphere L H N Q, whose centre is C, and let A, G, M be stations at different elevations above various points of its surface, represented by *a*, *g*, *m*, respectively. From each of them (as from M) let a line be drawn, as M N *n*, a tangent to the surface at N; then will this line represent the visual ray along which the spectator at M will see the visible horizon; and as this tangent sweeps round M, and comes successively into the positions M O *o*, M P *p*, M Q *q*, the point of contact N will mark out on the surface the circle N O P Q. The area of this circle is the portion of the earth's surface visible to a spectator at M, and the angle N M Q, included between the two extreme visual rays, is the measure of its apparent angular diameter. Leaving, at present, out of consideration the effect of refraction in the air below M, of which more hereafter, and which always tends, in some degree, to *increase* that angle, or render it more *obtuse*, this is the angle measured by the dip sector. Now, it is evident, 1st, that as the point M is more elevated above *m*, the point immediately below it on the sphere, the visible area, i. e. the spherical segment or slice N O P Q, increases; 2dly, that the distance of the visible *horizon*, or boundary of our view, from the eye, viz. the line M N, increases; and, 3dly, that the angle N M Q becomes *less obtuse*, or, in other words, the apparent angular diameter of the earth diminishes, being nowhere so great as 180°, or two right angles, but falling short of it by some sensible quantity, and that more and more the higher we ascend. The figure exhibits three states or stages of elevation, with the horizon, &c. corresponding to each, a glance at which will explain our meaning; or, limiting ourselves to the larger and more distinct, M N O P Q, let the reader imagine *n* N M, M Q *q* to be the two legs of a ruler joined at M, and kept extended by the globe N *m* Q between them. It is clear that as the joint M is urged home towards the surface, the legs will open, and the ruler will become more nearly *straight*, but will not attain *perfect* straightness till M is brought fairly up to contact with the surface at *m*, in which case its whole length will become a *tangent* to the sphere at *m*, as is the line *x y*. This explains what is meant by the *dip of the horizon.*



We propose to find how we can be placed in the centre of all the apparent celestial motions. The earliest idea entertained seems to have been, that the celestial dome touched the earth and was supported by it at the bounds of the horizon; but ere long it was discovered that the earth, which had been supposed a plane and limited by the columns of Hercules, was much more extensive, and there began to be a doubt if there were any limits to it. It was perceived that men did not call it the same hour when at the same absolute instant they beheld a celestial phenomenon, as an eclipse of the moon. Besides, the surface of the sea could not be a plane, for the navigator perceived, on approaching the shore, the highest summits first, and only in succession did he perceive lower situations. This could only be caused by the convexity of the sea. Even the best telescopes cannot bring within the view of a spectator on shore any thing but the highest parts of the mast of a very distant vessel: by its nearer approach the mast lengthens, and at last the hull of the vessel is distinguishable. If the sea were level, should we not see the hull before the mast?

These appearances and that of a horizon or sea offing cannot arise from any inability in the eye to follow objects to a greater distance, or from atmospheric indistinctness, (if this were the case how could we see the same moon or stars placed at such infinitely greater distances?) but from the curvature of the surface of the water.

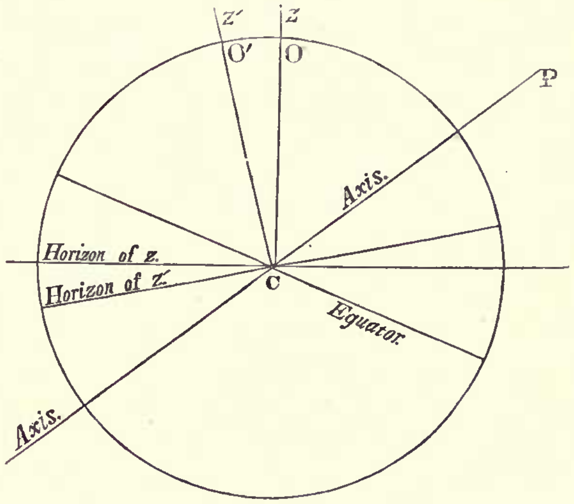
The convexity of the surface of the ocean once acknowledged, it is easy to come to a conclusion that the land also (with its irregularities) is rounded. Long voyages have confirmed this opinion. Navigators discover a new heaven, as it were, losing sight of ours, and perceiving the opposite part of the celestial sphere. Magellan made the first voyage round the world; and similar enterprises, often undertaken since, have demonstrated, that the earth has the form of a globe, isolated in space and surrounded by the heavens. If we had at first any difficulty in conceiving of this, it *was* because we mingled with it a false idea of *weight;* we demanded, why does not the earth, thus isolated, fall into the abyss? How can it sustain itself and float in the void? How can those on the opposite side of the globe remain upon the soil? Have they not need of some force to retain them there? But gravity, the cause of weight, is an attractive force resident in the earth itself. This retains every thing at the surface, and draws toward the centre of the earth every thing near the surface. The action of falling is toward this centre: our *antipodes* cannot be freed from this tendency, any more than ourselves. Beside, no resistance is requisite to keep the earth in this space, if there is not a power tending to draw it aside into some exterior region, having neither top nor bottom, which we are pleased to call a void.

We have also a proof of the rotundity of the earth from the conical figure of the shadow cast by the globe on the side opposite the sun. This, however, must be left until we come to treat of *eclipses.* We find that the earth must be round from moving to different parts of the surface, and from observations of the pole-star. If it were a plane, whatever might be the situation of the observer, the angle, formed by the vertical with that directed to the north pole, would always be the same; since the pole being situated at an infinite distance, the rays would be parallel as well as the verticals. Again, the circles described by the stars would everywhere have the same inclination to the horizon. But if the earth is a sphere, this no longer will happen, and we know that it does not happen. In advancing toward the regions in the direction of the pole-star, that star is perceived to rise more and more; and although the circles described by the stars have the same extent, yet to us, thus changing our places, they would be variously inclined to the horizon. Some of the stars which set to us would not set were we to go farther north, and some in the south which rise to us would cease to rise.

To persons situated between the equator and the pole the sphere is said to be *oblique.* To an inhabitant of the pole of the earth, the celestial pole would coincide with the zenith; the plane of the horizon would coincide with the plane of the equator; the stars neither rise nor set, but continually describe circles, parallel to the horizon. To a person thus situated the sphere is said to be *parallel.* To an inhabitant at the equator, the poles are in the horizon, the stars describe vertical circles, and the sphere is said to be *right.* To him, all the stars are visible through half their circles, and those stars that are in the equinoctial, by turns, pass through his zenith. All places on the surface of the earth, situated in the same great circle passing through both poles and perpendicular to the equator, have the same meridian, and the same hour at the same instant. Those not situated in this circle count different hours at the same instant. Suppose a star is on the meridian of a place; the inhabitants that are in another horary plane inclined to the first thirty degrees will have the same star in their meridian two hours before or two hours after the first mentioned place, according as their plane is east or west of the other.

The sun would pass the meridians of these places, so that when it was twelve or midday at one of them it would be ten A. M. or two P. M. at the other. This difference of hours is very sensible even on short voyages. If we were to travel from Boston to Buffalo, we should find our watch a little more than half an hour too fast, if it went with precision and had been set to Boston time. When the sun is on the meridian of Boston, that is, when it is twelve o'clock, at Buffalo the sun would be east of the meridian. It would want thirty-one minutes of twelve; while at Halifax, Nova Scotia, it would be about half an hour after noon. If we went entirely round the globe we should count a day, more or less, according as we went east or west; and could we advance westward with the same rapidity as the sun, we should pass entirely round the globe without changing our time at all, nor should we see a sunset or sunrise during our progress. This day, to him who circumnavigates the globe, is divided into small portions, proportionate to each day's travel, while the traveller is constantly changing his meridian. Suppose a phenomenon observed at the same *absolute instant* of time by different observers, but under the same meridian; it would of necessity be the same hour of the day; but it would not be so to two observers situated under different meridians. By calculating the difference of time between the two places, and allowing fifteen degrees for each hour, we should have the angle the planes of the two meridians make with each other. If the phenomenon, for example, were observed here at twelve or midday; at another place, at ten A. M.; at a third, at three P. M.; the plane of the meridian of the first place would form with that of the second an angle of thirty degrees, and with that of the third an angle of forty-five degrees. The second place would be thirty degrees west of the first; the third would be forty-five degrees east of the first, and seventy-five east of the second.

This experiment, so easily performed, of different observers noting the time of some particular phenomenon, and which has been frequently repeated, has made known the figure of the earth. If two observers, O and O′, under the same meridian, have at their zeniths, Z and Z′, stars whose distance from the pole differs one degree, the difference of the heights of the pole-star above the horizon, that is, the angle O C O′, will be also one degree. Let the distance O O′ be measured, and let similar observations be repeated elsewhere. It is evident that if we everywhere find the arc of one degree to contain an equal number of miles, the earth is perfectly spherical. Nor need the points O and O′ be under the same meridian, for geometry teaches us to calculate all the parts of the spherical surface after attaining a knowledge of some.



Methods the best conceived and the most exact have been employed for this important operation by Picard, Bouguer, Mason, Mechain, Delambre, Roy, Kater, Mudge, Svanburg, Struve, &c. and they have not been able to find any difference in the lengths of arcs of one degree on the meridians, except the arcs measured be very distant.

A degree measured in Sweden exceeds a degree at the equator by less than one thousand yards, or about 120th part,—a difference manifestly too small to be taken into account in merely settling the general form of the earth, which we may accordingly regard as a sphere. The dimensions of this sphere are easily found by geometry. We shall soon arrive at more definite conclusion on this subject.

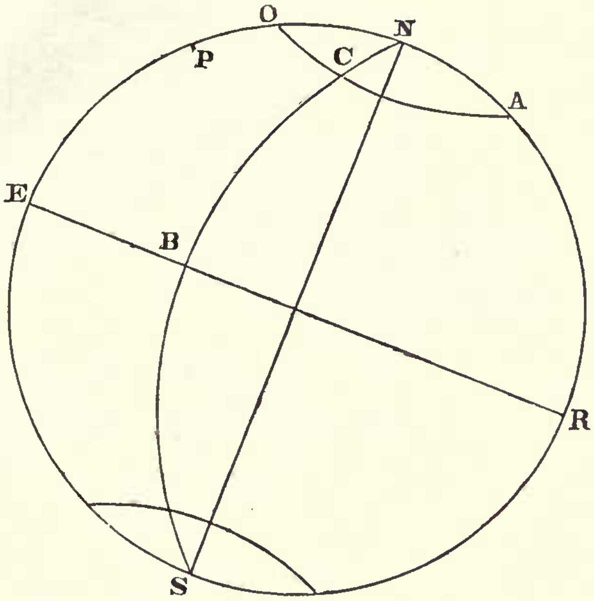
If at the place O we conceive a plane passing through the zenith and the pole, this will be the meridian of that place. Remove now to a place, O′, in the same plane, and continue the meridian; repeat these operations in several places one after the other, and the consecutive planes will cut the surface of the globe, forming a terrestrial meridian. Place a telescope at O, which is your *first station*, and direct it to O′, your *second* station, where a signal is to be placed, as also at the first station. Remove your instruments to O′ and direct your observation back to O, and then forward to a third point, which will be your *third* station, and so on. The operations, continued as far as you please, will give an arc of the meridian, which is only the first direction continued and curved, without departing from the same vertical plane.

The irregularities of the earth prevent us from measuring this arc exactly; but with the aid of a base line, and a series of triangles whose angles are measured by instruments, we can calculate the length of the arc of the meridian which connects the extreme stations with the same precision as if it had been directly measured. We should find that the curve very nearly, but not exactly, coincided with the arc of a circle, since the globe is a little different from a sphere. It has been found that the lengths of the arcs of one degree go on increasing from the equator to the poles. If we regard the terrestrial meridian as composed of a series of arcs of circles of different radii, placed with their extremities joining, since the longest arc of one degree must be at the pole and have the longest radius, the radii increase from the equator to the pole. The verticals cross each other in different points, and the more distant from the surface at the poles than at the equator; that is, the earth is less convex at the poles. *The earth is a little different from a sphere; it is a spheroid flattened at the poles.*

Although we suppose the small inequalities which form the mountains removed, there would be found but little difference between the meridian curves and ellipses. We can find in works of Geodesy all the reasonings that serve to prove, that *the earth is an ellipsoid of revolution about its smaller axis, which is that of the poles.* It is by comparing the results of observations with formulas of the dimensions of this body that we succeed in verifying this conclusion, in finding the lengths of the arcs, the flatness at the poles, the distance from the pole to the equator, and, in fine, all parts of our spheroid. The flattening at the poles has been differently estimated, from $\frac{1}{300}$ to $\frac{1}{318}$; a mean between the two, $\frac{1}{309}$, cannot be far from the truth. An arc then of a degree taken under the equator is exceeded by an arc at the pole by $\frac{1}{309}$ of its length. The radius of curvature at the equator is also less, by the same quantity, than the radius at the pole, since arcs of the same number of degrees in different circles are to each other as their radii. We have supposed the inequalities of surface removed, but in truth the most elevated mountains are but very small eminences compared to the whole mass, smaller than the asperities on the skin of an orange compared to the whole fruit. Mount Blanc, the highest mountain in Europe, is only elevated 15,665 feet above the level of the sea; Chimborazo, in Peru, is only 21,441 feet above the sea; finally, Dhawalageri, the highest peak of the Himalays, in Thibet, and the highest summit on the globe, is but 25,669 feet above the sea. If, then, we represent the earth by a globe of two feet radius, the mountains would be scarcely perceptible inequalities on its surface.

The whole surface of the earth is about *two hundred millions of square miles;* three quarters of which are covered with water, and scarcely half of the remainder is habitable.

To determine the position of any point, P, on the surface of the earth, we draw through P and the poles, N and S, a circle perpendicular to the equator, E R. The distance P E of the point P from the equator is called its latitude. If we conceive a plane, O A, parallel to the equator, it will cut the earth in a small circle, all whose points will have the same latitude, O E or A R, or the same distance from the equator. The points of this small circle



are the only points that can have the same degree of latitude, if we except those of a similar small circle drawn at an equal distance on the other side of the equator; and in speaking of a place it is necessary not only to indicate the degrees, but if it be situated toward the north or the south pole.

The latitude of a place is always a number of degrees, that, added to the distance of the zenith of that place from the nearest pole, will make ninety degrees, and consequently is equal to the arc which measures the elevation of the pole above the horizon. And as these arcs can be measured in the heaven, we can determine it easily for any place, and consequently determine the latitude of that place. *The distance of any place from the equator* (its latitude) *is equal to the elevation of the pole or the inclination of the earth's axis to the horizon of that place.* It remains to distinguish from each other the *different* points of the circle O A. Conceive through the point B of the equator another meridian, S B N, to be drawn: B N E, the angle that it makes with the first meridian, S E N, is measured by the arc B E of the equator intercepted by it. This arc B E expressed in degrees or in time is called the longitude of the point.

The place of the second meridian is evidently determined by the arc B E, provided it is stated on which side of the first meridian it is situated, to the right or left, to the east or west. This second meridian being thus determined, the point C is also determined.

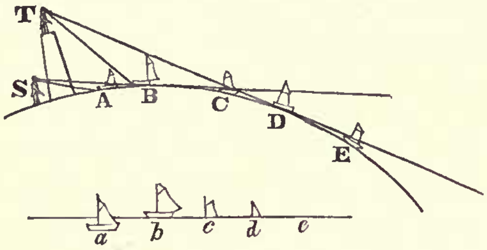
The position of the *first meridian* is arbitrary. Nations have not been able to agree upon one. Each prefer the meridian of its own capital city. In France they use the meridian of Paris. The English use that of London, or, which is nearly the same, Greenwich, where the royal observatory is situated. And some of our countrymen have been jealous enough to use the meridian of Washington, as if it were of so much importance to count from our capital, as that all the world should agree upon one first meridian.

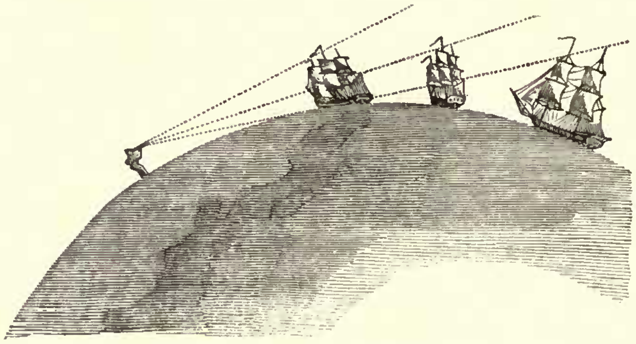
To determine the longitude of a place, we employ the method before explained, which consists in observing with care the precise instant of a celestial phenomenon, as an eclipse of the moon. If the observation were made in two places either situated or not under the same parallel to the equator, the difference of time at the instant of the observations, reduced to degrees, (fifteen degrees to the hour) will give the angles of the two meridians or the arc, that is, the longitude. That place will be east of the other at which the time counted was greatest, and *vice versa.*

When we consider the figure of the earth and the law of its increase in density from the surface to the centre, we are disposed to believe that in its original constitution it was not so solid as at present; for if it were at first in a less solid state, its parts, being more subject to the power of attraction and centrifugal force, would more readily assume the form we find it possesses.

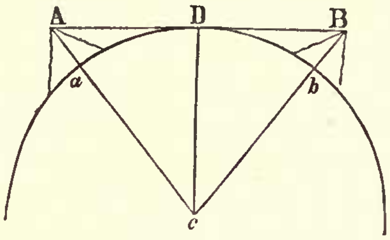
Imagine a bent tube, one branch of which, lying in the axis of rotation, might represent half the polar diameter, the other being in the direction of the radius of the earth's equator. Fill this siphon, open at both ends, with a liquid, and impart to it a motion similar to the rotation of the earth. The column in the direction of the polar diameter, obeying the action of gravity only, while the column in the equatorial radius was acted upon by the centrifugal force also, the polar column would sink enough to compensate for the diminution of weight in the equatorial column, and the liquid in the latter would rise in the same proportion, in order to restore the equilibrium in the two branches.

Every one who has passed a little while at the sea-side is aware that objects may be seen perfectly well beyond the *offing* or visible horizon, but not the *whole* of them. We only see their upper parts. Their bases, where they rest on or rise out of the water, are hid from view by the spherical surface of the sea, which protrudes between them and ourselves. Suppose a ship, for instance, to sail directly away from our station; at first, when the distance of the ship is small, a spectator, S, situated at some certain height above the sea, sees the whole of the ship, even to the *water line* where it rests on the sea, as at A. As it recedes it diminishes, it is true, in apparent size, but still the *whole* is seen down to the water line, till it reaches the *visible* horizon at B. But as soon as it has passed this distance, not only does the visible portion still continue to diminish in apparent *size*, but the hull begins to disappear bodily, as if sunk below the surface. When it has reached a certain distance, as at C, its hull has entirely vanished, but the masts and sails remain, presenting the appearance *c*. But if, in this state of things, the spectator quickly ascends to a higher station, T, whose visible horizon is at D, the hull comes again in sight; and when he descends again he loses it. The ship still receding, the lower sails seem to sink below the water, as at *d*, and at length the whole disappears: while yet the distinctness with which the last portion of the sail *d* is seen is such as to satisfy us, that were it not for the interposed segment of the sea, A B C D E, the distance T E is not so great as to have prevented an equally perfect view of the whole.





In this manner, therefore, if we could measure the heights and exact distance of two stations which could barely be discerned from each other over the edge of the horizon, we could ascertain the actual size of the earth itself: and, in fact, were it not for the effect of refraction, by which we are enabled to see in some small degree *round* the interposed segment, (as will be hereafter explained,) this would be a tolerably good method of ascertaining it. Suppose A and B to be two eminences, whose perpendicular heights A *a* and B *b* (which, for simplicity, we will suppose to be exactly equal) are known, as well as their exact horizontal interval *a* D *b*, by measurement; then it is clear that D, the visible horizon of both, will lie just half-way between them, and if we suppose *a* D *b* to be the sphere of the earth, and C its centre in the figure C D *b* B, we know D *b*, the length of the arc of the circle between D and *b*,—viz. half the measured interval, and *b* B, the excess of its secant above its radius—which is the height of B,—data which, by the solution of an easy geometrical problem, enable us to find the length of the radius D C. If, as is really the case, we suppose both the heights and distance of the stations inconsiderable in comparison with



the size of the earth, the solution alluded to is contained in the following proposition:—

The earth's diameter bears the same proportion to the distance of the visible horizon from the eye as that distance does to the height of the eye above the sea level.

When the stations are unequal in height, the problem is a little more complicated.

Although, as we have observed, the effect of refraction prevents this from being an exact method of ascertaining the dimensions of the earth, yet it will suffice to afford such an approximation to it as shall be of use in the present stage of the reader's knowledge, and help him to many just conceptions, on which account we shall exemplify its application in numbers. Now, it appears by observation, that two points, each ten feet above the surface, cease to be visible from each other over still water, and in average atmospheric circumstances, at a distance of about eight miles. But ten feet is the 528th part of a mile, so that half their distance, or four miles, is to the height of each as 4 × 528 or 2112: 1, and therefore in the same proportion to four miles is the length of the earth's diameter. It must, therefore, be equal to $4 \times 2112 = 8448$, or, in round numbers, about 8,000 miles, which is not very far from the truth.

We have before likened the inequalities on the earth's surface, arising from mountains, valleys, buildings, &c. to the roughnesses on the rind of an orange, compared with its general mass. The comparison is quite free from exaggeration. The highest mountain known does not exceed five miles in perpendicular elevation: this is only one 1600th part of the earth's diameter; consequently, on a globe of sixteen inches in diameter, such a mountain would be represented by a protuberance of no more than one hundredth part of an inch, which is about the thickness of ordinary drawing-paper. Now as there is no entire continent, or even any very extensive tract of land, known, whose general elevation above the sea is any thing like half this quantity, it follows, that if we would construct a correct model of our earth, with its seas, continents, and mountains, on a globe sixteen inches in diameter, the whole of the land, with the exception of a few prominent points and ridges, must be comprised on it within the thickness of thin writing paper; and the highest hills would be represented by the smallest visible grains of sand.

The deepest mine existing does not penetrate half a mile below the surface: a scratch, or pinhole, duly representing it, on the surface of such a globe as our model, would be imperceptible without a magnifier.

The greatest depth of sea, probably, does not much exceed the greatest elevation of the continents; and would, of course, be represented by an excavation, in about the same proportion, into the substance of the globe: so that the ocean comes to be conceived as a mere film of liquid, such as, on our model, would be left by a brush dipped in color and drawn over those parts intended to represent the sea: only, in so conceiving it, we must bear in mind that the resemblance extends no farther than to proportion in point of quantity. The mechanical laws which would regulate the distribution and movements of such a film, and its adhesion to the surface, are altogether different from those which govern the phenomena of the sea.

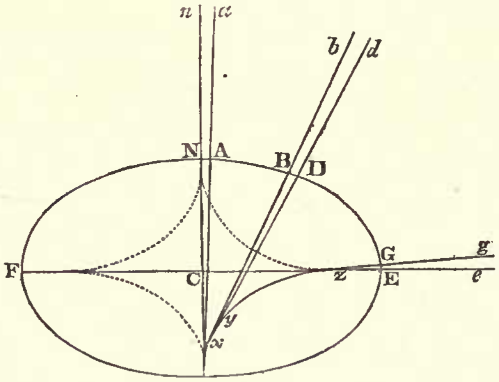
Lastly, the greatest extent of the earth's surface which has ever been seen at once by man, was that exposed to the view of MM. Biot and Gay-Lussac, in their celebrated aeronautic expedition to the enormous height of 25,000 feet, or rather less than five miles. To estimate the proportion of the area visible from this elevation to the whole earth's surface, we must have recourse to the geometry of the sphere, which informs us that the convex surface of a spherical segment is to the whole surface of the sphere to which it belongs as the versed sine or thickness of the segment is to the diameter of the sphere; and further, that this thickness, in the case we are considering, is almost exactly equal to the perpendicular elevation of the point of sight above the surface. The proportion, therefore, of the visible area, in this case, to the whole earth's surface, is that of five miles to 8000, or 1 to 1600. The portion visible from Ætna, the Peak of Teneriffe, or Mowna Roa, is about one 4000th.

As we cannot grasp the earth, nor recede from it far enough to view it at once as a whole, and compare it with a known standard of measure in any degree commensurate to its own size, but can only creep about upon it, and apply our diminutive measures to comparatively small parts of its vast surface in succession, it becomes necessary to supply, by geometrical reasoning, the defect of our physical powers, and from a delicate and careful measurement of such small parts to conclude the form and dimensions of the whole mass. This would present little difficulty, if we were sure the earth were strictly a sphere, for the proportion of the circumference of a circle to its diameter being known, (viz. that of 3·1415926 to 1·0000000,) we have only to ascertain the length of the entire circumference of any great circle, such as a meridian, in miles, feet, or any other standard units, to know the diameter in units of the same kind. Now the circumference of the whole circle is known as soon as we know the exact length of any aliquot part of it, such as one degree or $\frac{1}{360}$th part; and, this being not more than about seventy miles in length, is not beyond the limits of very exact measurement, and could, in fact, be measured (if we knew its exact termination at each extremity) within a very few feet, or, indeed, inches, by methods presently to be particularized.

Supposing, then, we were to begin measuring with all due nicety from any station, in the exact direction of a meridian, and go measuring on, till by some indication we were informed that we had accomplished an exact *degree* from the point we set out from, our problem would then be at once resolved. It only remains, therefore, to inquire by what indications we can be sure, 1st, that we *have* advanced *an exact degree;* and, 2dly, that we have been measuring in the *exact direction of a great circle.*

Now, the earth has no landmarks on it to indicate degrees, nor traces inscribed on its surface to guide us in such a course. The compass, though it affords a tolerable guide to the mariner or the traveller, is far too uncertain in its indications, and too little known in its laws, to be of any use in such an operation. We must, therefore, look outwards and refer our situation on the surface of our globe to natural marks, *external* to it, and which are of equal permanence and stability with the earth itself. Such marks are afforded by the stars. By observations of their meridian altitudes, performed at any station, and from their known polar distances, we conclude the height of the pole; and since the altitude of the pole is equal to the latitude of the place, the same observations give the latitudes of any stations where we may establish the requisite instruments. When our latitude, then, is found to have diminished a degree, we know that, *provided we have kept to the meridian,* we have described one three hundred and sixtieth part of the earth's circumference.

The direction of the meridian may be secured at every instant by observations, and although local difficulties may oblige us to deviate in our measurement from this exact direction, yet, if we keep a strict account of the amount of this deviation, a very simple calculation will enable us to reduce our observed measure to its *meridional* value. Such is the principle of the measurement of an arc of the meridian.



Let N A B D E F represent a meridional section of the earth, C its centre, and N A, B D, G E, arcs of a meridian, each corresponding to one degree of difference of latitude, or to one degree of variation in the meridian altitude of a star, as referred to the horizon of a spectator travelling along the meridian. Let *n* N, *a* A, *b* B, *d* D, *g* G, *e* E, be the respective directions of the *plumb-line* at the stations N, A, B, D, G, E, of which we will suppose N to be at the pole and E at the equator; then will the tangents to the surface at these points respectively be perpendicular to these directions; and, consequently, if each pair, viz. n N and a A, b B and d D, g G and eE, be prolonged till they intersect each other, (at the points x, y, z,) the angles N x A, B yD, G z E, will each be one degree, and, therefore, all equal; so that the small curvilinear arcs N A, B D, G E, may be regarded as arcs of circles of one degree each, described about x, y, z, as centres. These are what in geometry are called *centres of curvature*, and the radii x N or x A, y B or y D, z G or z E, represents *radii of curvature*, by which the curvatures at those points are determined and measured. Now, as the arcs of different circles, which subtend equal angles at their respective centres, are in the direct proportion of their radii, and as the arc N A is greater than B D, and that again than G E, it follows that the radius N x must be greater than B y, and B y than E z. Thus it appears that the mutual intersections of the plumb-lines will not, as in the sphere, all coincide in one point, C, the centre, but will be arranged along a certain curve, $x\,y\,z$, (which will be rendered more evident by considering a number of intermediate stations.) To this curve geometers have given the name of the *evolute* of the curve N A B D G E, from whose centres of curvature it is constructed.

In the flattening of a round figure at two opposite points, and its protuberance at points rectangularly situated to the former, we recognise the distinguishing feature of the elliptic form. Accordingly, the next and simplest supposition that we can make respecting the nature of the meridian, since it is proved not to be a circle, is, that it is an ellipse, or nearly so, having N S, the axis of the earth, for its shorter, and E F, the equatorial diameter, for its longer axis; and that the form of the earth's surface is that which would arise from making such a curve revolve about its shorter axis, N S. This agrees well with the general course of the increase of the degree in going from the equator to the pole. In the ellipse, the radius of curvature at E, the extremity of the longer axis is the least, and at that of the shorter axis, the greatest it admits, and the form of its *evolute* agrees with that here represented. Assuming, then, that it is an ellipse, the geometrical properties of that curve enable us to assign the proportion between the lengths of its axes which shall correspond to any proposed rate of variation in its curvature, as well as to fix upon their absolute lengths, corresponding to any assigned length of the degree in a given latitude. Without troubling the reader with the investigation, it will be sufficient to state that the lengths which agree on the whole best with the entire series of meridional arcs which have been satisfactorily measured, are as follows:—

		Feet.		Miles.
Greater or equatorial diameter	=	41,847,426	=	7925·648
Lesser or polar diameter	=	41,707,620	=	7899·170
Difference of diameters, or polar compression	=	139,806	=	26·478
Equatorial circumference	=		=	24·899

One of the most curious labors, of the present age, we owe to the energy and perseverance of Humboldt. It is an inquiry into the laws, which seem to exist in the distribution of organized matter over the surface of the earth. By measuring the elevation above the level of the sea of various places, and of the highest mountains of the earth, and by comparing all these measures together, he has found the localities in which certain plants delight. For instance, the cinchona, or jesuit's bark, has been discovered only in a certain zone, whose situation he determined. The same laws are applicable also to animals, whose more perfect organization and immediate dependence on physical causes would seem to free them from such laws.

For example, in South America, observers have remarked, according to their assertions, on the parallel corresponding to the latitude of New Holland, animals whose organization presents very remarkable similarities to that of the echidnas,* which

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* This animal and the duck-bill platypus are the only genera of a peculiar tribe called monotrema. They partake of the triple form of a quadruped, bird, and reptile; having the body of an otter, the legs of a tortoise, the wings and beak of a bird. There is a spur on the hind leg of the male, that emits an acrid humor. The legs are short, and end in five toes. The body is covered with fur, mixed with spines, like porcupine's quills. The animal can roll up his body, like the porcupine, and assume a spherical form. The echidna is toothless, has a small and conical head, very small eyes, a tongue capable of being elongated and thrown out like those of the chameleon and the woodpecker.

exist in the latter country, and which are, without doubt, among the number of those whose strange organization merits the particular attention of the most learned zoologists. It would seem then, according to these observations, that such a combination of organs can only be produced in certain determinate places. These curious results have induced philosophers to seek out their causes, and they regard the difference of temperature in the various countries of the earth as the most probable cause of their production, as well as the most important.

But whence originates this temperature of the earth? Is it the sun that develops it? Some have been of this opinion, which is supported by the regularity observable in the phenomena of the universe. Still, some facts seem to prove that the prolonged action of the sun is not the sole cause of the earth's temperature. It is a result of experience, that at the bottom of wells a hundred feet deep the temperature remains uniform and invariable; and ice that covers, throughout the year, the summits of certain mountains, is constantly melting at their base, and supplying streams of living water, that continue to flow during the winter. The earth, therefore, seems to possess a peculiar heat, independent of that which it receives from the sun. Some persons, on a consideration of the above facts, have thought that at a time very distant the earth was in a state of incandescence, (white heat;) that by degrees its surface cooled, until it reached its present temperature, the centre still retaining a greater heat, which they have called the *central heat;* and that this produces the effects mentioned above.

The following extract on this subject is from one of professor Hitchcock's geological lectures.

In regard to the central or internal heat of the earth, the first question is, has it disappeared? Is there any evidence of its existence now? The arguments in favor of its presence are, in the first place, experiments made in mines and other deep parts of the globe, in France, England, Switzerland, Peru, Mexico, &c. It is found that the heat increases as you descend below the surface. From three hundred experiments, (indeed many more than that,) made with a thermometer, upon the air at different depths, upon the water, and in the solid rock, with great care and exactness, all geologists agree that the heat rapidly increases as you descend. In Europe the increase is one degree of Fahrenheit for every twenty-four feet; in America one degree for every seventy-two feet; making the average for the whole globe about one degree for every forty-six feet. Analogy therefore leads us to infer very confidently that there is a continual increase to the centre. Taking the foregoing proportions, and at the depth of sixty miles, the rocks exist in a state of fusion, and at the depth of one and a half miles water would boil. The heat at the centre would thus equal 450,000 degrees of Fahrenheit. But it is asked, why then does not the ocean boil, it being much more than one and a half miles deep in some place, instead of growing cooler, as it actually does. The answer is, that when water is subjected to heat, the hottest is always at the surface, because the particles are lighter, and the cold, being heavier, descends. Another answer is found in the suggestion, that the crust of the earth beneath the deepest part of the ocean may be equally thick as in other parts, but more depressed or indented. A map was exhibited, in which the crust of the globe bears about the same proportion to the whole earth as the rind of an orange to the whole pulp, or as sixty miles to eight thousand, the diameter of the earth, all within being liquid fire. Another objection made to the theory is, that as the melted mass is growing cooler, our climate would thus become cooler all over the globe. But a celebrated French geologist has demonstrated that the climate depends upon the sun, and that the internal heat now can have no perceptible effect. The experiment, by way of illustration, can be made with a red-hot cannon ball. At first it cools rapidly, but as soon as an external crust is formed it cools very slowly. By the aid of fluxions he has mathematically demonstrated, that the temperature of the earth at the surface cannot be varied more than a one hundred and fiftieth part of a degree for two thousand years, and that it is not one fifteenth of a degree warmer with the internal fires than if the central parts were ice instead of heat: also, that the internal heat now escaping from the earth would not melt ice six feet thick at the surface in one hundred years. Dr. Bowditch, one of the first mathematicians in the world, has pronounced the demonstration complete and perfect. Another answer to the objection is found in the fact that there has actually been a change in the temperature of the globe.

Without discussing further the validity of this hypothesis, we think that it is extremely probable, that the earth has of itself a heat that is susceptible of variation, from causes with which we are as yet unacquainted. Since Galvani and Volta, by their discoveries, have proved that there cannot exist two bodies of a different nature without their developing electricity and heat, who can suppose that the earth, into the composition of which enters such a multitude of different bodies, and which is consequently traversed by incessant currents of active electricity, is incapable of possessing a heat of its own?

Still, it is reasonable to consider the sun as the principal source of terrestrial heat. This last is dissipated insensibly, by radiating into space, and the more rapidly the more the temperature is raised; and as there is a certain equilibrium between the heat that comes annually from the sun and that which is annually dissipated, the temperature of the earth ought to remain constant. The places on the globe not receiving the same quantity of heat, on account of their different situations and the obliquity with which the sun's rays fall on them, ought to be variable in their temperature. These observations are confirmed by experience. In certain parts of Siberia the earth never thaws, while in Egypt the Fahrenheit* thermometer would indicate seventy-one degrees at more than two hundred feet below the surface. At an intermediate place, cellars preserve constantly the temperature of fifty-four degrees. The temperature of our globe, observed near its surface, would be found to decrease from the equator to the poles; the law of this decrease has not yet been discovered. We shall not here recount the causes of the difference of temperature at various places. They are extremely numerous, and constitute topics more suitable to *physical geography* than to this work.

The atmosphere, that gaseous fluid which surrounds us, is composed of various substances, and is the cause of a thousand phenomena. It contains water in a state of vapor, which does not destroy its transparency, and water in suspension, which forms clouds and mists. The air diminishes in density as we ascend, and when we arrive at any considerable elevation we are made aware, by many uneasy sensations, of an insufficient supply. Acosta, in his relation of a journey among the mountains of Peru, states, that he and his companions were surprised with such extreme pangs of straining and vomiting, casting up blood, and with so violent a distemper, that they would undoubtedly have died had they remained two or three hours longer in that elevated situation. Count Zambecari and his companions, who ascended in a balloon to a great height, found their hands and feet so swelled that it was necessary for a surgeon to make incisions in the skin. A calculation, founded on our knowledge of the properties of air, is sufficient to show that at an altitude not exceeding the hundredth part of the earth's diameter, the rarefaction must be so excessive, that the most delicate means we possess of ascertaining the existence of air would fail to afford the slightest indication of its presence. For all practical purposes, therefore, we may consider those regions which are more distant above us than the hundredth part of the earth's diameter (or seventy-five miles) as void of air, and, of course, of clouds, they being only vapor condensed and *floating* in the air, and sustained by it. Now the greatest height at which clouds ever exist seems not to exceed ten miles. We may consider, then, the atmosphere, with its clouds, as a coating to the earth, bearing about the same proportion to the globe as the downy skin of a peach does to the fruit within. Still, the atmosphere is one of the

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* Bailey says the temperature of twenty-two degrees by the *centigrade* thermometer, reduced to degrees of Fahrenheit by multiplying by nine, dividing by five, and adding thirty-two to the quotient.

most essential appendages to the globe we inhabit, and exhibits a most striking scene of divine skill and omnipotence. The term atmosphere is applied to the whole mass of fluids, consisting of air, vapors, electric fluid, and other matters, which surround the earth to a certain height. This mass of fluid matter gravitates to the earth, revolves with it in its diurnal rotation, and is carried along with it in its course round the sun every year. From experiments made by the barometer, it has been ascertained, that it presses with a weight of about fifteen pounds on every square inch of the earth's surface; and, therefore, its pressure on the body of a middle-sized man is equal to about thirty-two thousand pounds, or fourteen tons avoirdupois,—a pressure which would be insupportable, and even fatal, were it not equal in every part, and counterbalanced by the spring of the air within us. The pressure of the whole atmosphere upon the earth is computed to be equivalent to that of a globe of lead sixty miles in diameter, or about 5,000,000,000,000,000 tons; that is, the whole mass of air which surrounds the globe compresses the earth with a force or power equal to that of *five thousand millions of millions of tons.* This amazing pressure is, however, essentially necessary for the preservation of the present constitution of our globe, and of the animated beings which dwell on its surface. It prevents the heat of the sun from converting water, and all other fluids on the face of the earth, into vapor; and preserves the vessels of all organized beings in due tone and vigor. Were the atmospherical pressure entirely removed, the elastic fluids contained in the finer vessels of men and other animals would inevitably burst them.

Whatever evidences of contrivance and design the celestial globes may exhibit, it is not in the heavens that the most striking displays of divine *wisdom* can be traced by the inhabitants of our world. It is only a few *general relations* and adaptations that can be distinctly perceived among the orbs of the firmament; though, in so far as we are able to trace the purposes which they subserve, the marks of beauty, order, and design, are uniformly apparent. But we are placed at too great a distance from the orbs of heaven to be able to investigate the particular arrangements which enter into the physical and moral economy of the celestial worlds. Were we transported to the surface of the planet Jupiter, and had an opportunity of surveying, at leisure, the regions of that vast globe, and the tribes of sensitive and intellectual existence which compose its population—of contemplating the relations of its moons to the pleasure and comfort of its inhabitants—the constitution of its atmosphere as to its reflective and refractive powers, in producing a degree of illumination to compensate for the great distance of that planet from the sun—its adaptation to the functions of animal life—the construction of the visual organs of its inhabitants, and the degree of sensibility they possess, corresponding to the quantity of light received from the sun—the temperature of the surface and atmosphere of this globe, corresponding to its distance from the central source of heat, and to the physical constitution of sensitive beings;—in short, could we investigate the relations which inanimate nature, in all its varieties and sublimities, bears to the necessities and the happiness of the animated existences that traverse its different regions, we should, doubtless, behold a scene of divine wisdom and intelligence far more admirable and astonishing than even that which is exhibited in our sublunary world. But since it is impossible for us to investigate the economy of other worlds, while we are chained down to this terrestrial sphere, we must direct our attention to those arrangements and contrivances in the constitution of our own globe which lie open to our particular inspection, in order to perceive more distinctly the benevolent designs of Him "in whom we live and move, and have our being." And here an attentive observer will find, in almost every object, when minutely examined, a display of goodness and intelligence which will constrain him to exclaim, "O the depth of the riches both of the wisdom and the knowledge of God."

Wisdom, considered as consisting in contrivance, or the selection of the most proper means in order to acomplish an important end, may be exemplified and illustrated in a variety of familiar objects.

The *earth*, on which we tread, was evidently intended by the Creator to support man and other animals, along with their habitations, and to furnish those vegetable productions which are necessary for their subsistence ; and, accordingly, he has given it that exact degree of consistency which is requisite for these purposes. Were it much harder than it now is—were it, for example, as dense as a rock—it would be incapable of cultivation, and vegetables could not be produced from its surface. Were it softer, it would be insufficient to support us, and we should sink at every step, like a person walking in a quagmire. Had this circumstance not been attended to in its formation, the earth would have been rendered useless as a habitable world for all those animated beings which now traverse its surface. The exact adjustment of the solid parts of our globe to the nature and necessities of the beings which inhabit it, is, therefore, an instance and an evidence of *wisdom.*

The *diversity of surface* which it everywhere presents, in the mountains and vales with which it is variegated, indicates the same benevolent contrivance and design. If the earth were divested of its mountains, and its surface everywhere uniformly smooth, there would be no rivers, springs, or fountains; for water can flow only from a higher to a lower place; the vegetable tribes would droop and languish; man and other animals would be deprived of what is necessary for their existence and comfort; we should be destitute of many useful stones, minerals, plants, and trees, which are now produced on the surface and in the interior of mountains; the sea itself would become a stagnant marsh, or overflow the land; and the whole surface of nature in our terrestrial sphere would present an unvaried scene of dull uniformity. Those picturesque and sublime scenes which fire the imagination of the poet, and which render mountainous districts so pleasing to the philosophic traveller, would be completely withdrawn; and all around, when compared with such diversified landscapes, would appear as fatiguing to the eye as the vast solitudes of the Arabian deserts, or the dull monotony of the ocean. But in consequence of the admirable distribution of hills and mountains over the surface of our globe, a variety of useful and ornamental effects is produced. Their lofty summits are destined by Providence to arrest the vapors which float in the regions of the air; their internal cavities form so many spacious basins for the reception of waters distilled from the clouds; they are the original sources of springs and rivers, that water and fertilize the earth; they form immense magazines, in which are deposited stones, metals, and minerals, which are of essential service in the arts that promote the comfort of human life; they serve for the production of a vast variety of herbs and trees ; they arrest the progress of storms and tempests ; they afford shelter and entertainment to various animals which minister to the wants of mankind: in a word, they adorn and embellish the face of nature, they form thousands of sublime and beautiful landscapes, and afford from their summits the most delightful prospects of the plains below. All these circumstances demonstrate the consummate wisdom of the Great Architect of nature, and lead us to conclude, that mountains, so far from being rude excrescences of nature, as some have asserted, form an essential part in the constitution, not only of our globe, but of all habitable worlds. And this conclusion is confirmed, so far as our observation extends, with regard to the moon, and several of the planetary bodies which belong to our system, whose surfaces are found to be diversified by sublime ramifications of mountain scenery. This circumstance forms one collateral proof, among many others, that they are the abodes of sentient and intellectual beings.

Again, the *coloring* which is spread over the face of nature indicates the wisdom of the Deity. It is essential to the present mode of our existence, and it was evidently intended by the Creator, that we should be enabled easily to recognise the forms and properties of the various objects with which we are surrounded. But were the objects of nature destitute of color, or were the same unvaried hue spread over the face of creation, we should be destitute of all the entertainments of vision, and be at a loss to distinguish one object from another. We should be unable to distinguish rugged precipices from fruitful hills; naked rocks from human habitations; the trees from the hills that bear them, and the tilled from the untilled lands. "We should hesitate to pronounce whether an adjacent inclosure contain a piece of pasturage, a plot of arable land, or a field of corn; and it would require a little journey, and a minute investigation, to determine such a point. We could not determine whether the first person we met were a soldier in his regimentals, or a swain in his Sunday suit; a bride in her ornaments, or a widow in her weeds." Such would have been the aspect of nature, and such the inconveniences to which we should have been subjected, had God allowed us light, without the distinction of colors. We could have distinguished objects only by intricate trains of reasoning, and by circumstances of time, place, and relative position. And to what delays and perplexities should we have been reduced, had we been obliged every moment to distinguish one thing from another by reasoning! Our whole life must then have been employed rather in study than in action; and, after all, we must have remained in eternal uncertainty as to many things, which are now quite obvious to every one as soon as he opens his eyes. We could neither have communicated our thoughts by writing, nor have derived instruction from others through the medium of books: so that we should now have been almost as ignorant of the transactions of past ages as we are of the events which are passing in the planetary worlds; and, consequently, we could never have enjoyed a written revelation from heaven, nor any other infallible guide to direct us in the path to happiness, if the Almighty had not distinguished the rays of light, and painted the objects around us with a diversity of colors: so essentially connected are the minutest and the most magnificent works of Deity. But now, in the present constitution of things, color characterizes the class to which every individual belongs, and indicates, upon the first inspection, its respective quality. Every object wears its peculiar livery, and has a distinguishing mark by which it is characterized.

The different hues which are spread over the scenery of the world are also highly ornamental to the face of nature, and afford a variety of pleasures to the eye and the imagination. It is this circumstance which adds a charm to the fields, the valleys, and the hills, the lofty mountain, the winding river, and the expansive lake; and which gives a splendor and sublimity to the capacious vault of heaven. Color is, therefore, an essential requisite to every world inhabited by sensitive beings; and we know that provision has been made for diffusing it throughout all the globes which may exist in the distant regions which our telescopes have penetrated; for the light which radiates from the most distant stars is capable of being separated into the prismatic colors, similar to those which are produced by the solar rays; which furnishes a presumptive proof that they are intended to accomplish designs in their respective spheres analogous to those which light subserves in our terrestrial habitation; or, in other words, that they are destined to convey to the minds of sentient beings impressions of light and color, and, consequently, beings susceptible of such impressions must reside within the sphere, or more immediate influence of these far distant orbs.

The same benevolent design is apparent in the *general color which prevails throughout the scene of sublunary nature.* Had the fields been clothed with hues of a deep red or a brilliant white, the eye would have been dazzled with the splendor of their aspect. Had a dark blue or a black color generally prevailed, it would have cast a universal gloom over the face of nature. But an agreeable green holds the medium between these two extremes, equally remote from a dismal gloom and excessive splendor, and bears such a relation to the structure of the eye that it refreshes instead of tiring it, and supports instead of diminishing its force. At the same time, though one general color prevails over the landscape of the earth, it is diversified by an admirable variety of shades, so that every individual object in the vegetable world can be accurately distinguished from another; thus producing a beautiful and variegated appearance over the whole scenery of nature. "Who sees not in all these things that the hand of the Lord hath wrought this?"

If from the earth we turn our attention to the *waters,* we shall perceive similar traces of the exquisite wisdom and skill of the Author of nature. Water is one of the most essential elementary parts in the constitution of our globe, without which the various tribes of beings which now people it could not exist. It supplies a necessary beverage to man, and to all the animals that people the earth and the air. It forms a solvent for a great variety of solid bodies; it is the element in which an infinitude of organized beings pass their existence; it acts an important part in conveying life and nourishment to all the tribes of the vegetable kingdom, and gives salubrity to the atmospherical regions. Collected in immense masses in the basins of the sea, it serves as a vehicle for ships, and as a medium of communication between people of the most distant lands. Carried along with a progressive motion over the beds of streams and of rivers, it gives a brisk impulse to the air, and prevents the unwholesome stagnation of vapors; it receives the filth of populous cities, and rids them of a thousand nuisances. By its impulsion it becomes the mover of a multitude of machines; and, when rarified into steam, it is transformed into one of the most powerful and useful agents under the dominion of man. All these beneficial effects entirely depend on the exact degree of density, or specific gravity, which the Creator has given to its constituent parts. Had it been much more rarified than it is, it would have been altogether unfit to answer the purposes now specified; the whole face of the earth would have been a dry and barren waste; vegetable nature could not have been nourished; our floating edifices could not have been supported; the lightest bodies would have sunk, and all regular intercourse with distant nations would have been prevented. On the other hand, had its parts been much denser than they are;—for example, had they been of the consistency of a thin jelly,—similar disastrous effects would have inevitably followed; no ships could have ploughed the ocean; no refreshing beverage would have been supplied to the animal tribes; the absorbent vessels of trees, herbs, and flowers would have been unable to imbibe the moisture requisite for their nourishment; and we should thus have been deprived of all the beneficial effects we now derive from the use of that liquid element, and of all the diversified scenery of the vegetable world. But the configuration and consistency of its parts are so nicely adjusted to the constitution of the other elements, and to the wants of the sensitive and vegetable tribes, as exactly to subserve the ends intended in the system of nature.

The most appropriate and impressive illustrations of Omnipotence are those which are taken from the *permanent* operations of Deity, which are visible every moment in the universe around us; or, in other words, those which are derived from a detail of the facts which have been observed in the material world respecting *magnitude* and *motion.*

We must endeavor to form a conception of the bulk of the world in which we dwell, which, though only a point in comparison of the whole material universe, is in reality a most astonishing magnitude, which the mind cannot grasp without a laborious effort. We can form some definite idea of those protuberant masses we denominate *hills,* which arise above the surface of our plains; but were we transported to the mountainous scenery of Switzerland, to the stupendous range of the Andes in South America, or to the Himalayan mountains in India, where masses of earth and rocks, in every variety of shape, extend several hundreds of miles in different directions, and rear their projecting summits beyond the region of the clouds—we should find some difficulty in forming an adequate conception of the objects of our contemplation. "For," (to use the words of one who had been a spectator of such scenes,) "amidst those trackless regions of intense silence and solitude, we cannot contemplate but with feelings of awe and admiration the enormous masses of variegated matter which lie around, beneath, and above us. The mind labors, as it were, to form a definite idea of those objects of oppressive grandeur, and feels unable to grasp the august objects which compose the surrounding scene." But what are all these mountainous masses, however variegated and sublime, when compared with the bulk of the whole earth? Were they hurled from their basis, and precipitated into the vast Pacific ocean, they would all disappear in a moment, except perhaps a few projecting tops, which, like a number of small islands, might be seen rising a few fathoms above the surface of the waters.

In order to form a tolerable conception of the whole globe, we must endeavor to take a leisurely survey of its different parts. Were we to take our station on the top of a mountain, of a moderate size, and survey the surrounding landscape, we should perceive an extent of view stretching forty miles in every direction, forming a circle eighty miles in diameter, and two hundred and fifty in circumference, and comprehending an area of five thousand square miles. In such a situation the terrestrial scene around and beneath us, consisting of hills and plains, towns and villages, rivers and lakes, would form one of the largest objects which the eye, or even the imagination, can steadily grasp at one time. But such an object, grand and extensive as it is, forms no more than the *forty thousandth part* of the globe; so that, before we can acquire an adequate conception of the magnitude of our own world, we must conceive forty thousand landscapes of a similar extent to pass in review before us: and were a scene, of the magnitude now stated, to pass before us every hour, till all the diversified scenery of the earth were brought under our view, and were twelve hours a day allotted for the observation, it would require nine years and forty-eight days before the whole surface of the globe could be contemplated, even in this *general* and *rapid* manner. But such a variety of successive landscapes passing before the eye, even although it were possible to be realized, would convey only a very vague and imperfect conception of the scenery of our world; for objects at the distance of forty miles cannot be distinctly perceived: the only view which would be satisfactory, would be that which is comprehended within the range of three or four miles from the spectator.

Again, we have already stated that the surface of the earth contains nearly 200,000,000 of square miles. Now, were a person to set out on a minute survey of the globe, and to travel till he passed along every square mile on its surface, and to continue his route without intermission, at the rate of thirty miles every day, it would require 18,264 years before he could finish his tour, and complete the survey of "this huge rotundity on which we tread:" so that, had he commenced his excursion on the day in which Adam was created, and continued it to the present hour, he would not have accomplished one-third part of this vast tour.

In estimating the size and extent of the earth, we ought also to take into consideration the vast variety of objects with which it is diversified, and the numerous animated beings with which it is stored;—the great divisions of land and water, the continents, seas, and islands, into which it is distributed; the lofty ranges of mountains which rear their heads to the clouds; the unfathomed abysses of the ocean; its vast subterraneous caverns and burning mountains; and the lakes, rivers, and stately forests with which it is so magnificently adorned;—the many millions of animals, of every size and form, from the elephant to the mite, which traverse its surface; the numerous tribes of fishes, from the enormous whale to the diminutive shrimp, which "play" in the mighty ocean; the aerial tribes which sport in the regions above us, and the vast mass of the surrounding atmosphere, which incloses the earth and all its inhabitants as "with a swaddling band." The immense variety of beings with which our terrestrial habitation is furnished, conspires, with every other consideration, to exalt our conceptions to that Power by which our globe, and all that it contains, were brought into existence.

The preceding illustrations, however, exhibit the vast extent of the earth considered only as a superficies. But we know that the earth is a solid globe, whose specific gravity is nearly five times denser than water, or about twice as dense as the mass of earth and rocks which compose its surface. Though we cannot dig into its bowels beyond a mile in perpendicular depth, to explore its hidden wonders, yet we may easily conceive what a vast and indescribable mass of matter must be contained between the two opposite portions of its external circumference, reaching eight thousand miles in every direction. The solid contents of this ponderous ball is no less than 263,858,149,120 cubical miles—a mass of material substance of which we can form but a very faint and imperfect conception—in proportion to which all the lofty mountains that rise above its surface are less than a few grains of sand when compared with the largest artificial globe. Were the earth a hollow sphere, surrounded merely with an external shell of earth and water, ten miles thick, its internal cavity would be sufficient to contain a quantity of materials *one hundred and thirty-three times* greater than the whole mass of continents, islands, and oceans on its surface, and the foundations on which they are supported. We have the strongest reasons, however, to conclude, that the earth, in its general structure, is one solid mass, from the surface to the centre, excepting, perhaps, a few caverns scattered here and there amidst its subterraneous recesses: and that its density gradually increases from its surface to its central regions. What an enormous mass of materials, then, is comprehended within the limits of that globe on which we tread! The mind labors, as it were, to comprehend the mighty idea, and after all its exertion feels itself unable to take in such an astonishing magnitude at *one* comprehensive grasp. How great must be the power of that Being who commanded it to spring from nothing into existence, who measureth the ocean in the hollow of his hand, who weigheth the mountains in scales and hangeth the earth upon nothing.

CHAPTER III.

SECTION I.

Sun—Comparatively stationary—Cause of twilight—Sun's mass—Gravity—Real diameter—Probable conclusions of the solar astronomer—Sun's disc as seen from the different planets—Sun the source of heat—What proportion of solar light falls on our globe—Divine wisdom—Solar spots—Variable in size and number—First authentic observations on—Scheiner imagines they are planets—Their course and changes—Sun's revolution about its axis—Theories of different observers respecting the spots—Herschel's theory prevalent—Is the sun inhabited?—Zodiacal light—Sun's progressive motion—Herschel's theory confirmed by a late experiment in France.

The sun, that might at first be ranked in the number of planets or wanderers, has been found to be comparatively stationary, and may therefore be regarded as a star, occupying the centre of our system, appearing larger than the rest of the stars only on account of its greater proximity to us.

It appears to us under the form of a round and dazzling circle, called its disc. Owing to the diurnal motion of the earth, the sun, like the other stars, which become invisible in the splendor of his light, appears to describe a circle, whose variable extent determines the length of the days. His descent below the horizon does not instantly plunge us into the shades of night; but his luminous rays, refracted by the strata of the atmosphere before rising and after setting, cause that feeble light which we call twilight, and present to our view that succession of colors so remarkable for their variety of agreeable shades.

Besides this apparent daily motion of the sun, it has another apparent motion in the plane of the ecliptic, resulting from the real motion of the earth in its annual orbit. It is owing to this motion of the earth, which varies the position of the sun in respect to an observer, that the latter body appears under very different magnitudes, its diameter being very sensibly less when in apogee (which happens at midsummer) than in perigee, (which happens in midwinter;)—a circumstance which is common to it with bodies near the surface of our globe, which appear to us larger in proportion to their proximity.

Calculations give the following results as the distance between the sun and the earth at different times:—

Perigee or perihelion	93,745,287
Apogee or aphelion	96,950,457
Mean distance	95,347,872
Longest diameter	190,695,744

Thus the greatest distance exceeds the mean by about one and a half millions of miles,—a quantity very small in comparison with the dimensions of the orbit.

When we calculate from the known distance of the sun, and from the period in which the earth circulates about it, what must be the centrifugal force of the latter, by which the sun's attraction is balanced, (and which, therefore, becomes an exact measure of the sun's attractive energy as exerted on the earth,) we find it to be immensely greater than would suffice to counteract the *earth's* attraction on an equal body at that distance—greater in the high proportion of 354,936 to 1. It is clear, then, that if the earth be retained in its orbit about the sun by *solar attraction*, conformable in its rate of diminution with the general law, this force must be no less than 354,936 times more intense than what the earth would be capable of exerting, other things being equal, at an equal distance.

What, then, are we to understand from this result? Simply this, that the sun attracts as a collection of 354,936 earths, occupying its place, would do, or, in other words, that the sun contains 354,936 times the mass or quantity of ponderable matter that the earth consists of. When we compare its *mass* with its *bulk*, we find its density to be less than that of the earth, being no more than 0·2543; so that it must consist, in reality, of far *lighter* materials, especially when we consider the force under which its central parts must be condensed. This consideration renders it highly probable that an intense heat prevails in its interior, by which its elasticity is reinforced, and rendered capable of resisting this almost inconceivable pressure without collapsing into smaller dimensions.

This will be more distinctly appreciated, if we estimate the intensity of gravity at the sun's surface.

The attraction of a sphere, being the same as if its whole mass were collected in its centre, will, of course, be proportional to the mass directly, and the square of the distance inversely; and, in this case, the distance is the radius of the sphere. Hence we conclude, that the intensities of solar and terrestrial gravity at the surfaces of the two globes are in the proportions of 27·9 to 1. A pound of terrestrial matter at the sun's surface, then, would exert a pressure equal to what 27·9 such pounds would do at the earth's. An ordinary man, for example, would not only be unable to sustain his own weight on the sun, but would literally be crushed to atoms under the load.

We must then consent to dismiss all idea of the earth's immobility, and transfer that attribute to the sun, whose ponderous mass is calculated to exhaust the feeble attractions of such comparative atoms as the earth and moon, without being perceptibly dragged from its place. Their centre of gravity lies, as we have already hinted, almost close to the centre of the solar globe, at an interval quite imperceptible from our distance; and whether we regard the earth's orbit as being performed about the one or the other centre makes no appreciable difference in any one phenomenon of astronomy.

That at so vast a distance the sun should appear to us of the size it does, and should so powerfully influence our condition by its heat and light, requires us to form a very grand conception of its actual magnitude, and of the scale on which those important processes are carried on within it, by which it is enabled to keep up its liberal and unceasing supply of these elements. As to its actual magnitude we can be at no loss, knowing its distance, and the angles under which its diameter appears to us. An object, placed at the distance of ninety-five millions of miles, and subtending an angle of 32′ 3″, must have a real diameter of eight hundred and eighty-two thousand miles. Were its central parts placed adjacent to the surface of the earth, its circumference would reach two hundred thousand miles beyond the moon's orbit, on every side, filling a cubical space of 681,472,000,000,000,000 miles. If it would require eighteen thousand years to traverse every square mile on the earth's surface, at the rate of thirty miles a day, it would require more than *two thousand millions of years* to pass over every part of the sun's surface, at the same rate. Even at the rate of ninety miles a day it would require more than eighty years to go round its circumference. Of a body so vast in its dimensions, the human mind, with all its efforts, can form no adequate conception. It appears an extensive universe in itself; and, although no other body existed within the range of infinite space, this globe alone would afford a powerful demonstration of the omnipotence of the Creator. Were the sun a hollow sphere, surrounded by an external shell, and a luminous atmosphere; were this shell perforated with several hundreds of openings into the internal part; were a globe as large as the earth placed at its centre, and another globe as large as the moon, and at the same distance from the centre as the moon is from us, to revolve round the central globe,—it would present to the view a universe as splendid and glorious as that which now appears to the vulgar eye,—a universe as large and extensive as the whole creation was conceived to be by our ancestors, in the infancy of astronomy.

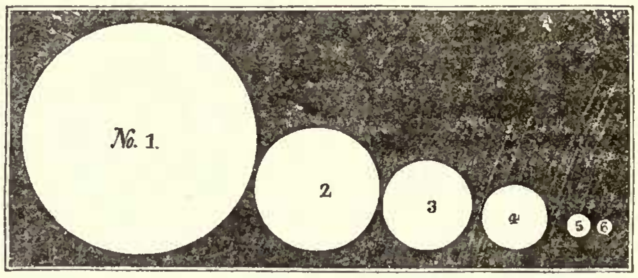
It is hardly possible to avoid associating our conception of an object of definite globular figure, and of such enormous dimensions, with some corresponding attribute of massiveness and material solidity. That the sun is not a mere phantom, but a body having its own peculiar structure and economy, our telescopes distinctly inform us. They show us dark spots on its surface, which slowly change their places and forms, and by attending to their situation, at different times, astronomers have ascertained that the sun revolves about an axis inclined at a constant angle of 82° 40′ to the plane of the ecliptic, performing one rotation in a period of twenty-five days, and in the same direction with the diurnal rotation of the earth, i..e. from west to east. Here, then, we have an analogy with our own globe; the slower and more majestic movement only corresponding with the greater dimensions of the machinery, and impressing us with the prevalence of similar mechanical laws, and of, at least, such a community of nature as the existence of inertia and obedience to force may argue. Now, in the exact proportion in which we invest our idea of this immense bulk with the attribute of inertia, or weight, it becomes difficult to conceive its circulation round so comparatively small a body as the earth, without, on the one hand, dragging it along, and displacing it, if bound to it by some invisible tie; or, on the other hand, if not so held to it, pursuing its course alone in space, and leaving the earth behind. If we tie two stones together by a string, and fling them aloft, we see them circulate about a point between them, which is their common centre of gravity; but if one of them be greatly more ponderous than the other, this common centre will be proportionally nearer to that one, and even within its surface, so that the smaller one will circulate, in fact, about the larger, which will be comparatively but little disturbed from its place. The sun being at the centre of all the planets' motions, the only place from which these motions would appear such as they actually are would be the centre of that luminary.

There, the observer, not being supposed to turn round with the sun's rotation, would see all the stars at rest and seemingly equidistant from him. The planets would appear to move among the fixed stars in a simple, regular and uniform manner, only they would not describe equal portions of their orbits in equal times. They would appear to move from west to east in the heavens, in paths that cross at small angles, and then separate a little from each other. So that if the solar astronomer should take the orbit of any one planet as his standard, and consider it as having no obliquity, he would judge the paths of all the rest to be inclined to this standard, each planet having one half its path on one side and the other half on the opposite side of the standard.

Suppose now he should see all the planets start from the same line, crossing the standard orbit at right angles. Mercury would move so much faster than Venus as to go wholly round his orbit and again overtake her in the space of one hundred and forty-five of our days; Venus so much faster than the Earth as to overtake it again in five hundred and eighty-five days; the Earth so much faster than Mars as to overtake him again in seven hundred and seventy-eight days.

But as the solar astronomer would have no idea of measuring by our days, he might perhaps take the period of Mercury's revolution, being the most rapid in its motions, as a measure, with which to estimate the periods of the rest. As all the stars would appear without motion, he would not think that they had any dependence on the sun; but would naturally conclude that the planets have, because they move round the sun; and perhaps he might suppose that those planets whose periods were shortest, moved in orbits proportionably less than those whose periods were longer. But as to him they would have no parallax, he could not know their real distances or magnitudes. Their relative distances he might guess at from their periods, and thence infer something of their relative sizes, by comparing their apparent sizes with one another. For example, Jupiter appearing larger than Mars, he would conclude it much larger, as he had from its period concluded that it was much more distant. Mercury and the Earth would appear nearly of the same size; but having concluded, from the Earth's longer period, that it was farther off than Mercury, he would conclude that our globe was really larger. And as each planet would appear sometimes larger than at others, and to move most rapidly when it seemed largest, he could determine that all the planets moved in orbits of which the sun is not exactly at the centre.

As the planets are at very different distances from the sun, the apparent disc of that luminary will vary in magnitude at the different planets. Suppose No. 1 to represent the size of the disc as seen from Mercury; then at Venus it will appear a little more than one half as large, and may be represented by No. 2. No. 3 will be the apparent disc at the Earth; No. 4 at Mars; No. 5 at Jupiter; No. 6 at Saturn. At Herschel it would be represented by a circle one half as large as No. 6; Herschel being twice as far from the sun as Saturn.

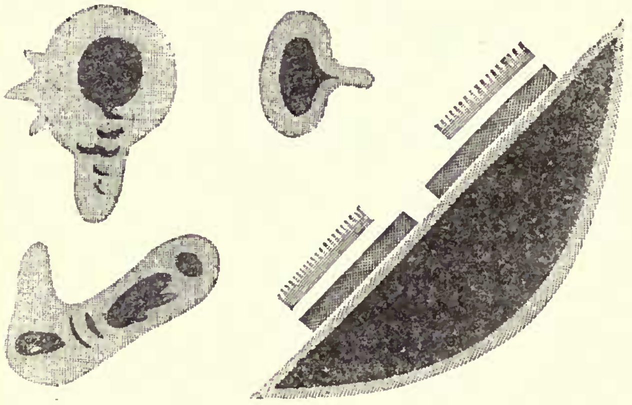


The sun is the grand source of light and heat, both to the earth and to all the other planetary bodies. The heat he diffuses animates every part of our sublunary system, and all that variety of coloring which adorns the terrestrial landscape is produced by his rays. It has been lately discovered, that the rays of light, and the rays of heat, or *caloric*, are distinct from each other; for, it can be demonstrated, that some rays from the sun produce heat, which have no power of communicating light or color. The greatest heat is found in the *red* rays, the least in the *violet* rays; and in a space beyond the red rays, where there is no light, the temperature is greatest. The rays of the sun have also been found to produce different chemical effects. The white muriate of silver is blackened in the violet ray, in the space of fifteen seconds, though the red will not produce the same effect in less than twenty minutes. Phosphorus is kindled in the vicinity of the red ray, and extinguished in the vicinity of the violet. The solar light, therefore, consists of *three* different orders of rays, one producing *color*, a second producing *heat*, and a third *chemical* effects. Euler has computed that the light of the sun is equal to six thousand five hundred candles at a foot distance, while the moon would be as one candle at seven and a half feet; Venus at four hundred and twenty-one feet; and Jupiter at one thousand three hundred and twenty feet. That this immense luminary appears so small to our eyes is owing to its vast distance, which is no less than ninety-five millions of miles. Some faint idea of this distance may be obtained, by considering, that a steam-boat, moving at the rate of two hundred miles a day, would require *thirteen hundred years* before it could traverse the space which intervenes between us and the sun.

From a consideration of the rays of light, we are led to investigate *what proportion of the solar light falls upon our globe,* in order to produce so diversified a scene of sublimity and beauty. Supposing the sun's rays to be chiefly confined, in their effects, within the limits of the planetary system, since they diverge in every direction, they must fill a cubical space 3,600,000,000 miles in diameter; which, consequently, will contain about 24,000,000,000,000,000,000,000,000,000 of cubical miles; so that an eye, placed in any point of this vast space, would receive a distinct impression from the solar rays. The solidity of the earth is about 264,000,000,000 cubical miles, and, therefore, it receives only the $\frac{1}{90,000,000,000,000,000}$th part of the light which fills the sphere of the solar system. So that the light which cheers all the inhabitants of the world, and unveils such a variety of beautiful and magnificent objects, is nothing more than *a single stream* of celestial radiance out of ninety thousand billions of similar streams, which the great source of light is every moment diffusing throughout the surrounding worlds. But the solar rays are not confined within the bounds of the planetary system; their influence extends, in every direction, as far as the nearest stars, filling a cubical space at least 40,000,000,000,000 miles in diameter, and which contains 33,500,000,000,000,000,000,000,000,000,000,000,000,000,000, or thirty-three thousand five hundred sextillions of cubical miles. And, were we to institute comparisons and calculations, with respect to the possible variety of effects they might produce throughout this immense region, whole pages might be filled with figures, cyphers, and computations. We might compute how many globes similar to the earth, or any of the larger planets, might be contained within this vast space, allowing several hundreds of cubical miles of empty space around each globe—how many myriads of refractions and reflections the rays of light would suffer, in regard to the peculiar objects connected with every one of these globes—how many eyes of sentient beings might be affected by the diversities of color, shape, and motion which would thus be produced—and what a variety of shades of light and color, and what a diversity of scenery, would be produced, according to the distance of the respective globes from the central luminary. The planetary system—that portion of the heavens with which we are best acquainted—displays both the magnificence and the skill of its Divine Author,—in the magnitudes, distances, revolutions, proportions, and uses of the various globes of which it is composed, and in the diversified apparatus by which light and darkness are alternately distributed. The sun, an immense luminous world, by far the largest body in the system, is placed in the centre. No other position would have suited for an equable distribution of illumination and heat through the different parts of the system. Around him, at different distances, eleven primary planets revolve, accompanied with eighteen secondaries, or moons,—all in majestic order and harmony, no one interrupting the movements of another, but invariably keeping the paths prescribed them, and performing their revolutions in their appointed times. To all these revolving globes, the sun dispenses motion, light, heat, fertility, and other unceasing energies, for the comfort and happiness of their respective inhabitants; without which, perpetual sterility, eternal winter, and eternal night, would reign over every region of our globe, and throughout surrounding worlds.

The distance at which the heavenly bodies, particularly the sun, are placed from the earth, is a manifest evidence of divine wisdom. If the sun were much nearer us than he is at present, the earth, as now constituted, would be wasted and parched with excessive heat; the waters would be turned into vapor, and the rivers, seas, and oceans, would soon disappear, leaving nothing behind them but frightful barren dells and gloomy caverns; vegetation would completely cease, and the tribes of animated nature languish and die. On the other hand, were the sun much farther distant than he now is, or were his bulk, or the influence of his rays, diminished one half of what they now are, the land and the ocean would soon become one frozen mass, and universal desolation and sterility would overspread the fair face of nature, and, instead of a pleasant and comfortable abode, our globe would become a frightful desert, a state of misery and perpetual punishment.[*]

When viewed through powerful telescopes, provided with colored glasses, to take off the heat, which would otherwise injure our eyes, the sun is observed to have frequently large and perfectly black spots upon it, surrounded with a kind of border, less completely dark, called a penumbra. Some of these are represented in this figure.



Occasionally they break up, or divide into two or more, and in those offer every evidence of that extreme mobility which belongs only to the fluid state, and of that excessively violent agitation which seems only compatible with the atmospheric or gaseous state of matter. The scale on which their movements take place is immense. A single second of angular measure, as seen from the earth, corresponds on the sun's disc to four hundred and sixty-five miles; and a circle of this diameter (containing therefore nearly two hundred and twenty thousand square miles) is the least space which can be distinctly discerned on the sun as a *visible area.*

The part of the sun's disc not occupied by spots is far from uniformly bright. Its *ground* is finely mottled with an appearance of minute dark dots, or *pores*, which, when attentively watched, are found to be in a constant state of change. There is nothing which represents so faithfully this appearance as the slow subsidence of some flocculent chemical precipitates in a transparent fluid, when viewed perpendicularly from above: so faithfully, indeed, that it is hardly possible not to be impressed with the idea of a luminous medium intermixed, but not confounded, with a transparent and non-luminous atmosphere, either floating as clouds in our air, or pervading it in vast sheets and columns like flame, or the streamers of our northern lights.

It has been noticed, (not without great need of further confirmation,) that extinct spots have again broken out, after long intervals of time, on the same identical points of the sun's globe. Our knowledge of the period of its rotation (which, according to Delambre's calculations, is 25·01154 d., but, according to others, materially different,) can hardly be regarded as sufficiently precise to establish a point of so much nicety.

That the temperature at the visible surface of the sun cannot be otherwise than very elevated, much more so than any artificial heat produced in our furnaces, or by chemical or galvanic processes, we have indications of several distinct kinds: 1st, From the law of decrease of radiant heat and light, which being inversely as the squares of the distances, it follows, that the heat received on a given area exposed at the distance of the earth, and on an equal area at the visible surface of the sun, must be in the proportion of the area of the sky occupied by the sun's apparent disc to the whole hemisphere, or as one to about three hundred thousand. A far less intensity of solar radiation, collected in the focus of a burning-glass, suffices to dissipate gold and platina in vapor. 2dly, From the facility with which the calorific rays of the sun traverse glass, a property which is found to belong to the

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[*] It forms no objection to these remarks, that *caloric*, or the matter of *heat*, does not altogether depend upon the direct influence of the solar rays. The substance of caloric may be chiefly connected with the constitution of the globe we inhabit. But still, it is quite certain, that the earth, *as presently constituted*, would suffer effects most disastrous to sentient beings, were it removed much nearer or much farther from the central luminary.

heat of artificial fires in the direct proportion of their intensity. 3dly, From the fact, that the most vivid flames disappear, and the most intensely ignited solids appear only as black spots on the disc of the sun when held between it and the eye. From this last remark it follows, that the body of the sun, however dark it may appear when seen through its spots, *may*, nevertheless, be in a state of most intense ignition. It does not, however, follow of necessity that it *must* be so.

The sun's rays are the ultimate source of almost every motion which takes place on the surface of the earth. By its heat are produced all winds, and those disturbances in the electric equilibrium of the atmosphere which give rise to the phenomena of terrestrial magnetism. By their vivifying action vegetables are elaborated from inorganic matter, and become, in their turn, the support of animals and of man, and the sources of those great deposites of dynamical efficiency which are laid up for human use in our coal strata. By them the waters of the sea are made to circulate in vapor through the air, and irrigate the land, producing springs and rivers. By them are produced all disturbances of the chemical equilibrium of the elements of nature, which, by a series of compositions and decompositions, give rise to new products, and originate a transfer of materials. Even the slow degradation of the solid constituents of the surface, in which its chief geological changes consist, and their diffusion among the waters of the ocean, are entirely due to the abrasion of the wind and rain, and the alternate action of the seasons; and when we consider the immense transfer of matter so produced, the increase of pressure over large spaces in the bed of the ocean, and diminution over corresponding portions of the land, we are not at a loss to perceive how the elastic power of subterranean fires, thus repressed on the one hand, and relieved on the other, may break forth in points where the resistance is barely adequate to their retention, and thus bring the phenomena of even volcanic activity under the general law of solar influence.

The great mystery, however, is to conceive how so enormous a conflagration (if such it be) can be kept up. Every discovery in chemical science here leaves us completely at a loss, or, rather, seems to remove farther the prospect of probable explanation. If conjecture might be hazarded, we should look rather to the known possibility of an indefinite generation of heat by friction, or to its excitement by the electric discharge, than to any actual combustion of ponderable fuel, whether solid or gaseous, for the origin of the solar radiation. The spots are very variable in their number, their form, and their position. Sometimes they suddenly disappear, and their places are supplied by others; sometimes there can be counted *fifty or more*, and yet the succeeding year there may be none discoverable.

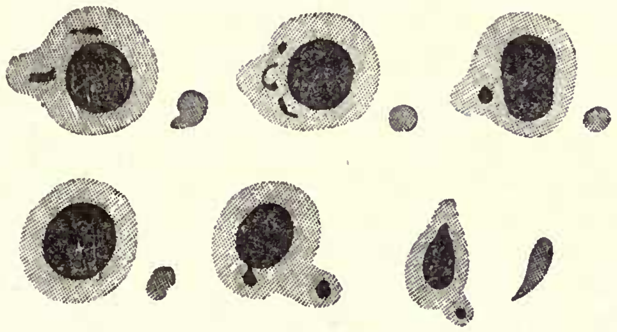
Some of the spots are as large as would cover the whole continent; others have been observed of the size of the whole surface of the earth; and one was seen in 1779 which was computed to be more than *fifty thousand miles* in diameter. But from certain accounts we have reason to believe that there have been spots observed much larger even than that, or rather that the sun was all spot; for it is related that, about the year 535, the light of the sun was dimmed for the space of fourteen months, and that, in the year 626, half the disc was obscured during the whole summer.

We now proceed to give a more full account of the spots, as they have been observed by various astronomers, and the theories to which they have given rise; considering them all as opinions merely, which future discoveries may establish or overthrow. Though these spots have sometimes been sufficiently large to be distinguished by the naked eye, yet they were not discovered till after the invention of the telescope. They appear to have been first seen by Harriot, to whom the science of algebra was under great obligations, or by John Fabricius, who published an account of his observations in 1611 at Wittemberg. The observations of Harriot upon the solar spots began on the 8th of December, 1610. It is obvious, indeed, from the work of Fabricius, that he had seen the sun's spots during the year 1610, but it is not certain that he saw them before Harriot. It is a remarkable circumstance that Fabricius was acquainted with no method of intercepting the sun's rays in order to save the eye. He observed the sun when he was in the horizon, and when his brilliancy was impaired by thin clouds and floating vapors: and he advises those who repeat his observations to receive at first a small portion of the sun, and gradually accustom the eye to a greater portion, till it is able to bear the full blaze of its light. When the altitude of the sun became considerable, Fabricius was compelled to abandon his observations.

At the beginning of the year 1611, Scheiner and Galileo seem to have observed, about the same time, the spots of the sun. Scheiner was professor of mathematics at Ingolstadt: and having accidentally turned his telescope to the sun when thin clouds were flying across his disc, he perceived a number of black spots, and showed them to several of his pupils. The report of this discovery was widely propagated, and though Scheiner was solicited by many of his friends to publish an account of the solar spots, yet he was prevented from yielding to their wishes by a dread of the ecclesiastical power. Scheiner imagined that the spots which appeared on the sun did not belong to that luminary, but were planets, like Mercury and Venus, which revolved in orbits not very distant from the sun. Galileo, who had already made many observations on the solar spots, and to whom Velser transmitted a copy of Scheiner's letters, with the request that he would favor him with his opinion of the new phenomena, was at first averse to hazard his sentiments on a subject which might again provoke the hostility of the church; but on the 4th of May, 1612, he at length ventured to express his opinions to Velser, and to combat the notion entertained by Scheiner of the cause of the solar spots. Galileo observed that these spots were not of a permanent form, as they ought to have been if they were satellites, but that they often united, separated, increased and dispersed, like vapors or clouds. He maintains that these spots are upon the surface of the sun; that they describe circles parallel to each other; that the motion of the sun around its axis every month again presents the spots to our view; that some of the spots continue one or two days, and others thirty or forty; that they contract in their breadth, when they approach the sun's limb, without suffering any diminution of their length; and that they are seldom seen at a greater distance than thirty degrees from the sun's equator. Galileo likewise perceived on the disc of the sun faculæ or luculi, which are spots brighter than the rest of his disc, and which move in the same manner as the dark spots.

The spots of the sun have been distinctly observed since the time of Galileo, and many new and curious facts have been brought to light respecting these interesting phenomena. The spots are very various, both in magnitude and shape. Most of them have a very dark nucleus, surrounded by an umbra or a fainter shade. The boundary between the umbra and the nucleus is distinct and well defined, and the part of the umbra nearest the dark nucleus is generally brighter than the more distant portion. However irregular be the outline of the dark nucleus, the outer circumference of the umbra is always curvilineal, without any angles or sharp projections. When any spot begins to increase or diminish, the nucleus and umbra expand and contract at the same time. During the process of diminution, the umbra encroaches gradually upon the nucleus; so that the figure of the nucleus, and the boundary between it and the umbra, are in a state of perpetual change; and it often happens that, during these variations, the encroachment of the umbra divides the nucleus into two or more nuclei. When the spots disappear the umbra continues for a short time visible after the nucleus has vanished, and unless the umbra is succeeded by a facula, or luminous spot, the place where it disappears resembles the other portions of the solar surface. Large umbræ are seldom seen without a nucleus in their centre, but small umbræ frequently appear by themselves. When Dr. Long was examining the sun's image, received upon a sheet of white paper, he observed a large round spot divide itself into two spots, which receded from each other with immense rapidity. Dr. Wollaston perceived a phenomenon of a similar kind with a twelve inch reflector. A spot burst in pieces when he was observing it, like a piece of ice, which, thrown upon a frozen pond, breaks in pieces and slides in various directions.

Besides these changes in the spots, which are owing to some cause with which we are yet unacquainted, they undergo variations of an optical kind, from their change of position on the disc of the sun. The nature of this variation will be easily understood by placing a black spot upon a common globe, and observing the different shapes which it assumes while the globe is made to revolve about its axis. When the spot is near the middle of the sun's disc, its breadth is then greater, but it diminishes gradually as it advances towards the edge of his disc. This variation in the figure of the spots, and some of the other variations already mentioned, are represented in the annexed plate, where are given the appearances of a spot on seven successive days, as observed by Helvelius. Hence it is obvious that these spots are upon the surface of the sun, and that their motion across his disc from east to west is produced by the revolution of the sun about his axis. The time in which any spot returns to its former position upon the sun's disc is about twenty-seven days seven hours and thirty-seven minutes: but as the earth has, during this time, advanced in its orbit from east to west, and in some measure followed the motion of the spot, the real time in which the spots perform their revolution will be found to be twenty-five days and ten hours. This will be understood by supposing that a spot has just vanished behind the western limb of the sun: in the course of twenty-seven days seven hours and thirty-seven minutes it again vanishes behind the same limb; but during this interval of time the earth has advanced in its orbit, and in the same direction with the spot: and therefore, when the spot reaches the sun's western limb, after one complete revolution, the western limb of the sun, behind which it vanishes, has shifted in absolute space to the westward, so that the spot has performed a complete revolution and part of a revolution around the centre of the sun. We have therefore 365d. 5h. 48′ + 27d. 7h. 37′, or 392d. 13h. 25′ is to 365d. 5h. 48′ as 27d. 7h. 37′, the apparent revolution of the spots, is to 25d. 9h. 56′, the real revolution of the spot, or the time in which the sun performs its rotation about its axis. The axis of the sun, around which this revolution is performed, is inclined 7° 20′ to the ecliptic, and the node of the solar equator is in the 18th degree of the *Twins*. The solar spots are never seen towards the poles of that luminary. They are generally confined within a zone stretching about 30° 5′ on both sides of his equator, though sometimes they have been seen in the latitude of 39° 5′.



Silberschlay, of Magdeburgh, made several observations on the solar spots in the year 1768, from which he draws the strange conclusions, that they have a motion of rotation, and that they change their place on the surface of the sun, independent of his monthly revolution. He also concluded that the spots had not merely the dimensions of length and breadth, but that they consisted of thick masses of opaque matter.

Galileo, Hevelius and Maupertuis seem to have considered the spots as scoria (dross) floating in the inflammable liquid matter of which they conceive the sun to be composed. This opinion, however, will appear highly improbable, when we consider the regularity with which the spots frequently reappear on the eastern limb of the sun, and the effect that the centrifugal force of the sun would have in carrying all this floating dross to the equatorial regions.

De la Hire and La Lande considered the solar spots as arising from the opaque body of the sun, the eminences of which are sometimes uncovered, in consequence of the alternate flux and reflux of the liquid igneous matter in which that opaque mass is generally enveloped. The part of the opaque mass which thus rises above the general surface gives the appearance of the nucleus, while those parts of the opaque mass which lie only a little beneath the igneous matter produce the appearance of the surrounding umbra.

This theory was very ably opposed by Dr. Wilson, professor of practical astronomy in the university of Glasgow, who maintained, with great appearance of truth, that the solar spots are depressions rather than elevations, and that the black nucleus of every spot is the opaque body of the sun, seen through an opening in the luminous atmosphere with which he is encircled. This explanation was suggested to Wilson by the phenomena of the great solar spot which appeared in November 1769, and is founded on the following facts:—when any spot is about to disappear behind the sun's western limb, the eastern portion of the umbra first contracts in its breadth, and then vanishes. The nucleus then gradually contracts and vanishes, while the western portion of the umbra still remains visible. When a spot comes into view on the sun's eastern limb, the eastern portion of the umbra first becomes visible, then the dark nucleus, and then the western part of the umbra makes its appearance. When two spots are near each other, the umbra of the one spot is deficient on the side next the other; and when one of the spots is much larger than the other, the umbra of the largest will be completely wanting on the side next the smaller. If the large spot have little ones on each side of it, its umbra does not totally vanish, but seems flattened and pressed in towards the nucleus: but the umbra again expands from this compressed state as soon as the little spots disappear. From this cause Wilson concluded, that the western portion of the umbra may disappear before the nucleus, when a small spot happens to appear on the western side of the nucleus. All these appearances strongly confirmed the opinion of Wilson, that the black part of the spots is the dark body of the sun, seen through an opening in the luminous matter.

Dr. Wollaston and La Lande, however, maintained, that though the umbra generally varies according to the manner now described, yet the phenomenon is not universal, and cannot therefore be employed as the foundation of a system. La Lande mentions three observations of his own, and four observations by Cassini and De la Hire, in which the umbra did not vanish, as Dr. Wilson describes it. This anomaly, however, may have arisen from some small spots in the neighborhood of the large one, and cannot possibly be considered as an argument that the spots are not excavations in the sun's surface. At all events, it may be shown that in some spots the umbra may not change as it approaches the limb, in consequence of the shallowness and gradual shelving of the opening in the luminous atmosphere.

In order to confirm experimentally his theory of the solar spots, Dr. Wilson constructed a globe, consisting of two strong hollow hemispheres, formed by pasting slips of paper upon a wooden ball, and afterwards fastened together upon an iron axis. A thick paste, made of glue and Spanish white, was laid, in successive coats, upon this outward shell, till it became of considerable thickness. The globe was then made smooth and spherical; and as soon as it was dried, and the crust white, the spots or excavations were made in its surface, by boring instruments of steel, constructed, in all their cutting edges, from a scale of parts of the diameter of the ball. The bottom of the hollows were then painted black with India ink, and the slope, or shelving sides of the excavations, were distinguished from the brightness of the external surface by a shade of the pencil, which increased toward the external border. When this artificial sun was fixed in a suitable frame, and examined, at a great distance, with a telescope, the umbra and the nucleus exhibited the same phenomena which have been observed in the real sun.

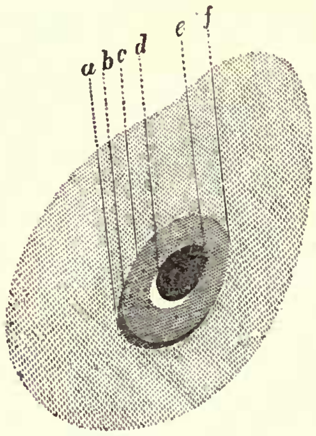
La Lande objected to Dr. Wilson's theory, that the great spots seen by De la Hire on the 3d of June 1703, and by Cassini in 1719, made an indentation or notch in the solar disc, which he conceived to be incompatible with the opinion that this spot was an excavation. Wilson, however, showed, that excavations may cause something like an indentation in the sun's limb; and maintained that the notches did not always accompany large spots; and that the infrequency of their occurrence, and the want of accurate observations, should preclude astronomers from bringing them forward in support of any class of opinions.

We conceive that the most irrefragable objection to the opinion that the spots are eminences which rise above the general level of the luminous matter, arises from the uniform diminution of the spots as they advance from the central part of the sun to his western limb. If these dark solar mountains are deserted by the luminous matter, why do they appear largest when they reach the centre of the sun's disc? Whenever the height of the mountains greatly exceeds the diameter of their base, instead of contracting in the dimension of breadth, they ought to increase as they approach the limb; and, at all events, should exhibit phenomena very different from what should take place upon the supposition that the spots are depressions in the luminous matter. It may be said, indeed, that the height of these eminences bears no proportion to the diameter of their base; but this is an assumption of which no theorist is entitled to avail himself.

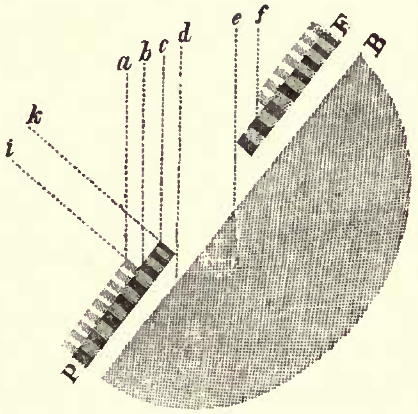
The faculæ, or parts of the surface of the sun which are brighter than the rest of his disc, require to be examined with good telescopes. They are generally seen in the places where spots have appeared: and sometimes the facula which envelopes an assemblage of spots is distinguished by a very great degree of brilliancy. These bright spots, according to Wollaston, are often converted into dark ones. He observed a bright spot appear on the east limb of the sun, which next day became a dark spot. He also observed a mottled appearance over the face of the sun, which, though most visible near the limb, was also perceptible in the centre, but never appeared towards the poles. The celebrated astronomer Messier made a number of curious observations upon the solar faculæ. He often saw them enter upon the disc of the sun, disappear as they approached the centre, and afterwards reappear on his other limb. In general they continued visible for about three days after they appeared, and were seen for the same space of time before they quitted the sun's western limb. In these faculæ, spots generally arise of a magnitude proportioned to the brightness of the faculæ. When this did not happen, Messier found that the faculæ were the precursors of spots, which ordinarily appeared near the same place on the following day; and hence he was always able to predict the appearance of spots about twenty-four hours before they entered the sun's disc, and to anticipate, from the situation and brightness of the faculæ, the brilliancy and position of the spots themselves. Schroeter saw these faculæ in every part of the sun's limb, but particularly in a zone between twenty degrees of north and twenty degrees of south latitude. They generally subtended an angle of about two or three minutes, and always appeared most brilliant when they were near the limb.

Such are the observations which were made on the solar spots before they were examined by the powerful telescope of Dr. Herschel. This astronomer continued his observations from 1779 to 1794, and has disclosed a number of curious phenomena, which throw much light upon the nature and construction of the sun. Before we direct the attention of the reader to the several conclusions which he has deduced, we shall give an account of the different phenomena which he observed on the surface of that luminary. It will be necessary, however, to premise, that he regarded the luminous surface of the sun as neither a liquid substance nor an elastic fluid, but as luminous clouds floating in the solar atmosphere; and that he considered the dark nucleus of the spots as the opaque body of the sun, appearing through the openings of his atmosphere. Rejecting the old terms of spots, nuclei, umbræ, faculæ, &c. Dr. Herschel framed a new nomenclature, and comprehended all the solar appearances under the names of openings, shallows, ridges, nodules, corrugations, indentations, and pores.

Openings are those appearances in which the opaque body of the sun is visible, in consequence of the removal of part of the luminous clouds. One of these openings, with a shallow about it, which was seen on the 4th of January 1801, a good way past the sun's centre, is represented in the plate.



On the western side of the shallow, its thickness was visible from its surface downwards; but on the eastern side its thickness could not be seen, the edge of the shallow only being visible. A section of this opening is shown in the figure, where the lines *a b c d e f*, corresponding with those in the last figure, are supposed to be drawn from the eye of the observer. The line *d* passes through the opening to the opaque body of the sun. It is obvious that the thickness of the shallow is visible only on one side, from the position of the observer's eye. Large openings are generally surrounded with shallows, though many openings, and particularly small ones, have no shallows. Openings have a tendency to run into each other, and new ones often break out near others. Ridges and nodules generally accompany openings. Dr. Herschel imagined that the openings are produced by an elastic gas, which issues through the incipient openings or pores, and, forcing its way through them, spreads itself on the luminous clouds. The direction of the gaseous stream is often oblique; so that the luminous clouds are drawn laterally, and form a larger shallow on one side. Openings sometimes have a difference of color. They divide when decayed, and sometimes they increase again, but in general, when they are divided, they diminish and disappear, leaving the surface more than usually disturbed. They are sometimes converted into large indentations, and not unfrequently into pores.



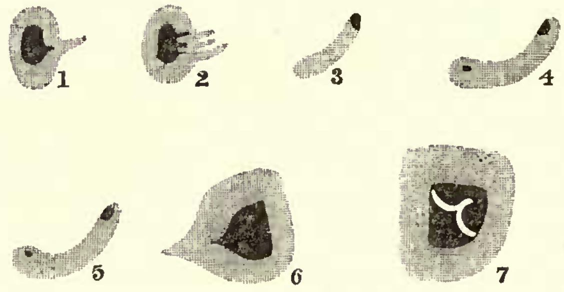
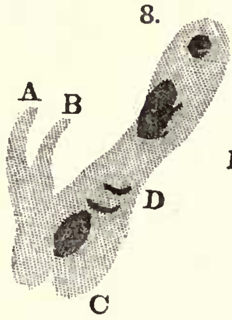


Fig. 1 represents an opening, with a branch from its shallow. In the course of an hour it assumed the appearance shown in fig. 2. Fig. 3 is another opening with a long shallow. In three hours it assumed the appearance of fig. 4; and an hour after this an opening appeared in the shallow, as in fig. 5. The openings are generally at their greatest extent, as in fig. 6, when the shallows begin to vanish and the lips or projections to disappear. The division of the decaying opening is shown in fig. 7, where the luminous passage across the opening resembles a bridge thrown over a hollow.

Shallows are places from which the luminous solar clouds of the upper regions are removed, and are therefore depressed below the general level of the surface of the sun. The thickness of the shallows is visible. They sometimes exist without openings. They generally begin from the openings, or branch out from the shallows already formed, and go forwards. Fig. 8 shows the two branches, A B, of a shallow proceeding from an opening, C. In the course of half an hour, the shallow B is nearly united to the narrow part of the shallow surrounding the opening D, while the shallow A seems to advance in a direction towards the opening E. In the space of another half hour, the shallow B (fig. 9) has completely run into the shallow about D, while the shallow A has increased in breadth towards F. The shallow became afterwards pointed, as in fig. 10, and in the course of an hour it became broad at the point, and a new branch broke out. From these changes Herschel concluded that the shallows are occasioned by something issuing from the openings, which drives away the luminous clouds from the parts where it finds the least resistance, or which dissolves these clouds as soon as it reaches them. The new branch afterwards began to increase, and another branch, marked H, fig. 9, began to break out from the shallow around E. These changes Dr. Herschel attributed to the gas or substance which at first forced open the passages and was then widening them. Three small branches, *a*, *b*, *c*, were seen to project from the shadow of the large opening in fig. 12. The vacancies between these branches were afterwards filled up by the same cause that occasioned them, so as to increase the breadth of the shallow on that side of the opening. The shallows have no corrugations, but are tufted, like masses of dense clouds. The decay of the shallows is supposed to arise from the encroachment of the luminous clouds, in consequence of the enfeebled energy of the gas or substance that produced them.

8.



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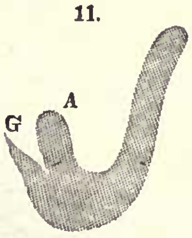

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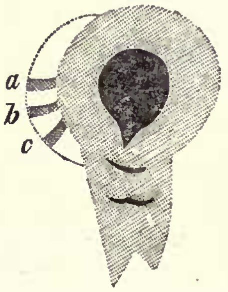

13.

Ridges are elevations of the luminous clouds above their general level, or above the general surface of the sun. These elevations generally surround openings, though they have sometimes been perceived where openings do not exist. Ridges soon disperse. One of them occupied a space which subtended an angle of 2′ 46″, corresponding to 75,000 English miles. Herschel ascribed the formation of the ridges to the disturbance of the luminous clouds, by the elastic gas which issues from the openings; or he conceived that this gas may act below the luminous clouds, so as to elevate them above their ordinary level.

Nodules, formerly called faculæ or luculi, are small, but brilliant and highly elevated parts of the luminous clouds. Dr. Herschel imagined that they may be ridges, seen obliquely or foreshortened.

Corrugations are elevations and depressions of the luminous matter, having a mottled appearance, and consisting of light and dark places. The dark places appear to be lower than the bright places; and, in a favorable atmosphere, the corrugations may be as distinctly perceived as the rough surface of the moon. They extend over every part of the sun's surface. Their shape and position is perpetually changing, and they increase, diminish, divide and vanish quickly.

Indentations are the dark parts of corrugations; and, from the circumstance of their being visible very near the limb of the sun, it would appear that they are not much depressed below the level of the luminous clouds. The sides of the indentation are like circular arches, (fig. 13,) with their bottoms occasionally flat. Indentations are of the same nature with shallows, varying in size, and sometimes containing small openings, and at other times changing into openings. They extend over the whole surface of the sun, and with small magnifying powers they have the appearance of points.

Pores are small holes or openings in the low places of indentations. Sometimes they increase and become openings, and frequently vanish in a short time.

We give below a telescopic view of the sun, exhibiting the daily appearance of several remarkable spots, that have appeared at various times on his surface, the appearance for a day being contained by two lines drawn at right angles, or nearly so, to the direction of the spots' motion, which is from right to left in the plate, or on the sun's disc from the eastern to the western edge.

From the interesting facts above given, Herschel deduced a theory of the solar phenomena, which, however ingenious it may be, is founded on assumptions too arbitrary and gratuitous to be recognised in a science which admits of no evidence but demonstration. To suppose that the numerous irregularities on the surface of the sun are occasioned by an elastic empyreal gas, which rises through the openings and disturbs the equilibrium of the luminous mass, is to show how these irregularities may be produced by the action of a hypothetical agent; but it never can be considered as an explanation of the process which nature is carrying on in that immense depository of fire. But though we cannot admit the hypothesis proposed by this learned and ingenious astronomer, we are disposed to acquiesce in some of the important conclusions which he drew from his observations. From the numerous elevations and depressions of the luminous matter, and from the length of time during which they are visible, Herschel justly inferred that the shining matter of the sun is not a fluid, but a mass of luminous or phosphoric clouds. He conceived, from the uniformity of color in the shallows, that below these self-luminous clouds there is another stratum of clouds of inferior brightness, which is intended as a curtain to protect the solid and opaque body of the sun from the intense brilliancy and heat of the luminous clouds. By means of his photometer, Dr. Herschel found that the light reflected by the inferior clouds is four hundred and sixty-nine out of one thousand; and that the light reflected by the opaque body of the sun is only seven. Hence it appears that the sun consists of a dark solid nucleus, surrounded by two strata of clouds. The outermost of these is the region of that light and heat which is diffused from the centre to the remotest parts of the system, while the interior stratum is supposed to protect the inhabitants of the sun from the fiery blaze of the stupendous furnace by which they are inclosed.*

That the sun may at the same time be the source of light and heat, and yet capable of supporting animal life, is one of those conclusions which we are apt to admit without hesitation, and to cherish with peculiar complacency. The mind is filled with admiration of the wisdom of God, and swells with the most sublime emotions, when it conceives that apparently the most inaccessible regions of creation are peopled with animated beings, and that while the sun is the fountain of the most destructive of the elements, it is at the same time the abode of life and felicity. In impressions of this kind, however, delightful though they be, we must not rashly indulge, lest we should afterwards find that we have been admiring an order of things which does not exist in nature, and have thus been indirectly reflecting on the infinite wisdom that sanctioned an opposite arrangement. Whenever we allow our feelings to interfere with our reasonings, we are apt to yield ourselves to the guidance of loose analogies and imperfect views, and become the defenders of opinions which every subsequent observation and discovery will only tend to overthrow. We conceive that the opinion of the sun's being a habitable globe rests on reasonings of this nature; and as the subject is curious and worth examination, we shall endeavor to place it in its proper light.

When the invention of the telescope enabled astronomers to detect the striking resemblances between the different planets of the system, it was natural to conclude that, as they were composed of similar materials, as they revolved around the same centre, and were enlightened by similar moons, they were all intended by their wise Creator to be the region in which he chose to dispense the blessings of existence and intelligence to various orders of animated beings. The human mind cheerfully embraced this sublime view of creation; and, guided by the principle that nothing was made in vain, man extended his views to the remotest corners of space, and perceived in every star that sparkles in the sky the centre of a new system of bodies, teeming with life and happiness, and displaying fresh instances of the power and beneficence of their Maker. Having thus traversed the illimitable regions of space, and considering every world which rolls in the immense void as the scene on which the Almighty has exhibited his perfections, the mind, unable to command a wider range, rests in satisfaction on the faithful analogies that it has pursued. While the planets were thus regarded as habitable worlds, astronomers considered the sun and the stars as the reservoirs from which light and heat were dispensed to man, and as the great central magnets that bound together, and guided in their course, the various planets which surround them. These offices were reckoned sufficient for

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* The opinions of Dr. Herschel respecting the nature of the sun were maintained some years earlier in England by Dr. Elliot, who was tried at the Old Bailey for the murder of Miss Boydell. The friends of the doctor maintained that he was insane, and called several witnesses to establish this point. Among them was Dr. Simmons, who declared that Dr. Elliot had for some months before shown a fondness for the most extravagant opinions; and that in particular he had sent to him a letter on the light of the celestial bodies, to be communicated to the Royal Society. This letter confirmed Dr. Simmons in the belief that this unhappy man was under the influence of mental derangement; and as a proof of the correctness of this opinion he directed the attention of the court to a passage of the letter in which Dr. Elliot states "that the light of the sun proceeds from a dense and universal aurora, which may afford ample light to the inhabitants of the surface (of the sun) beneath, and yet be at such a distance aloft as not to annoy them. No objection," says he, "ariseth to that great luminary being inhabited: vegetation may obtain there as well as with us. There may be water and dry land, hills and dales, rain and fair weather; and as the light, so the season must be eternal; consequently, it may easily be conceived to be by far the most blissful habitation of the whole system."

the great luminary; and astronomers were led, by no analogy and by no consideration of final causes, to view it as the seat of animal existence; they left it to the poets to people with a colony of salamanders these regions of eternal fire.

The solar observations of Dr. Wilson first suggested the opinion that the sun was an opaque and solid body, surrounded with a luminous atmosphere, and the telescopes of Dr. Herschel have tended still farther to establish this opinion. The latter of these astronomers, therefore, imagined that the functions of the sun, as the source of light and heat, might be performed by the agency of its external atmosphere; while the solid nucleus was reserved and fitted for the reception of inhabitants. This conjecture, however, is consonant with nothing which we find in nature. It is inconceivable, indeed, that luminous clouds, yielding to every impulse, and in a state of perpetual change, could be the depository of that devouring flame, and that insupportable blaze of light, which are emitted by the sun; and it is still more inconceivable that the feeble barrier of planetary clouds could shield the subjacent mass from the destructive elements that raged above.

If we inquire (says Dr. Young) into the intensity of the heat that must necessarily exist wherever this combustion is performed, we shall soon be convinced that no clouds, however dense, could impede its rapid transmission to the parts below. Besides, the diameter of the sun is one hundred and eleven times as great as that of the earth; and at its surface a heavy body would fall through no less than four hundred and fifty feet in a single second; so that, if every other circumstance permitted human beings to reside in it, their own weight would present an insuperable difficulty, since it would become thirty times as great as upon the surface of the earth, and a man of moderate size would weigh *above two tons.* Again, the quantity of heat that is transmitted to the habitable regions of the sun, for the purposes of vegetation, must necessarily accumulate, till it becomes insupportable, as there is no possibility of its escaping back to the luminous atmosphere.

The opacity of the interior globe of the sun is no reason why it may not act a part in the production or preservation of the solar heat. On the contrary, it appears highly probable and consistent with other discoveries, that the dark solid nucleus of the sun is the magazine from which its heat is discharged, while the luminous or phosphorescent mantle, which the heat freely pervades, is the region where its light is generated. Herschel's own experiments assure us, that invisible rays, which have the power of heating, and which are totally distinct from those that produce light, are actually emitted from the sun; and that luminous rays incapable of producing heat are discharged from the same source. These facts, therefore, not only confirm the theory which we have stated, but receive in return from that theory the most satisfactory explanation. The invisible rays which pervade every part of the solar spectrum formed by a prism, and which extend beyond its red extremity, are emitted from the *opaque* nucleus, and therefore excite no sensation of light on the human retina; while the colored rays, which form the spectrum itself, are discharged from the luminous matter that encircles the solid nucleus, and are therefore endowed with the property of illumination. Hence it is easy to assign the reason why the light and heat of the sun are apparently always in a state of combination, and why the one emanation cannot be obtained without the other. The heat projected from the dark body, and the light emitted from the luminous atmosphere, are thrown off in lines diverging in every possible direction; so that the two radiations must be uniformly intermingled, and, as in a stream flowing from two contiguous sources, the heat must always accompany its kindred element. That light and heat are two different substances, distinguished by different properties, is a proposition which seems to flow from the most recent experiments. We find the invisible heat of the sun existing separately from its light, and possessing a degree of refrangibility less than the least refrangible rays of the prismatic spectrum. Light has likewise been found separate from heat, and though it may be imagined that this arises from the extreme attenuation of the light, yet, when the light of the moon is concentrated by powerful burning mirrors, we ought certainly to have expected that the heat, if any did exist, would be appreciable by delicate thermometers. Every attempt, however, to detect heat in the rays of the moon has completely failed, and we are therefore entitled to presume that a greater proportion of heat than of light has been absorbed by that luminary. If light and heat, then, be two different substances, endowed with different chemical and physical properties, is it not unphilosophical to suppose that they are emitted from the same source, when we have actually two different regions in the sun, to which we can with more propriety refer their origin?

This opinion, which is proposed only as a conjecture, founded on the most probable analogies, will receive considerable confirmation if we can adduce any strong analogical arguments against the supposition that the sun is a habitable world; for if the nucleus is not fitted for the reception of living beings, it is the more probable that it acts a capital part in the production or preservation of the solar heat. Some arguments have already been suggested relative to this point. We shall endeavor to illustrate two other considerations, which, we trust, will have some weight in favor of this opinion. Since those who consider the sun as a habitable world found this opinion upon analogical arguments, we are entitled to avail ourselves of all the assistance which can be drawn from the same source. If the sun, then, be a great habitable planet, we may expect to find in it those points of resemblance to the other planets which are regarded as distinctive marks of a habitable world; and if we shall find that any analogy, which subsists with respect to all the other planets, fails when applied to the sun, we are entitled to consider this difference as a proof that the sun is not inhabited.

In proceeding from the remotest of the planets to the centre of the system, we find that a general law prevails respecting the densities of the planets. These densities appear to increase as the planet is nearer the sun. With the single exception in the case of the planet Herschel, whose density is not yet accurately ascertained, the densities uniformly increase according as the habitable world approaches to the centre of light and heat. We should therefore have expected, from analogy, that the habitable part of the sun would have exceeded Mercury in density, because it is nearer than that planet to the source of light and heat. This, however, is far from being the case; the density of the sun is only a little greater than the density of water. Here then we have a complete breach in the analogy which we anticipated; and it is no objection to this argument to say, that the situation of the sun, in the centre of the system, may exempt it from the general law of density; because this is a virtual admission that analogical reasoning, on which Herschel's opinion is founded, cannot be fairly applied in such a case.

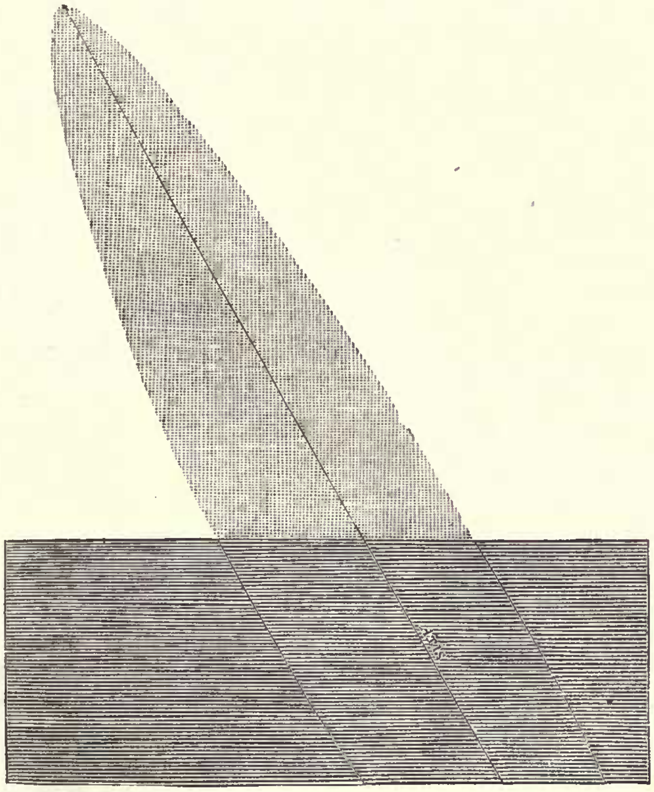
If the sun is a habitable globe, we can scarcely avoid drawing the conclusion, with Dr. Elliot, that "it must be by far the most blissful habitation in the whole system." We should expect, at least, that the solar inhabitants would be rational beings, endowed with intelligence equal to that of man, and availing themselves of their central position to study the interesting phenomena of the various planets which revolve around them, and of the numerous suns which their own globe would seem to resemble. If there is one place in the system more than another where astronomy could be studied with the greatest facility and carried to the highest perfection, that place would be in the sun, where, excepting the phenomena arising from its monthly rotation, the *real* and *apparent* motions of the heavenly bodies must be exactly the same. But these results of analogy are mere illusions of the mind. Nature has drawn an impenetrable curtain between the inhabitants of the sun and the worlds which circulate around them: she has doomed them to the most solitary dwelling in the whole circle of creation, and has marked them as either unfit or unworthy to enjoy the noblest privileges of intelligent beings. The planets and the stars are equally invisible from the surface of this luminary, unless when a transient glimpse of the heavens is obtained through an accidental opening in the solar atmosphere. From the year 1676 to the year 1684 there was not a single spot in the sun's atmosphere; so that during eight successive years the inhabitants of that globe, if they do exist, never once obtained a glimpse of that starry firmament, from the contemplation of which a Supreme Being could scarcely have excluded any of his rational creatures.

To maintain, therefore, that the sun is peopled by intelligent beings, is to reason in defiance of the strongest analogies, and support opinions which posterity will rank among the aberrations of the human mind. Might we not as well suppose that the central caverns of our own planet, which cosmogonists have filled with fire or with water, are the abode of a rational population, who, like the inhabitants of the sun, are occasionally permitted to obtain a transient view of the heavens through the craters of volcanoes, or the chinks and fissures which may accompany the convulsions of the globe?

Before concluding our remarks on the construction of the sun, we must take notice of another opinion of Herschel's respecting the solar spots, which has been less generally received than that which we have been combating. Imagining that the luminous atmosphere of the sun is the region of light and heat, he concluded that when the ridges, corrugations and openings in this atmosphere are numerous, the heat emitted by the sun must be proportionally increased, and that this augmentation must be perceptible by its effects upon vegetation. He expected, therefore, that in those years when the solar spots were most numerous vegetation would be most luxuriant, and that this effect might be ascertained from the price of wheat, as marking the productiveness of the season. By comparing the solar appearances as given by La Lande with the table of the price of wheat in Smith's Wealth of Nations, he obtained results which, on the whole, appear favorable to his hypothesis. We do not readily see upon what principle Herschel concluded that the existence of spots indicates an abundance of luminous matter. We should rather have been disposed to think that, in proportion to the number and magnitude of the openings, the light and heat of the sun would have been diminished, as so much of the sun's surface is then disqualified for the discharge of its usual functions. If there is really an increased luxuriance of vegetation in those years when the solar openings, &c. are most numerous, (an opinion which we are much disposed to call in question,) we conceive that the theory which we have already explained affords a very satisfactory explanation of the fact. The heat being supposed to be emitted from the dark body of the sun, it is obvious that when there is any opening in his luminous atmosphere, the heat emanating from the internal nucleus must be more copiously discharged, in consequence of receiving no obstruction from the luminous clouds; or if we regard the variations in the sun's surface as produced by variations in the heat which rises from the nucleus, we may naturally suppose that, when the heat of the sun is most intense, it will produce the greatest changes in the luminous atmosphere.

Herschel invented a very ingenious contrivance for moderating the heat and light of the sun, when it is examined by means of powerful telescopes. He abandoned the common method of using dark colored glasses, and had recourse to fluids. For this purpose, he employed a small square trough, having in two of its opposite sides well polished plates of glass. A small handle on one side of the trough, and a spout on the other, were made for the purpose of pouring out any portion of the liquid, when the rest was to be diluted. The trough was then placed in an excavation in the eye-piece of the telescope, so that the rays of the sun might pass through the fluid before they reached the eye of the observer. By coloring the fluid, the light may be softened at pleasure, and the heat is completely removed by the water. Herschel found that ink, diluted with water and filtered through paper, gave a distinct image of the sun, as white as snow. By this mixture he could observe the sun in the meridian without the smallest injury to his eye or to the glasses, even when he used a mirror nine inches in diameter, and when the eye-pieces were open, as in night observations.

As the phenomenon called the zodiacal light has been generally supposed to arise from the sun's atmosphere, we consider this as the proper place for giving an account of the appearance. Though this light seems to have been observed by Descartes and by Childrey about 1659, yet it did not attract general notice till the year 1693, when it was observed by Cassini, and received its present name. The zodiacal light, which is less bright than the milky-way, is seen at certain seasons of the year before the rising and after the setting of the sun. It resembles a triangular beam of light, rounded a little at the vertex. Its base is turned towards the sun, and its axis is inclined to the horizon, and lies in the direction of the zodiac. The vertical angle of this luminous cone is sometimes twenty-six degrees and sometimes ten degrees; its length, reckoning from the sun, which is its base, is sometimes forty-five degrees, and at other times one hundred and fifty degrees. Pingre saw one, in the torrid zone, which was one hundred and twenty degrees long, and whose horizontal breadth was from eight degrees to thirty degrees. The best time for seeing the zodiacal light is about the first of March, at seven o'clock in the evening, when the twilight is ending, and the equinoctial point in the horizon. The luminous triangle will then appear to be directed towards Aldebaran, as in the plate, its axis forming an angle of sixty-four degrees with the horizon: but if it is viewed in the morning, before sunrise, the angle which it makes with the horizon will be only twenty-six degrees. In the year 1781, Flauzeres observed it in the month of January. On the 21st of March, at half past seven o'clock, it ended beyond the Pleiades, and was sixty-one degrees long, ten and a half broad, and eight high. According to Foulquier, the zodiacal light is always seen at Guadaloupe, unless when the weather is bad. Humboldt observed the zodiacal light at Caraccas on the 18th of January, after seven P. M. The point of the pyramid was at the height of fifty-three degrees. The light totally disappeared at 9h. 35′ apparent time, about 3h. 50′ after sunset, without any diminution in the serenity of the sky. On the 15th of February it disappeared 2h. 50′ after sunset; and the altitude of the pyramid was fifty degrees on both those occasions; the intensity of the zodiacal light varied in a very sensible manner, at intervals of two or three minutes. These changes took place in the whole pyramid, especially towards the interior, far from the edges; sometimes the light was very faint, and sometimes it exceeded that of the milky-way in Sagittarius.



As this phenomenon uniformly accompanies the sun, it has been naturally ascribed to an atmosphere round this luminary, extending beyond the orbit of Mercury, and sometimes even beyond that of Venus. The zodiacal light is supposed to be a section of this atmosphere, which, being extremely flat at its poles, cannot be supposed to partake of the sun's monthly motion. La Place has shown that the sun's atmosphere cannot reach even the orbit of Mercury, and that it could not in any case display this particular form. Dr. Young remarks, that the only probable manner in which it can be supposed to retain its figure, is by means of a revolution much more rapid than the sun's rotation. Some philosophers have ascribed the phenomenon, without any reason, to the refraction of the earth's atmosphere.*

Besides the revolution of the sun round his axis in twenty-five days, and his irregular motion about the centre of gravity of the solar system, he appears to have a progressive motion in absolute space. As all the bodies of the system necessarily partake of this motion, it can only be perceptible from a change in the position of the fixed stars, to which the system is advancing or from which it recedes. This change of place, or proper motion in the fixed stars, as it has been called, was first observed by Halley, and afterwards by Le Monnier. Mager, however, advanced a step farther than these astronomers. He compared the places of about eighty stars, as determined by Roemer, with his own observations, and he found that the greater number of them had a proper motion. He was aware that this change of place might be explained by a progressive motion of the sun towards one quarter of the heavens: but as the result of his observations does not accord with this hypothesis, he remarks that many centuries must elapse before the true cause of this motion is explained. Dr. Wilson suggested, upon theoretical principles, the possibility of a solar motion, and La Lande deduced the same opinion from the rotary motion of the sun. But these conjectures have been almost completely confirmed by another species of argument.

If the sun has a motion in absolute space directed towards any quarter of the heavens, it is obvious that the stars in that quarter must appear to recede from each other, while those in the opposite region seem gradually approaching. The proper motion of the stars, therefore, in those opposite regions, as ascertained by a comparison of ancient with modern observations, ought to correspond with this hypothesis.

Herschel examined this subject, with his usual success, and he certainly discovered the direction in which our system is gradually advancing. He found that the apparent proper motion of about forty-four stars, out of fifty-six, are very nearly in the direction which should result from a motion of the sun towards the constellation Hercules.

By considering the motion of the satellites around their primary planets, and of the primary planets around the sun, Dr. Herschel supposed that the proper motion of the sun is not rectilineal, but that it is performed around some distant and unknown centre. Just, however, as the conception appears to be, we can scarely allow ourselves to think that there is an immense central body, of sufficient magnitude to carry around it all the systems with which astronomers have filled the regions of space: but we may suppose, with La Lande, that there is a kind of equilibrium among all the systems of the world, and that they all have a periodical circulation around their common centre of gravity.

We ought to add, that Herschel's theory, as far as regards the existence of a luminous atmosphere round the sun, appears to be confirmed by an experiment reported to the French Academy in 1824. Fourrier had proved, by certain experiments upon the *polarization* of luminous rays, that those which escaped from a metallic sphere heated to a red heat possessed this property; but those which proceeded from a gaseous sphere heated to a white heat were destitute of it. Arago tried the experiment with the solar light, and, finding that it did not possess the property of *polarization*, admitted, as a consequence of this result, that the medium, whence the solar ray proceeded, did not essentially differ from an elastic fluid, and that, consequently, there existed around the sun an incandescent atmosphere.

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* For a farther account of the zodiacal light, see chapter X.

CHAPTER IV.

SECTION I.

Horizontal moon—An illusion—Mode of estimating distances—Variation of the moon's distance from the earth—Motion from west to east—Amount of motion per day—Per minute—Moon's nodes—Syzygies—Lunar cycle—Golden number—The moon's periodic, synodic and sidereal revolution—Disturbance of the moon's orbit.

We may observe that in proportion as the moon rises above the horizon its apparent diameter changes. To our eyes it appears to be largest at the horizon, when, in fact, from its being more distant by the semidiameter of the earth, it ought on this account to appear actually smaller. This difference of distance in regard to the sun and stars is so small in comparison with their whole distance, that it may be left out in considering *their* diameters. But with the moon it is not so; and the apparent diameter at the zenith must be about sixteen seconds greater than at the horizon.

Yet, if we observe the moon with the naked eye, our observation would reverse this fact. Our sight contradicting the results of the micrometer, we judge the moon and sun larger at their rising. This is an illusion to be removed. The constellations, also, when near the horizon seem to occupy a greater extent in the heavens. We shall explain this singular error of our senses.

At the same time that experience teaches us how to use the image of an object on the retina of the eye in estimating the form of that object, it teaches us to form an estimate of its position in space, its size and distance; and if the distance is so great that the hand cannot reach, we approach the object until we can touch it, and then, removing from it, we judge of its distance by the extent of motion required in us to approach or recede from it. When, afterward, we wish to estimate the distance of any body situated so that we cannot approach to its touch, the distance of some object previously determined is taken as a scale of measurement. But in proportion as the distance increases, the circumstances under which we judge become less favorable, and beyond a certain limit objects are presented to us under appearances more or less deceitful, and we are led into optical errors.

In estimating the distance, then, of an object, we must take into consideration the angle under which we see it, the diminution of the tints caused by its distance, its real magnitude, the intermediate bodies, which serve as points of comparison,—circumstances that we may be skilled in estimating within certain limits, but which beyond those limits are constant causes of deception.

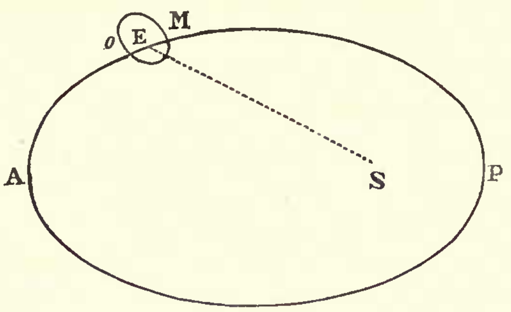
We cannot judge of the distance of a mountain or a ship, unless we have often passed over similar intervals; the want of intermediate objects deprives us of the means of comparison.

At the rising of the moon, terrestrial objects are the points of comparison, which fail us when she is in the zenith. The heavens seem to us more distant at the horizon than at the zenith, and thus present in appearance an elliptical arch. This is an involuntary effect of habit; we cannot resist it, any more than the broken appearance of a staff, plunged obliquely into water. We are carried away by the invincible power of our senses.

Now the optical angle remaining the same, if we judge the moon much more remote, it ought in the same proportion to appear larger to us. This deception is confirmed also by its diminution of light at the horizon. Its rays, traversing an extensive and misty portion of the atmosphere, present to us the appearance of light enfeebled by greater distance from us.

The moon is in reality a little more distant when in the horizon, and consequently its diameter is a little less. If our senses tell us otherwise, the error may be corrected by looking at that body through a tube or a smoked glass, so fixed as to conceal all other objects which might serve as terms of comparison.

From the apparent diameters of the moon we may deduce the variations of its *radius vector*, or of its distance from the earth, around which it revolves in an elliptical orbit from west to east. While the earth describes the ecliptic in a year in the direction P E A, around the sun S, the moon M describes an ellipse M O about the earth E, situated in one of its foci. This ellipse is movable, being carried with the earth around the sun every year; the moon in the mean time going through its ellipse thirteen and a half times. By measuring the greatest latitude of the moon, it has been found that its orbit is inclined 5° 9′ to the plane of the earth's orbit.



The appearances are to us the same as if, our globe being stationary, the moon described its orbit around us in about twenty-seven days, while the sun travels in an orbit four hundred times more remote, in about three hundred and sixty-five days, the earth seeming to be fixed in a focus common to the two ellipses, and turning on its axis in twenty-four hours. This rotation of the earth makes us attribute to the heavenly bodies a daily revolution from east to west. During this time, the moon moves on in its orbit, in reality from west to east, describing arcs of variable lengths, which, as seen from the earth and measured in the heavens, have a mean value of 13° 11′. The sun's *apparent* daily motion in the ecliptic is but one degree, or $\frac{1}{13}$ of the moon's mean daily motion in her ellipse. The variation of declination of these bodies is the cause of the changes in their rising, setting and meridian altitudes. The motion in their orbits toward the east is the cause of the daily retardation in the time of their transit over the meridian.

The velocity of the moon's motion is thirty-nine miles a minute, or $\frac{1}{29}$ of that of the earth in its orbit, that being $1133\frac{1}{3}$ miles a minute. But in estimating the rapidity of the moon, we ought to unite these two motions, since, as we have said before, the moon accompanies the earth around the sun. Thus the absolute rapidity of the moon's motion is from 1094 miles to 1172 miles a minute, according to its position.

The planes of the lunar and terrestrial ellipses cut each other in two points, called the nodes (crossings) of the moon's orbit.

The moon is sometimes on one side and sometimes the other side of the plane of the ecliptic. The point where the moon crosses this plane when approaching the north pole is called the *ascending node.* The point where it crosses the same plane when going south is called the *descending node.* The line joining these points is named the *line of the nodes.* These points vary their position at each revolution of the moon, *the line of the nodes being subject to a slow motion of revolution from east to west, or in a direction contrary to the order of the signs of the zodiac.* Every year the nodes describe about $19\frac{1}{3}$°, which gives one degree for every nineteen days, or 1° 28′ for a lunar month, or, finally, an entire revolution in eighteen and a half years.

Not only does the line of the nodes revolve in the plane of the ecliptic, but the lunar ellipse changes a little its inclination to this plane, librating slowly above and below a mean position. In the plane of this movable orbit, the line of the *syzygies* (i. e. the line joining the points nearest and farthest from the earth) revolves around our globe.

During nineteen years, there occur two hundred and thirty-five *lunations;* and after this space of time, new and full moons recur at the same date as before. The solar year is eight days more than twelve lunations, which form the *lunar year.* These eight days accumulating, there result, after nineteen years, seven lunations to be added to the two hundred and twenty-eight, which allow but twelve for a year. Out of these nineteen years, then, seven, which are called embolismic, (intercalary,) must have thirteen new moons, instead of twelve, and one of the months must have two new moons.

It follows, that if we have a series of lunar observations during nineteen years, the phases would return periodically at the same dates. Of this number (nineteen) consists the *cycle* of Meton, also called *the golden number*, because the Athenians, in their admiration of the properties of the *lunar cycle*, engraved the discovery of it in letters of gold. One year of this cycle will have a new moon on the first of January.

There may be constructed, then, by aid of attentive observations for nineteen years, tables of the lunar phases and motions, which will return periodically in the same order, and may be predicted by the use of these tables.

We have stated, that the moon moves round the earth from west to east. The sun *apparently* moves in the same direction, but is much longer in completing an entire revolution than the moon. It is evident, therefore, that if the sun and moon are at some one instant in the same direction with respect to the earth, the moon will continually outstrip him, until she returns to the same place at which we suppose her to have been when they were observed together. When she arrives there, the sun will be there no longer, but at some distance to the eastward of that position, and the moon will have to go on for some time longer before she overtakes him, and is again seen in the same direction with him. Her time of returning to this point in her orbit, from which we have supposed her to set out, or of making a complete revolution round the earth, is called her *periodic time;* her time of being again in the same direction with the sun is called her *synodic revolution*, or *period*, from a Greek word, meaning a *coming together*. The synodic period may be determined by observation ; and the best mode of doing so is by the observation of eclipses of the moon. The nature of these phenomena will be explained hereafter; they are easily observed, and the middle of the eclipse is very near the time at which the earth is directly between the sun and moon, and that exact time may be easily computed from the observations made of the eclipse. From one of these times, therefore, to another, or from the commencement or close of one eclipse to those of another happening under similar circumstances, (for then, in each case, the moon will be in the same position with respect to the earth,) is necessarily either one synodic period of the moon, or some exact number of synodic periods: and if the time at which each takes place be observed, the interval between them, divided by the number of synodic revolutions, will give the length of the synodic period. If the eclipses are taken at the same, or very nearly the same period of the year, the moon and sun will each of them be nearly in the same position with respect to the earth at each observation, or each will have revolved a certain number of times round the earth; and, consequently, as the principal inequalities of the motion of each are gone through in the space of one revolution, each will have gone through all the varieties of its motion a certain number of times, and may therefore be considered as having passed through the same space as if it had always moved with its mean motion. The synodic period therefore, thus deduced, will be the *mean* synodic period; except indeed that the motion of the moon's apogee, being considerable, must not be entirely left out of the account, as the rate of her motion in her orbit depends on her situation with relation to that point. To make the correctness of the result deduced complete, therefore, we should add the further condition that the apogee of the moon should be about the same place at each observation. It would not, however, be easy to find observations so fully corresponding to each other. If, however, we take observations very distant from each other in time, the apogee will have revolved a certain number of times, and in each of these revolutions the moon will have had all her varieties of motion; there will besides be one incomplete revolution of the apogee, and one only, occasioning some deviation from the mean value. Still the error thus produced will be divided among all the synodic periods included between the two observations, and will therefore produce very little effect on each; and on the same principle, if the time intervening be great enough, even the inequalities produced by observing at different seasons of the year may be neglected.

Now eclipses are phenomena so remarkable, that they have been very long observed; and the time of the occurrence of some has been recorded with sufficient accuracy even before the Christian era. By comparing these with recent observations, made at the same season of the year, the duration of the mean synodic period may be ascertained with very great accuracy; and it is thus found to be 29d. 12h. 44m. 2s. 8.

But 27d. 7h. 43m. 11s. 51 is the *sidereal revolution* of the moon,—her time of describing three hundred and sixty degrees, or of returning to the same position with respect to the stars. But while she performs her revolution, the equinox will have retrograded, and her return to the same position with respect to the equinox, or her *tropical period*, will be shorter. It is in fact but 27d. 7h. 43m. 2s. and $\frac{7}{10}$.

These results do not help to explain the most remarkable appearances of the moon, or those to which the attention of a common observer is first directed; and we therefore shall proceed in the next section to state the nature of those appearances, and to explain the cause from which they proceed. But we shall stop here to make a few general remarks, which, we hope, may not be uninteresting or out of place.

The best way to form a distinct conception of the moon's motion is to regard it as describing an ellipse about the earth in the focus, and, at the same time, to regard this ellipse itself to be in a twofold state of revolution: 1st, in its own plane, by a continual advance of its axis in that plane; and 2dly, by a continually *tilting* motion of the plane itself, exactly similar to, but much more rapid than, that of the earth's equator, produced by the conical motion of its axis.

The physical constitution of the moon is better known to us than that of any other heavenly body. By the aid of telescopes, we discern inequalities in its surface which can be no other than mountains and valleys—for this plain reason, that we see the shadows cast by the former in the exact proportion, as to length, which they ought to have, when we take into account the inclination of the sun's rays to that part of the moon's surface on which they stand. The convex outline of the limb turned towards the sun is always circular, and very nearly smooth; but the opposite border of the enlightened part, which (were the moon a perfect sphere) ought to be an exact and sharply defined ellipse, is always observed to be extremely ragged, and indented with deep recesses and prominent points. The mountains near this edge cast long black shadows, as they should evidently do, when we consider that the sun is in the act of rising or setting to the parts of the moon so circumstanced. But as the enlightened edge advances beyond them, i. e. as the sun to them gains altitude, their shadows shorten; and at the full moon, when all the light falls in our line of sight, no shadows are seen on any part of her surface. From micrometrical measures of the lengths of the shadows of many of the more conspicuous mountains, taken under the most favorable circumstances, the heights of many of them have been calculated. The existence of such mountains is corroborated by their appearance as small points or islands beyond the extreme edge of the enlightened part, which are their tops, catching the sunbeams of light before the intermediate plain, and which, as the light advances, at length connect themselves with it, and appear as prominences from the general edge.

The generality of the lunar mountains present a striking uniformity and singularity of aspect. They are wonderfully numerous, occupying by far the larger portion of the surface, and almost universally of an exactly circular or cup-shaped form, foreshortened, however, into ellipses towards the limb; but the larger have for the most part flat bottoms within, from which rises centrally a small, steep, conical hill. They offer, in short, in its highest perfection, the true *volcanic* character, as it may be seen in the crater of Vesuvius. And in some of the principal ones, decisive marks of volcanic stratification, arising from successive deposites of ejected matter, may be clearly traced with powerful telescopes. What is, moreover, extremely singular in the geology of the moon, is, that although nothing having the character of seas can be traced, (for the dusky spots which are commonly called seas, when closely examined, present appearances incompatible with the supposition of deep water,) yet there are large regions perfectly level, and apparently of a decided alluvial character.

It is in consequence of the *mutual* gravitation of all the several parts of matter, which the Newtonian law supposes, that the earth and moon, while in the act of revolving, monthly, in their mutual orbits about their common centre of gravity, yet continue to circulate, without parting company, in a greater annual orbit round the sun. We may conceive this motion by connecting two unequal balls by a stick, which, at their centre of gravity, is tied by a long string, and whirled round. Their joint *systems* will circulate as one body about the common centre to which the string is attached, while yet they may go on circulating round each other in subordinate gyrations, as if the stick were quite free from any such tie, and merely hurled through the air. If the earth alone, and not the moon, gravitated to the sun, it would be dragged away, and leave the moon behind, and *vice versa;* but, acting on both, they continue together under its attraction, just as the loose parts of the earth's surface continue to rest upon it. It is, then, in strictness, not the earth or the moon which describes an ellipse around the sun, but their common centre of gravity. The effect is to produce a small, but very perceptible, monthly *equation* in the sun's apparent motion as seen from the earth, which is always taken into account in calculating the sun's place.

And here, i. e. in the attraction of the sun, we have the key to all those differences from an exact elliptic movement of the moon in her monthly orbit, which we have already noticed, viz. to the retrograde revolution of her nodes; to the direct circulation of the axis of her ellipse; and to all her other deviations from the laws of elliptic motion. If the moon simply revolved about the earth under the influence of its gravity, none of these phenomena would take place. Its orbit would be a perfect ellipse, returning into itself, and always lying in one and the same plane: that it *is not so*, is a proof that some cause *disturbs* it, and interferes with the earth's attraction; and this cause is no other than the sun's attraction—or, rather, that part of it which is not *equally* exerted on the earth.

Suppose two stones, side by side, or otherwise situated with respect to each other, to be let fall together; then, as gravity accelerates them equally, they will retain their relative positions, and fall together, as if they formed one mass. But suppose gravity to be rather more intensely exerted on one than the other; then would that one be rather more accelerated in its fall, and would gradually leave the other; and thus a relative motion between them would arise from the difference of action, however slight.

The sun is about 400 times more remote than the moon; and, in consequence, while the moon describes her monthly orbit round the earth, her distance from the sun is alternately $\frac{1}{400}$th part greater and as much less than the earth's. Small as this is, it is yet sufficient to produce a perceptible excess of attractive tendency of the moon towards the sun, above that of the earth when in the nearer point of her orbit, M, and a corresponding defect on the opposite part, N; and, in the intermediate positions, not only will a difference of *forces* subsist, but a difference of *directions* also; since, however small the lunar orbit, M N, it is not a *point*, and, therefore, the lines drawn from the sun, S, to its several parts cannot be regarded as strictly parallel. If, as we have already seen, the force of the sun were equally exerted, and in parallel directions on both, no disturbance of their relative situations would take place; but from the non-verification of these conditions arises a *disturbing force*, oblique to the line joining the moon and earth, which in some situations acts to *accelerate*, in others to *retard*, her elliptic orbitual motion; in some to draw the earth from the moon, in others the moon from the earth. Again, the lunar orbit, though very nearly, is yet not quite coincident with the plane of the ecliptic; and hence the action of the sun, which is very nearly parallel to the last-mentioned plane, tends to draw her somewhat *out of the plane* of her orbit, producing the revolution of her nodes, and other phenomena less striking.

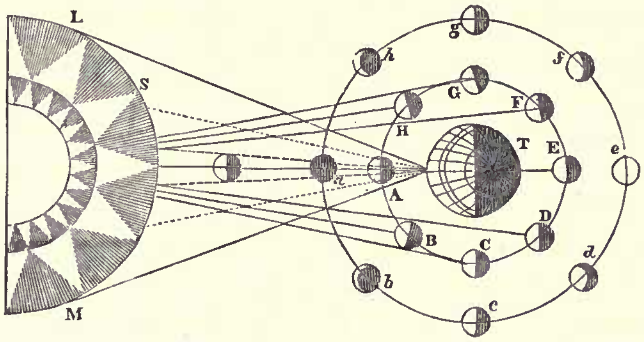
SECTION II.

Phases of the moon—Law of their variation—The new holding the old moon—Earthshine—Earth new when the moon is old, and *vice versa*—Proportion of moonlight at different seasons and places—Harvest-moon—Libration in latitude—In longitude—Diurnal—Lunar mountains—Atmosphere.

The period of time during which the appearances now in question succeed each other, is the synodic revolution of the moon, or, as it is commonly called, *a lunar month.* There is a certain period during which the moon is not at all visible; and in the course of which, as we know from observation and computation of her course, she has the same right ascension with the sun, or comes to the meridian at the same time with him. It is some time after this before she becomes visible, and when she does so, she is seen in the west soon after sunset, with the appearance of a very thin crescent, the bright and visible part having the side nearest to the sun convex towards him, and apparently semicircular; the inner part, or the part farther from the sun, being elliptical, and convex in the same direction with the outer. From this time, as the moon's motion eastward in the heavens is greater than the sun's, in the ratio of thirteen to one nearly, their distance from each other continually increases, as the moon comes to the meridian continually at a longer interval after the sun; and while she does so, the breadth of the crescent continually increases, the outward or western line continuing to be circular, but the inner ellipse continually becoming less strongly curved, until, when the moon is distant about ninety degrees from the sun, and comes upon the meridian about six hours after him, this inner curve is changed into a straight line, and the appearance is that known by the name of *half-moon.* After this time the line becomes again elliptical, but has its convexity towards the side most distant from the sun, or bulges out in that direction, and the two lines which appear to bound the moon become concave to each other. In this condition the moon is called *gibbous,* and the side of the moon most distant from the sun continually becomes more and more strongly curved, and the apparent breadth of the moon consequently greater, until, when the right ascension of the moon is one hundred and eighty degrees different from that of the sun, and she comes to the meridian twelve hours after him, or at midnight, this side of the moon, as well as the other, is a semicircle; and the moon appears completely round in the heavens, or, as we say, it is *full moon.* From this period, although the moon still comes upon the meridian longer and longer after the sun, she approaches him in distance, for no points upon the sphere can be distant from each other more than one hundred and eighty degrees; and when the difference of right ascension, in the direction in which it is measured, exceeds this quantity, the distance measured backward must fall short of it: thus, if the moon comes to the meridian fifteen hours after the sun, or the difference of their right ascension is two hundred and twenty-five degrees, the distance between them, measured in the opposite direction, is only nine hours, or one hundred and thirty-five degrees, or she comes on the meridian only nine hours before the succeeding noon. After the full moon, therefore, the distance begins to diminish, and as it diminishes it is found that the appearances visible during its increase succeed each other in the contrary order; that the moon becomes gibbous, and her apparent breadth continually diminishes, the side now next the sun continuing apparently circular, the other becoming elliptical, and continually less and less strongly curved, until, about the time when the distance between them is two hundred and seventy degrees in one direction, or ninety degrees in the other, the appearance of half-moon is again presented; and from that time forward the moon appears as a crescent, continually diminishing in breadth, until, at length, when she has arrived as near the sun as she was when she first became visible at the beginning of the month, she disappears, and is not again seen till the corresponding period of the next month, when the same order of appearances recommences. The appearances during the period of her diminution are exactly the same with those during the period of her increase, and correspond to exactly the same distances in each case. Thus, if the shape of the moon be observed when her angular distance from the sun is seventy degrees east, it is found that she has exactly the same shape when two hundred and ninety degrees east, or seventy degrees west of him: the only difference is, that the circular part, or *limb*, of the moon, which was turned in the former case towards the west, is turned in the latter towards the east.

It is obvious, therefore, that these appearances, or *phases*, as they are called, of the moon, depend upon her angular distance from the sun, for they continually vary with the variation of that quantity; the visible magnitude of the moon increasing when that quantity increases, and diminishing when it diminishes; and, when that quantity is equal at different periods, these visible magnitudes being equal also. Nor is it difficult to perceive that the appearances presented correspond to those which would obtain, if the moon were an opaque body, giving forth no light of its own, but capable of reflecting the light received from the sun.

It is evident that the moon is not luminous of herself, for if she were she would always be visible when above the horizon, whatever were her position with respect to the sun. Considering her, therefore, as opaque, but capable of reflecting light, it is plain that one portion of the moon would always be light, namely, the whole portion which is turned towards the sun, and the rest would be dark. We should consequently see only that portion which the sun illuminated, and only so much of that portion as was on the side of the moon turned towards us. When therefore the moon was between us and the sun, she would be invisible, because the whole of her enlightened side would be turned from us; gradually, as she receded from this position, some part of her enlightened side would be within the view of an observer at the earth, and this part would continually increase as she got farther from the sun, until, at length, when she was upon the opposite side of the earth, or the earth was between her and the sun, the same portion of the moon would be turned towards the sun and earth, or the whole of the enlightened portion would be visible to us. From this time she would again approach the sun, and some part of the enlightened portion would continually disappear; and as the quantity visible would depend merely on the relative positions of the sun, moon, and earth, the decrease would follow the same law as the increase, although in a reversed order, for the relative positions would succeed each other in this manner. These conclusions may be illustrated by a figure.

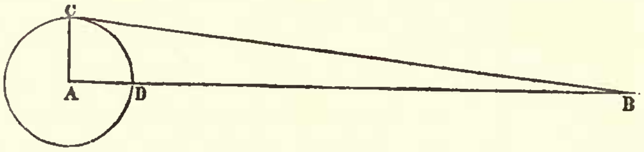


Let T represent the earth, S the sun, (of which, however, the distance must be taken to be very great, although it is not represented so for the convenience of the figure,) and A, B, C, D, E, &c., different positions of the moon (which we will suppose spherical) in her orbit. The enlightened portions of those circles will represent the enlightened part of the moon in each case; and, as the part of the moon turned towards the earth will be that, or very nearly that, within the circle passing through A, B, C, &c., the part visible in each case will be only so much of the enlightened part as is within that circle. The figures in the outer circle, *a*, *b*, *c*, &c., will represent the appearances, or phases, of the moon in the corresponding situations, the light parts only being visible. Thus, at A, the whole of the enlightened part of the moon is turned from the earth, and none of it, in consequence, is visible; at B and H, a small part only, and that equal in both instances, is visible, namely, the light parts within the circle; and the appearances presented are represented by *b* and *h*, two similar figures, but with the convexity of the light part turned, in each case, towards S, and consequently in different directions with respect to T. To explain fully the correctness of the representation, the figures *b*, *c*, &c., should be considered as if they were perpendicular to the plane of the paper. The circle drawn through A, B, &c., will very nearly represent the line bounding the part of the moon visible from the earth; and this will be a circle described on the sphere very nearly perpendicular to the plane of the moon's orbit, and to the line joining the earth and moon, or the moon's radius vector; it will therefore be seen as a circle perpendicular to that same plane, or as the outer line of the light part of *b*. The dark line also, the boundary of the enlightened part of the moon visible from the earth, will also be a circle of the sphere, but this will be seen obliquely from the earth, and will therefore assume an oval appearance; it therefore will be represented by the inner boundary of the light part of *b*. These lines will evidently meet in a point, as they do in the figure, because the corresponding circles in B do actually meet so, and the visible light part of the moon itself consequently terminates in one.

The reader will have no difficulty in ascertaining, in the same manner, the correctness of the other delineations. We conclude therefore that the moon shines by light reflected from the sun; and we shall find a still farther proof of it when we treat of eclipses, for we shall see that even when she is opposite to the sun, at the time of the full moon, if the earth is directly between her and the sun, so as to intercept his light entirely, she then also becomes invisible.

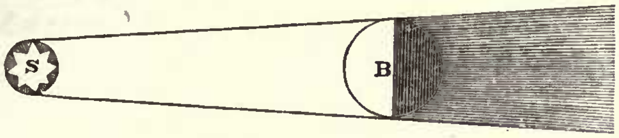
The law which determines the proportion of the surface of a spherical heavenly body, (depending for its light on the reflection of light from the sun,) visible at different times, according to its different situations with respect to the sun, may be investigated without any difficulty by a reader very slightly acquainted with mathematics; and it is of the more importance to do so, because we shall not only find that it accounts for the various phases of the moon, but that it serves to explain the appearances of other heavenly bodies. We proceed, therefore, to investigate it. We confine ourselves to the case of a spherical heavenly body, because all those to which we shall have to apply our results are very nearly of that form.

If the moon, or any other body which receives the sun's rays, be spherical, the boundary of the part on which they fall, or of the enlightened part, will necessarily be circular. This follows immediately from a very simple consideration. Let A represent the centre of any opaque sphere whatsoever, and B a luminous object shining upon it; and let the line A B be drawn joining A and B, and passing through the sphere at D; and let B C be a tangent to the sphere. It is evident that C will be a point in the boundary of the illuminated part of the sphere, for no point farther from B than C is, can receive a ray of light from B, as some part of the opaque sphere will be between them; and every point between C and D must receive such rays, for there is nothing to interpose and prevent them from arriving there.



Now, all tangents drawn to a sphere from the same point are equal to each other. At every point therefore in the boundary of the illuminated part the value of C B is the same; A C, the radius of the spherical body, is equal at all points, and A B is always the same line; the value of the angle D A C is the same in the case of every point in this boundary. Every point then in this boundary is at the same angular distance from the point B, or from D, and therefore in the circumference of a circle whose pole is D, and consequently whose plane is perpendicular to the line A B.

The result will require to be a little modified, as light actually proceeds from every part of a very large body, namely, the sun. If the sun were of the same size as the moon, the extreme rays would be parallel; if smaller, they would continually diverge from each other; if larger, they would converge to a point. These results are obvious in themselves; or they will immediately appear by the inspection of the plate, where, if S represents the sun, and A, B, C, three bodies, the first equal to the sun in size, the second larger, the third smaller, the extremities of the shaded figures beyond them will evidently represent the course of the extreme rays, and the figures themselves the shadows cast by the bodies, which, in the two former cases, would be prolonged to an *infinite* distance; in the latter, they would terminate as in the figure. The third case represents that of the moon, which is smaller than the sun; the boundary of the illuminated part therefore will be determined by rays, not diverging from the illuminating body S, but converging to a point on the other side of the moon. But still, as they all met in a point, the boundary of the illuminated part will be a circle, in the same manner as before; and as the difference of the diameters of the sun and moon is small in comparison with their distance, the rays will converge very slowly, and the extremity of the shadow, the point to which the extreme rays converge, will be very distant from the moon; and the boundary therefore, in this case also, will differ very little from a great circle. The whole part illuminated therefore rather exceeds half the sphere, but by so small a quantity, that we may say generally that half of any spherical heavenly body is illuminated by the sun, and that the boundary of the illuminated part is a great circle of the sphere, whose plane is perpendicular to the line joining the centre of the body with the centre of the sun.



Again, (in the last figure but one,) if we suppose B, instead of being the position of the luminous body, to be the position of an observer looking at the spherical body A, he will evidently see all between D and C, and nothing beyond C. C then will represent a point in the boundary of the part of the sphere visible to the observer, and, by the same reasoning as before, this boundary must be circular, and its plane perpendicular to A B; and it may be considered as a great circle of the sphere.

The boundary of the part turned toward the earth, and that of the enlightened part of the moon, are each of them great circles, and therefore bisect each other; or, the visible boundary is a complete semicircle. Whenever, therefore, the moon is visible, her *cusps*, or extreme points, are at the extremities of the diameter, and during all her phases (however small be the part of her surface visible to us) we may make observations of her apparent diameter for ascertaining her distance and the form of her orbit.

When the *moon is in conjunction with the sun*, i. e. between the sun and earth, the line joining the earth and moon is in the same direction as that joining the moon and sun. When *the moon is in opposition*, i. e. has the earth between her and the sun, the line joining the earth and moon is in the opposite direction from that joining the earth and sun, or they are the same lines prolonged, thus making an angle of one hundred and eighty degrees with each other. The whole face of the moon is therefore visible. When *the moon is in quadrature*, these lines make a right angle, and only one half of the moon's illuminated face is visible to the inhabitants of the earth.

It is perhaps necessary to observe, that, when we speak of the moon as reflecting light from the sun, we do not mean that she reflects it so as to present an image of the sun on one point of her surface, like a mirror; but that the light gets broken and diffused from part to part of her surface, and finally sent forward to us in such a manner as to render the whole surface of the enlightened part visible; just as light is diffused over bodies on the earth, which, if perfectly smooth would only form an image of the sun, but do actually show by reflected and broken light, the whole of their own surface, its form and color.

It is evident, from the law of variation which we have deduced, that almost immediately after the moon and sun cease to be in the same line, there is some portion of the illuminated part of the moon turned towards the earth. Yet it is some time before its magnitude becomes considerable. During this period also the moon is apparently near the sun, and consequently in a very light part of the heavens; and it is therefore a good while before she really becomes visible, for she cannot be seen till the light which she reflects is sufficient to be distinguished from that which the sun spreads generally over the region of the atmosphere through which the rays that proceed from her must pass. The length of time, therefore, during which she is not actually seen, furnishes no exception to the correctness of our results.

There is a remarkable appearance presented by the moon when the visible part, according to the principles we have established, would be small, which this is the proper season for explaining. At these periods the whole of the moon's disc is frequently seen, part bright, and having its magnitude the same with that which we have explained as the whole visible magnitude of the moon; the rest visible by a pale and delicate light, and appearing, from the ordinary effect of brightness in augmenting the apparent magnitude of objects, somewhat smaller in its dimensions than the brighter part. The appearance thus described, from its being much more frequently observed in the evening, soon after the moon's first appearance, or after *the new moon*, when more persons have the opportunity of seeing it than in the early morning, preceding the disappearance of the moon at the latter end of the month, has received, in common speech, the odd name of "*the old moon in the new moon's arms.*" The French, with more accuracy of expression, have named it, from the pale color of the greater part of the moon, *lumière cendrée*, or *ashy light*. The cause of this light is obvious: the earth, as well as the moon, reflects light, and, consequently, the enlightened part of the earth, or so much of it as is turned towards the moon, will reflect light to that body. Some of that light will again be reflected back to the earth; and thus even that part of the moon which receives no light directly from the sun, may, by indirectly receiving it from the earth, become, as we see it, faintly visible. The appearance, thus occasioned, has received the name of *earthshine*. The light indirectly supplied must necessarily be far inferior in quantity and brightness to that which the directly enlightened part of the moon receives immediately from the sun; and thus the great inequality of brightness in the two visible portions is accounted for. The only apparent difficulty arises from the circumstance that the appearance in question is only seen when the directly illuminated part is small. In reality, however, this seeming difficulty confirms the explanation given, for there are two obvious reasons for it. As the directly-illuminated part increases, its light becomes greater, and the light diffused over that part of the atmosphere through which the moon shines greater also: a stronger light therefore is required to be distinguishable. But this is not all; the light actually supplied to the moon from the earth diminishes. The earth being a spherical body, and reflecting light, appearances or phases will be presented by the earth to the moon similar to those which we, on the earth, observe in the moon; and all our results will be true for this case, as well as for that already examined. The order indeed will be different. Thus, when the moon is invisible to us, being between the earth and sun, the earth will turn the same part to the sun and moon, and will be visible to the moon with a full face; when we see the full moon, the earth is between the moon and sun, and therefore invisible to the moon. The part of the earth visible from the moon diminishes as the visible part of the moon increases, and of course the quantity of light which the earth reflects to the moon diminishes also. The power therefore of distinguishing the moon by this light reflected from the earth, is diminished as the part visible by light directly reflected from the sun is increased; both because less light is thus transmitted to the moon, and because more is required before it can be distinguished.

We have thus explained the manner in which the proportion of the moon which is visible at different periods of the month varies. This proportion, however, is not the only thing which we can observe with respect to her. Many singular marks and spots are apparent upon her, from which various and important conclusions may be drawn. But before we proceed to state these observations, and draw from them the inferences to which they lead, it will be worth while to pause, and deduce from the results already obtained some remarkable consequences, which materially tend to the convenience of mankind.

The most obvious practical service of the moon, as far as mankind are concerned, is the supply of light which she affords, during the otherwise dark hours, while the sun is below the horizon. But she herself is sometimes above, sometimes below, the horizon; and as her declination is continually varying, her periods of continuance above the horizon continually vary also. Her light also is different at different periods of her course,—sometimes none, sometimes little, and therefore of little practical utility; generally however enough to be of material service to the sailor, the traveller, and even to the husbandman; and this most when her light is the brightest, or at the full moon. It therefore matters little to man whether she is above or below the horizon at night, as long as her own light is little or nothing; but it is of much importance that she should be above the horizon at night, when her light is considerable. Now this, by the conditions of her motion, she necessarily is. The quantity of light which she reflects is greatest when her distance from the sun is greatest, or when the difference of their right ascensions is one hundred and eighty degrees, or the time between their appearances on the meridian is twelve hours. When the moon's light is greatest, therefore, she is on the meridian at midnight; and as her light is always greater as her distance from the sun, and consequently as the interval of time between their appearance on the meridian, is greater, the periods of her greater light will always bring her on the meridian nearer midnight than those of her less brilliancy; and, therefore, taking the whole course of one of her revolutions, she will be above the horizon during a larger proportion of the night, as her light, and consequently her power of being useful, are greater. The nights, however, are of different lengths at different periods of the year; and, consequently, if the moon, when at her greatest brightness, were always at the same declination, and thus had the same proportion of her diurnal course above the horizon in all these cases, she would supply light through a much smaller proportion of the long and dark nights of winter, than of the short and comparatively light nights of summer. But this is not the case. For the purpose of illustration, we will suppose the moon to move in the plane of the ecliptic, and, as usual, that the north pole is above the horizon. The full moon takes place when the difference of longitude of the sun and moon is one hundred and eighty degrees. Taking, then, the extreme cases of the two solstices, it is evident that when the sun is at the summer solstice, or in the tropic of Cancer, the full moon, being one hundred and eighty degrees distant, would be in the tropic of Capricorn; the sun therefore being at his greatest north declination, the moon would be at her greatest south declination: and throughout all that half of her orbit which is most distant from the sun, and where consequently her light is greatest, and more than half her face visible, her declination would be south. In this case, then, when the sun having his greatest north declination the day is longest, the moon would have her greatest south declination, and be least time above the horizon, when at the full: and during the whole time that more than half her face is visible, her declination would be south, and less than half of her diurnal course would be above the horizon. Exactly the contrary results would evidently follow when the sun is in the tropic of Capricorn, when he has his greatest south declination, or the days are shortest. In this case, the moon would be at the full when in the tropic of Cancer, or at her greatest north declination; and throughout all that half of her orbit most remote from the sun, and when more than half her face is visible, her declination would be north; and consequently, during this whole period, she would be more than half her time above the horizon, and longest of all when her light is the greatest. In intermediate positions of the sun, the results would be intermediate; but it is not necessary to enter into any detail of them. The reader will have no difficulty in pursuing, if he is inclined, a similar course of argument with respect to them.

Again, the greater the elevation of the pole above the horizon, the greater is the inequality of day and night, and the longer does a body with north declination continue above, or a body with south declination continue below, the horizon. The more elevated the pole, therefore, the longer is the moon above the horizon when her declination is north; and as, during the winter, her declination is north while her light is greatest, the proportion of time during which she continues above the horizon while her light is greatest increases, at that season, as the latitude increases, or as the nights themselves are longer. Taking the extreme case, where the pole is in the zenith, the moon will never set while her declination is north; and at the winter solstice it will be so during the whole time that more than half her face is visible. There will, therefore, be a fortnight of the brightest moonlight at that season when the night, from the complete absence of twilight, would otherwise be darkest. There will always be a fortnight at a time there, during which the moon will be above the horizon; but as the sun approaches the equinox, the light given by the moon during part of this fortnight will diminish. At this time, however, it may better be spared, for by this time, though the sun does not appear on the horizon, there will be a considerable twilight.

It is abundantly plain that the same consequences will follow from south declination where the south pole is above the horizon, as we have seen to follow from north declination where the north pole is so; and thus that this beneficent provision, by which the greatest quantity of moonlight is afforded to those regions, and at those seasons, in which it is most wanted, is general over the whole earth.

The moon however moves not in the plane of the ecliptic, but in one inclined to it at an angle of a little more than five degrees; but this difference will not materially affect the results we have obtained. It will, indeed, at different times, according to the place of the nodes of the moon's orbit, very materially affect the actual length of time during which she is above the horizon; but she never can be distant much more than five degrees from the ecliptic, and so much only during a very small portion of her course. The ecliptic itself is, at its greatest distance, more than twenty-three degrees from the equator. The distance of the moon from the ecliptic, therefore, being so much smaller, cannot, except for a very small space comparatively, vary the nature of our results, (though it will their amount,) or make that declination north which would otherwise be south, or the contrary. It cannot even materially alter the point at which the declination would be greatest, though it may make that greatest declination differ, in different cases, by upwards of ten degrees. Thus, if we suppose the nodes of the moon's orbit to coincide with the equinoxes, the moon, when ninety degrees from the node, will be about five degrees north or south of the ecliptic at the tropic of Cancer, as the part of her orbit between the vernal and autumnal equinox is that which lies above or below the plane of the sun's orbit. Her declination at this point, therefore, in the one case will be about 28° 30′ north, in the other only 18° 30′ north; but in each case it will be the greatest north declination which, during that revolution, she attains. When, however, the node is not at the equinox and solstice, this will not necessarily be the case; but it can never differ much from it. We may therefore conclude our results to be generally true; and we thus see that the shape and motions of the moon, and the manner in which she reflects light to the earth, are so ordained as to make her most serviceable whenever and wherever her services are most wanted,—an incidental consequence, indeed, of the general laws governing her motion, but one of the many remarkable instances in which, throughout the appearances of nature, we see, not only that the general scope and tendency of her operations are beneficial, but that collateral benefits continually flow from the manner in which those operations are conducted.

Another application of the same principles of reasoning, and, although in an inferior degree, a similar instance of a beneficial result arising incidentally from the operation of the general laws established in nature, will be found in the explanation of the phenomenon known by the name of the *harvest moon.* Whether we consider the moon as moving in the plane of the ecliptic, or in that of its real orbit, the variation of its declination will be most rapid where its orbit cuts the equator; and as no part of the real orbit is much more than five degrees distant from the ecliptic, its intersection with the equator cannot be far distant from the intersection of the ecliptic with the equator. The moon therefore moves most rapidly northward when near the equator, and also near the first point of Aries; most rapidly southward when near the equator and the first point of Libra.

When the sun is near one equinoctial point, the moon, when full, is near the other, and necessarily near the equator also. The difference of their right ascension, estimated in time, is twelve hours, and this is also the length of the day at that period. The moon therefore will rise in the east, just as the sun sets in the west. As the moon completes her revolution round the earth in a little less than twenty-eight days, her motion, if uniform, would be at the rate of about thirteen degrees a day; or, omitting any consideration of the manner in which the obliquity of her orbit would affect the results, she would come to the meridian of the place about fifty-two minutes later on each successive day. If, therefore, her declination continued the same, as she would always be an equal time above the horizon, she would rise and set about fifty-two minutes later every day; but when she is near the first point of Aries, her declination, and consequently the period during which she is above the horizon, rapidly increases; and consequently she is longer above the horizon before reaching the meridian, and the time of her rising is not retarded nearly to this average amount of fifty-two minutes. The time by which her setting is retarded is increased by as great a quantity as that by which the retardation of her rising is diminished. The degree of effect thus produced, differs in different regions of the earth: here it is such that for two or three days the moon's rising is nearly as much accelerated by her motion northward, as it is retarded by the continually later period at which she comes to the meridian: the consequence, therefore, is, that she appears during this time to rise at very nearly the same hour, that is to say, almost at the instant of sunset. Bright moonlight, therefore, (when the moon is full near Aries, or the sun is near Libra,) for two or three days immediately succeeds the disappearance of the sun; and as, by the general course of the seasons, this period is about the beginning of autumn, or the close of harvest-time, when the opportunity thus afforded of carrying on the works of husbandry after sunset is often very valuable, we speak, in common language, of the *harvest moon,* when we speak of her as rising at that season successively for two or three nights nearly at the same time.

About the vernal equinox, exactly a reverse operation must take place. The moon when full is then near the equator, but moving southward, and her change of declination from day to day is the greatest. Her appearance on the meridian still continues to be later from day to day; but as her periods of being above the horizon diminish, her rising and setting will each be brought nearer to the time of her being on the meridian, and her rising is therefore additionally retarded, but the time of her setting is accelerated. Instead, therefore, of setting every day considerably later, her settings at this period are nearly at the same time for two or three days near the full moon; and for the same reason as before, her setting must, at the full moon, be just when the sun rises. For two or three days, therefore, at this period, the moon sets just about sunrise. The result is of no practical importance here; but it furnishes another instance of the application of the same principle, and is therefore inserted to familiarize the reader with it. Besides, although unimportant in this hemisphere, the inhabitants of the southern half of the world, who have their autumn at the time of our spring, are thus furnished, in their turn, with the advantage of a harvest moon. Of course, in every revolution of the moon there are periods when her rising and setting are thus affected, for they must be so whenever her orbit crosses the equator; but they excite little observation in other instances, not being then connected with the close or the beginning of day.

Every one is aware that the moon does not present (as the sun does, at least to the naked eye,) a uniform face of uninterrupted light, but that she appears checkered and diversified with darkish spots and lines: indeed, these have been so constantly the subject of observation, that, in most countries, fanciful resemblances have been imagined for them; and we still hear of the man in the moon, his bush, and his dog. The probable cause of these appearances will be matter of consideration hereafter; but independently of any such speculations, they at once furnish us with the means of ascertaining a curious and important fact with respect to the motions of the moon.

As we have the means of making these observations upon the surface of the moon, we can tell by them what part of her surface is turned towards us. If these appearances are from time to time different, it would be natural to conclude that different parts of the moon are at different periods presented to us: if they are always the same, the same part of the moon is always turned towards us, unless, indeed, all her parts are marked so exactly alike that the one would be indistinguishable from the other. This, however, is not the case; for we see, at the period of full moon, half, or very near half, the surface of the moon, and the marks and spots with which it is diversified; and these, when examined through a telescope, are so different in their character, that any alteration in their positions with respect to us would be immediately detected. We are thus able by observation to ascertain what part of the moon's face is presented to us; and we are so, whether the full moon or any smaller portion of her disc be presented to us, because, if we once learn to distinguish the marks upon her surface, and any of these be upon the part which is actually visible to us, we see what part of her disc that is, and consequently in what manner she is placed with respect to us.

The result of these observations is, that very nearly the same part of the moon is always turned towards us. There are some slight differences in the appearances presented at different periods of the month, but they are so small that, for the present, they may be left out of our consideration. Hence we may easily ascertain that the moon must herself have a motion of rotation, and that the period of her rotation must be the same as that of her revolution round the earth. Referring again to the figure on page 125, we may take the figures in the inner circle to represent different positions of the moon: and the shaded part of the figure, A, will represent the half turned to the earth in that position; the white part, the part turned from it. As, in the figure, the boundaries of the white and shaded part in the figures of the inner circle are parallel in each case, the shaded part may, in every case, represent the side of the moon which was turned to the earth at A, if we suppose that the moon has no motion of rotation. The part of the moon actually turned towards the earth will, in each case, be very nearly represented by the part within the circle joining A, B, C, &c. It is obvious, therefore, from inspection of the figure, that, if the moon has no motion of rotation, a different part of her surface will be presented to the earth in every different position. Thus, at A she presents one side to the sun, the opposite side to the earth; at E she would present the same side, which she before presented to the sun, to the earth also; and in the intermediate positions, B, C, D, she would continually turn towards the earth less and less of the part turned towards it at A, as the positions B, C, D, themselves successively became more distant from A. We find, however, that this is not the case, but that at every position very nearly the same part of her surface is turned towards the earth. This can only be done in one way. If the same part of the moon is to be turned towards the earth at B which was so at A, or the shaded part in the figure is to coincide with the part within the connecting circle, it can only do so by a turning of the moon in the same direction, so as to bring it into the required position; and in the same manner the moon must have turned yet further to produce the same effect at a greater distance, as C, or D, and must have turned half round to make the same side face the earth at E, one extremity of the diameter A E, which had done so at A, the other. The same motion must evidently continue beyond E; and that the same part of the moon may again be presented to the earth on her return to A, the revolution must be completed at her return to A, and not sooner. There is, then, a revolution of the body of the moon, and it is completed during the space of a periodic month; for it is obvious that the position of the sun has nothing to do with the part of the moon which is really turned towards the earth, though it determines that which is visible, and consequently that the time of rotation is the same with that of the moon's return to the point A, not as a point situated between the earth and the sun, but as a point in a given direction from the earth; or, in other words, that it is the same with the length of the periodic, not of the synodic, revolution.

In the figure, as drawn, the moon is merely represented by a circle drawn on the plane of the paper; which obviously represents that of the moon's orbit, and the rotation deduced would be rotation in that plane, or round an axis perpendicular to that plane. If, however, the axis round which the moon turns is inclined at any angle to that plane, the appearances would be different. Let us call the extremity of the axis elevated above the plane of the paper, M, that depressed below it *m;* and let us suppose that, the axis is everywhere parallel to itself, and that, at the point A, the extremity M is inclined a little towards the earth, and of course the extremity *m* a little away from it. It is plain that, on this supposition, an observer at the earth would have turned towards him a part of the moon a little beyond M, and that, towards the other side, he would not see quite so far as *m.* When the moon arrived at E, these appearances would be reversed; the position of the axis continuing parallel to itself, but its situation with respect to the earth being reversed; the extremity *m* would now be inclined as much towards the earth, as, in the former position, M was; and as, in the former case, an observer would have had exposed to him parts beyond M, but not those extending to *m,* he would now have turned to him parts beyond *m,* but would not be able to observe those extending to M. There would, therefore, be a sensible difference in the parts which he could observe under the two circumstances. It is plain, also, that there would be similar and corresponding changes of appearance in the intermediate situations. The facts actually observed, however, are found to correspond with the results deduced upon this supposition of a rotation on an axis moving parallel to itself, but not quite perpendicular to the plane of the moon's orbit. The points M, and *m,* are called (from their correspondence with the points called the poles of the earth,) the *poles* of the moon; and the great circle perpendicular to the axis of the moon, is called, for a similar reason, the *equator* of the moon. The phenomenon which we have been explaining of the appearance of different parts of the moon's surface differently situated with respect to these poles, is called the moon's *libration* (rocking or balancing) *in latitude.* From the amount of this libration, the degree of inclination of the moon's axis to her orbit may be ascertained: the angle is 84° 51′ 11″.

This, however, is not all. The boundary of the part of the moon presented to the earth is a circle of the moon, the plane of which is perpendicular to the radius vector. The angle, therefore, which the positions of these planes will make with each other at different points of the orbit, will be equal to the angle made by the radii vectores at these points. The moon, however, moves in an ellipse, and consequently her angular velocity is not uniform: the angle traced by the radius vector, therefore, will not increase in the exact proportion of the time. If, then, the rotation of the moon be uniform, as well as complete in the periodic time of the moon, she will describe three hundred and sixty degrees on her axis in the same time that she takes to describe three hundred and sixty degrees round the earth: but while she takes exactly half this time to describe one hundred and eighty degrees, a quarter of it to describe ninety degrees, and a tenth of it to describe thirty-six degrees, on her axis, in whatever part of her orbit this time be taken, she will not take accurately these same proportions of time to describe the corresponding angles of 180°, 90°, and 36°, around the earth in every part of her orbit. At some periods, therefore, when the moon's motion in her orbit is less than her mean motion, she will have turned further on her axis than is necessary to keep the same face directly turned towards the earth; at other times, when the moon's motion exceeds the mean motion, she will not have turned sufficiently far on her axis for that purpose; and the consequence would be, that in the former case some of the eastern side of the moon, in the latter some of the western, will be seen, beyond what was originally turned towards the spectator. The poles of the moon would be unaffected by the motion of rotation, and of course by its equality or inequality. These appearances, again, are actually found to take place, and are known by the name of the moon's *libration in longitude.*

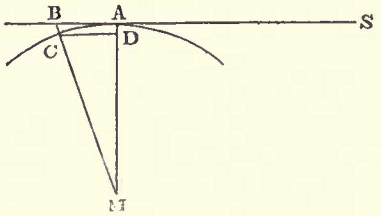
There is still another phenomenon of the same kind. The part of the moon presented to an observer at any place is bounded by a circle perpendicular to the line joining his place and the centre of the moon. To observers at different places, therefore, appearances in some degree different will be presented; for the moon is not so distant from the earth but that the lines joining her centre with different spots on the earth's surface may make a sensible angle,—in the extreme case not less than twice the horizontal parallax of the moon, or nearly two degrees on an average: and this angle will be that of the inclination of the planes bounding the part of the moon visible at each situation. A similar consideration will explain a further variation of the appearances of the moon, which every day presents to us. When the moon rises in the east, an observer on the earth's surface will see a little more of her western and then upper side than he would do if placed in the centre of the earth; and when she is setting in the west, he will see a little more of her eastern and then upper side. This is called the *diurnal*, or *parallactic, libration.*

A certain degree of variation in the appearances presented by the moon is thus shown necessarily to exist, on the supposition of her uniform rotation round a fixed axis; and the appearances which actually exist are found very nearly to correspond with that supposition. But in this, as in almost every astronomical result, we are obliged to qualify our first conclusions in order to arrive at complete correctness. We find that the appearances presented so nearly correspond with those necessary on the supposition of uniform rotation round a fixed axis, that we are induced to conclude, in the first instance, that this supposition is strictly true; but more minute observation teaches us that it is not so. We have indeed no reason to doubt the uniformity of the motion of rotation; but the position of the axis itself is found not to be invariably the same. It is always inclined at the same angle, or very nearly so, to the lunar orbit; but its direction is different, for it is always perpendicular to the line joining the nodes of the orbit; and as they make a complete revolution in 6793·42118 days, the axis of rotation of the moon will in that time go through all its positions with respect to the heavens.

The moon continually turning the same face, or very nearly so, towards us, we are able to observe it, by the aid of powerful telescopes, with great accuracy. The consequence has been, that maps of that part of its surface which is exposed to us have been constructed, and that we have obtained considerable knowledge of its constitution, as well as of its motions.

On looking at the moon through a powerful telescope, we observe very different degrees of brightness in different parts of the surface, and especially some bright spots, which have beyond them, in the direction opposite to that of the sun, a comparatively dark shadow. The length and position of this shadow vary as the position of the spot with relation to the sun varies; the shadow being always opposite to the sun, but longer or shorter as the sun is more or less elevated above a plane touching the moon at that point, *or the horizon of that point of the moon.* It is obvious, from these appearances, that the dark part is really a shadow created by the interposition of the bright spot between it and the sun, or that the bright spot is an elevation above the general level of that part of the moon where it stands, or a mountain in the moon.

We are led to the same conclusion of the existence of mountains in the moon by another remarkable appearance. The inner or oval edge of the moon is the boundary of light and darkness there. If the moon were perfectly smooth, this boundary, as we have seen, would be a perfect circle, and its appearance would be that of an accurate ellipse; but if there are inequalities on the moon's surface, some of the higher points, beyond the line which would be the boundary of the visible part if smooth, would project into the light, and would be visible sometimes even while the depressed parts between them and the boundary would be in shadow. Thus, upon the earth's surface, the tops of mountains continue to receive the light of the sun after he has set to the valleys or plains below them. Now these are exactly the appearances presented by the inner edge of the moon when seen through a telescope: whatever portion of the moon be visible, the edge is everywhere rough, with lines and points projecting beyond its general line, and with some insulated points completely beyond that line, and not connected with it by any lines of light. It is evident that the former must be elevated ridges rising above the general surface of the moon; the latter, single points yet more elevated, and more distant from the part generally enlightened. We conclude, therefore, that the surface of the moon is everywhere rugged, without any great plains or large spaces, like the sea here, covered with water or any fluid, which, from the laws regulating the equilibrium of fluids, would necessarily have a smooth surface.



It may seem that corresponding appearances ought to be presented by the other limb of the moon, and that, just as the sun's rays enlighten prominent objects beyond that part of her surface which he generally shines upon, we ought also to be able to see prominent points beyond the part of the moon directly turned towards us. And it is so; but, though such points are actually presented to our view, they are scarcely distinguishable to our senses, even when assisted by powerful instruments. It will be worth while to explain the cause of this difference, especially as it will show also how we are enabled to estimate the height of lunar mountains. For this purpose, let the arc C A represent a part of the moon's surface, and S A B any straight line touching it; and let B be any point in that line, and join B with M, the centre of the moon. The part of the line B C, intercepted between B and the surface of the moon at C, is evidently the height of the point B above that surface; and whenever the angle A M C is small, B C is much less than A B. Now the rays of light move in straight lines; S A B, therefore, may represent the course of a ray of light. A, where it touches the sphere, will be a point in the general boundary of light and darkness; but if B represent the top of a lunar mountain, whose height is C B, B will just receive the ray S A B, and will therefore be visible. The distance, A B, from the general boundary of light and shade, may be observed. It will not indeed be seen, except in particular cases, perpendicularly to the line joining the observer and the moon; but from the observed distance the real distance of A B may be computed, the inclination at which it is seen being known; and from the real distance, as computed, the angle A M B, and the height B C, may be ascertained. A B is necessarily greater than B C; but this, though it is one, is not the only reason why the distance of an elevated point from the boundary of the enlightened part of the moon is more easily observed than its actual prominence. We may now suppose S to represent the direction of an observer upon the earth; in which case it is plain that A will represent a point in the boundary of that part of the moon which, if she were perfectly smooth, would be visible from S. The observer at S, however, will be able to see the point B, if that be, as before, a point elevated above the general surface of the moon; but he will see it in the line S A B, or in the same direction with the point A, the extreme point of that part of the moon, which, independently of these prominences, would be presented to him: and he will not distinguish it as projecting beyond the general surface of the moon, though it is only by virtue of this projection that it is brought within his view at all. A similar mountain situated between the points A and C would indeed project beyond the line A B, and be partly distinguishable; and in the extreme case of its being situated exactly at A, it would project thus by its whole height: but even then, as we have already seen, the prominence is much less than A B.

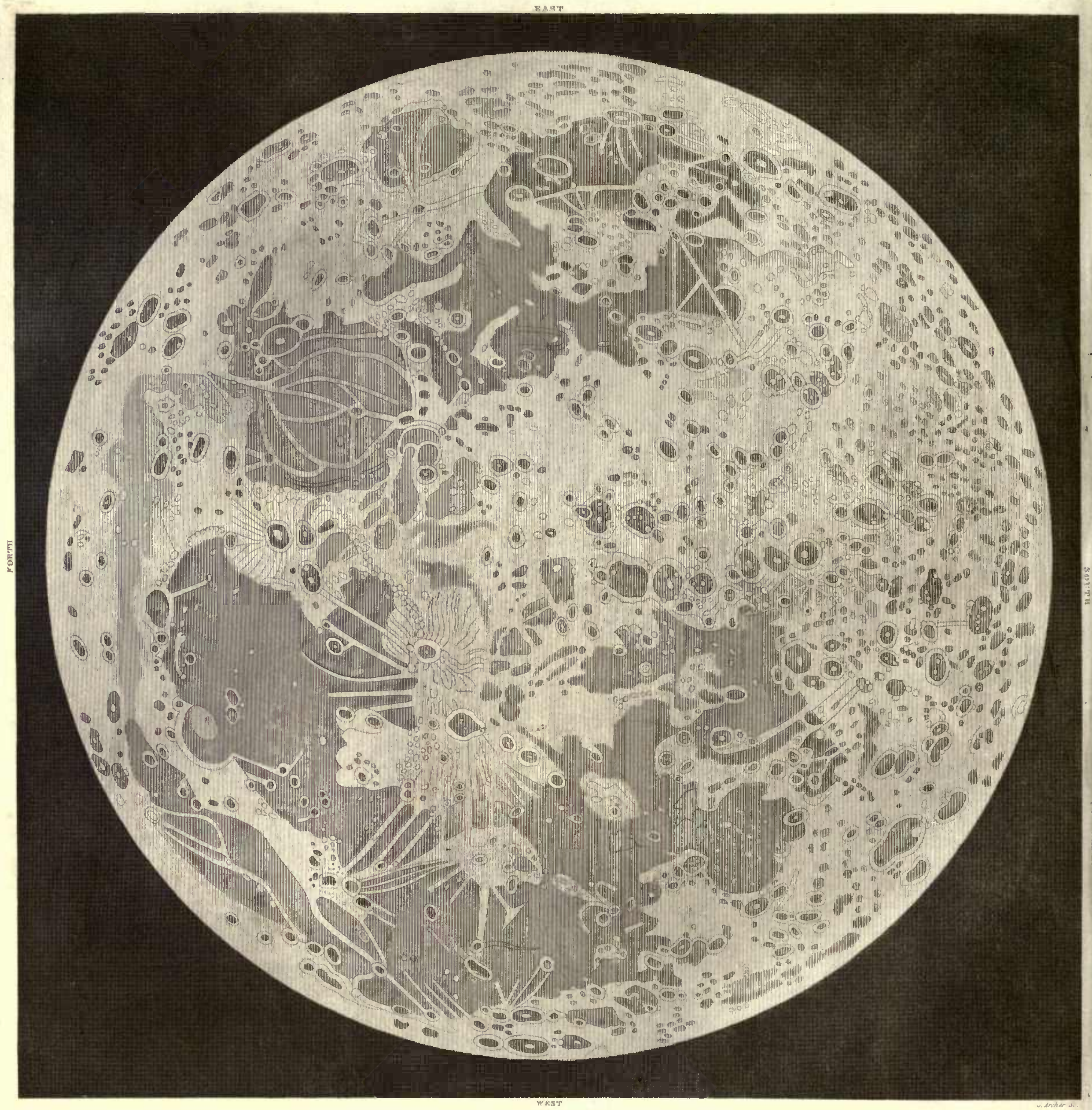
It will naturally be supposed that the nicety of observation required to detect such small quantities as the altitude of lunar mountains at the distance of the moon must be very great; and their values may in consequence be considered as not very accurately ascertained. They were much overrated when first observed, and the observations then registered would correspond to surprising heights, as fifteen miles, or thereabouts. Better observations, however, have reduced these extraordinary elevations; and Dr. Herschel considered few of these mountains to exceed half a mile in height. There are some, however, far higher; and one, in particular, named after the philosopher Leibnitz, has been computed by M. Schroeter to be twenty-five thousand feet, or nearly five miles, high.

Besides these points near the illuminated edge of the moon, other bright points are occasionally seen in the dark parts of it, at so great a distance from the edge that they cannot be accounted for in the same manner: for a mountain lofty enough to be enlightened in such a position could not escape our observation when in the generally enlightened part of the moon. These points, therefore, when seen, must be luminous in themselves. They are seen occasionally, not always; they are therefore luminous only occasionally: and the most probable account that has been given of them is, that they are volcanoes, and that when they are visible, independently of reflected light, they are in a state of active eruption. Their appearance, when seen in the generally enlightened parts of the moon, corresponds with and confirms this supposition.

If there be an atmosphere surrounding the moon, at all analogous to that of our earth, there must be twilight there; and if there is twilight, there must be a partial and faint light beyond the boundary of that part of the moon which is fully and directly illuminated by the sun. Such a light has been actually observed, but very faint, and of small extent; corresponding therefore to the supposition of there being such an atmosphere, but of little power in reflecting light. That its power is very small, is evinced also by another consideration. The same media generally are powerful both in refracting and reflecting light. Now we have complete proof that the atmosphere of the moon has very little power in refracting light. In the course of the moon's revolution through the heavens, she must necessarily sometimes be in the same direction with some of the stars, and, being much nearer to us than they are, pass between us and them, and conceal them from us. This is called the *occultation of the fixed stars by the moon.* Her motions being known, the time at which that part of her which first coincides in position with a star does so coincide, or the beginning of the occultation, may be computed; and so, in the same manner, may its end, and consequently its duration. This, however, is the duration independently of any refraction by the moon's atmosphere: for it is deduced from considering when the moon is exactly between the earth and the star, at which period it would intercept rays of light proceeding in a straight line from the star to the earth. If the moon have any refracting atmosphere, the duration would be shortened, for the rays would be bent towards the moon in passing through it, and, as they would pass first on one side of the moon, (that which first came in apparent contact with the star,) and afterwards on the other, (which last leaves it,) they would be bent towards each other, and towards the earth, and consequently in one case would continue to reach the earth after some part of the moon is

TELESCOPIC VIEW OF THE MOON

AT THE FULL.



J. Archer Sc.

between the earth and star, and in the other would begin to arrive at the earth before the whole of the moon had passed from between them. The observed duration of the occultation would be less than the computed duration. Such a difference is in reality scarcely observable: its amount has never been very completely ascertained, but it certainly does not exceed, in any case, eight seconds of time,—a diminution which is not greater than that which would correspond to a horizontal refraction not exceeding two seconds. The horizontal refraction at the earth is not less than thirty-three minutes; and as, on the supposition of the medium being similar, the refracting power increases with the density, it may be estimated from this, that the density of *the lunar atmosphere must be nearly one thousand times less than that of ours.* The identity of its nature, however, and, therefore, the conclusion drawn from it, is to a certain degree conjectural.

One other circumstance respecting the lunar atmosphere may here be mentioned. It is clear that it is not loaded with heavy clouds, as the atmosphere of the earth so frequently is: for these would either themselves be visible to us, or would, at least, be discovered by the shadows they would cast upon the moon's surface. We can observe the shadows of her mountains, and should equally be able to observe those of her clouds. This observation comes in aid of that already deduced from other appearances, of the absence of any large spaces covered with water, or any evaporable fluid in the moon; for, if there were any such, evaporation would take place, and clouds would be formed.

Many of our conclusions with respect to objects on the surface of the moon are, to a certain extent, conjectural; and it may possibly seem, that the conjectures are impugned by the dissimilarity of appearances presented by the moon and earth. Objects on the earth are seen by reflected light, as well as those at the moon; yet with how much less brilliancy, except occasionally when a brightly-reflecting surface is met with, and with how many shades of color, instead of one uniform and almost white brightness, only diversified by its different degrees of intensity. And when we see objects melted together in distance, and almost of uniform color, it is a pale bluish hue, of faint lustre. Any such objection may be removed by these considerations,—that the mixture of a great variety of colors will produce a white, or nearly a white, light, and, consequently, that the blended light reflected from a large distant tract ought, in general, to be nearly of that color; that if the distant objects which we see on the earth are not so, it is because the rays which proceed from them pass through a long space of the lower and denser parts of our atmosphere, and the objects become, in consequence, tinged with its blue color; that their faintness proceeds partly from this cause, and partly from their being visible only in the strong light of day; and that when the moon is seen so, also, there is not that striking difference in her appearance and theirs which we suppose, when we contrast them with our notion of her, as derived from common observations in the darkness of night. But it may be worth while to add, as a still further answer to any objections of this nature, the description which an accurate observer has given of the appearances presented by a part of the earth itself, where the brilliancy of the climate, and other accidental circumstances, diminished some of the causes of difference.

" On the 26th of May we sailed from Valparaiso, and proceeded along the coast to Lima. During the greater part of this voyage, the land was in sight, and we had many opportunities of seeing not only the Andes, but other interesting features of the country. The sky was sometimes covered by a low, dark, unbroken cloud, overshadowing the sea, and resting on the top of the high cliffs which guard the coast; so that the Andes, and, indeed, the whole country, except the immediate shore, were then screened from our view. But, at some places, this lofty range of cliffs was intersected by deep gullies, connected with extensive valleys, stretching far into the interior. At these openings we were admitted to a view of regions which, being beyond the limits of the cloud, and, therefore, exposed to the full blaze of the sun, formed a brilliant contrast to the darkness and gloom in which we were involved. As we sailed past, and looked through, these mysterious breaks, it seemed as if the eye penetrated into another world; and had the darkness around us been more complete, the light beyond would have been equally resplendent with that of the full moon, to which every one was disposed to compare this most curious and surprising appearance."

As the rays were not reflected from a bright, snowy surface, but from a dark-colored sand, we are furnished with an answer to the difficulties sometimes started respecting the probable dark nature of the soil composing the moon's surface.

SECTION III.

Recurrence to the phenomenon called the new holding the old moon—Moon supposed by some to be phosphorescent—Leslie's explanation of the thread of light connecting the horns of the new moon—True explanation—Surface viewed through a telescope—Mountains and hollows—Lunar volcanoes—Arguments respecting the atmosphere—Is the moon inhabited?—Discovery of a fortification and of roads in the moon.

If we observe the moon in serene weather, when she is three or four days old, the part of her disc which is not enlightened by the sun is faintly illuminated by the light that is reflected from the earth, and the horns of the enlightened part appear to project beyond the old moon, as if they were part of a sphere considerably larger in diameter than the unenlightened part. This appearance has been expressively called, in common parlance, as was before stated, the new moon holding the old moon in her arms. It was once deemed a sufficient explanation of it to say, that bright objects affected the retina to a greater distance than those which were less luminous, and that, as ink sinks upon soft paper, the image of the bright part of the moon expands on the retina, and gives it the appearance of projecting beyond the darker portion of her disc. The explanation of this phenomenon is thus given by Dr. Jurin. He supposes that the eye cannot accommodate itself, with sufficient distinctness, to view objects at such a distance as the moon. The pencils of rays unite before they reach the retina, and form an indistinct and enlarged image of the moon. It may be proved by cutting out a piece of white paper, to represent the moon, and placing it upon a dark ground. When this luminous body is viewed either at a distance too remote or too near for perfect vision, its image on the retina will be enlarged, and the illuminated part will encroach upon the obscure portion, and appear to embrace it, in the same way as it is seen in the heavens. We must, however, take it for granted, that the eye cannot see the moon with perfect distinctness,—a position which does not rest upon the evidence of experiment.

The less illuminated portion of the moon's disc, when she is three or four days old, obviously receives its light from the earth, which to the lunar inhabitants will then appear to be nearly *full.* As the age of the moon increases, this secondary light is gradually enfeebled, both in consequence of the diminution of the luminous part of the earth, and of the increase of the enlightened part of the moon. On one occasion, however, the weather being uncommonly favorable, Brewster states that he observed the secondary light when the moon was nearly ten days old.

Riccioli and Leslie supposed the moon to be phosphorescent. They conceived it impossible to account in any other way for the extreme brilliancy of her disc. And Leslie explained, on this hypothesis, the thread of light which seems to connect the two horns of the moon. His theory is thus stated by himself:—" After emerging from conjunction with the sun, the moon's sharp horns are seen to be connected by a silver thread, which completes the circle; and a very faint light seems to be suffused over the included space. This bright arch, however, becomes gradually less vivid, and before the moon is five or six days old, it has almost totally vanished. The pale outline of the old moon is commonly ascribed to the reflection from the earth; but if it were derived from that source, it would appear densest near the centre, and gradually dimmer toward the edge. I rather refer it to the spontaneous light which the moon may continue to emit for some time after the phosphorescent substance has been excited by the action of the solar beams."

"The lunar disc is visible when completely in the shadow of the earth; nor can this fact be explained by the inflection of the sun's rays in passing through our atmosphere; for why does the rim appear so brilliant? Any such inflection could only produce a diffuse light, obscurely tinging the boundaries of the lunar orb; and in this case the earth, presenting its dark side to the moon, would have no power to heighten the effect by reflection. But even when this reflection is greatest, about the time of conjunction, its influence seems extremely feeble. The lucid bounding arc is occasioned by the narrow *lunula*, which, having recently felt the solar impression, still continues to shine, and, from its extreme obliquity, glows with concentrated effect."

The phenomenon thus described is represented in the accompanying plate, where a diluted light appears to be shed over the obscure portion of the moon's disc, while a lucid bow, more bright than the rest of the obscure part, seems to join the lunar horns. When we examine this luminous bow in the heavens, the lower part of it, at *a*, is always much broader than the upper part, at *b;* and when the moon has considerable libration, so as to withdraw from the earth a portion of the eastern limb, the bow ceases to be continuous, and the part at *b* is no longer visible. These two appearances, which Brewster states he has often observed, are sufficient to overthrow the explanation that has been already given; for, upon that hypothesis, the lucid bow ought to have been broader in the centre, diminishing towards the horns, exactly like the enlightened part of the moon's disc. We are not, however, confined to arguments like this. The true explanation is so simple and convincing that it is scarcely possible not to adopt it. If we look at the *maps* of the moon here given, we shall find that the eastern limb is separated from the central parts of her disc by darker regions, and that the luminous portion between these darker regions and the circular line that bounds her eastern limb, has actually the form of a bow, broadest towards the southern horn, and gradually diminishing in breadth towards her northern horn.

The immediate cause, therefore, of the lucid bow is to be sought for in the accidental circumstance of the moon's eastern limb being more luminous than the adjacent regions towards the centre. The central parts, indeed, are equally luminous with the eastern limb, but their brilliancy is impaired by their proximity to the illuminated portion. We see, then, the reason why the bow is broadest at *a* and narrowest at *b*, and why the libration of the moon, withdrawing the narrow part *b* of the bow, destroys its continuity. This may be better understood by comparing the preceding plate with the maps of the moon.

When the surface of the moon is viewed with good telescopes, its appearance is found to be wonderfully diversified. Besides the large dark spots, which are visible to the naked eye, extensive valleys are distinguishable, and long ridges of elevated mountains, projecting their shadows on the plains below. Single mountains occasionally rise to a great height, while hollows, *more than three miles deep*, and almost exactly circular, exist in the plains. The margin of these cavities is often elevated a little above the general level, and a high eminence rises in the centre of the cavity. When the moon approaches to her opposition, the elevations and depressions upon her surface in a great measure disappear, while her disc is marked with a number of brilliant points and permanent radiations.

It may be observed with a common telescope, that the lunar surface is not only diversified with rocks and cavities, but that some parts of it are distinguished from others by their superior illumination. The dark parts of the disc are always smooth and apparently level, while the luminous portions are tracts which either rise into high mountains or sink into deep and extensive cavities, The general smoothness of the obscure regions naturally induced astronomers to believe that they were large collections of water. If, however, we examine the disc with minute attention, we shall find that these obscure portions are not exactly level, like a fluid surface. In many of them the inequality of surface and of light is considerable, and in some parts parallel ridges are visible. The large dark spot on the moon's western limb, called the *Crisian Sea*, appears in general to be extremely level; but it has been observed, when the moon was a little past her opposition, and the boundary of light and darkness passed through the Crisian Sea, that this bounding line, instead of being elliptical, as it would have been were the surface fluid, was irregular, and indicated that this portion of the disc was elevated in the middle. The light of these obscure regions varies much, according to the angle of illumination or the altitude of the sun above their horizon; and when the moon is near her conjunction, they are not much less luminous than the other parts of the disc. This could not happen if they were covered with water. It is thought, then, that there is no water in the moon, such as rivers, lakes, or seas, and therefore none of those atmospherical phenomena which on our globe are owing to the existence of water.

The strata of mountains, and the insulated hills, which mark the disc of this luminary, have no analogy with those of our globe. Her mountainous scenery bears a stronger resemblance to the towering sublimity and the terrific ruggedness of Alpine regions, than to the tamer inequalities of less elevated countries. Huge masses of rocks rise at once from the plains, and stretch their peaked summits to an immense height in the air, while projecting crags spring from their rugged flanks, and, threatening the valleys below, seem to bid defiance to the laws of gravitation. Around the base of these frightful eminences are strewed numerous loose and unconnected fragments, which time seems to have detached from their parent mass; and when one examines the rents and ravines which accompany the overhanging cliffs, he expects every moment that they are to be torn from their base, and that the process of destructive separation, that we had only contemplated in its effects, is about to be exhibited before us in tremendous reality. The strata of lunar mountains called the Appenines, that traverse a portion of her disc from north-east to south-west, rise with a precipitous and craggy front from the level of the "Stormy Sea." In some places their perpendicular elevation is above four miles, though they often descend to a much lower level. To the north-east they present an inaccessible barrier, while on the south-west they sink in gentle declivity to the plains.

On examining the circular cavities, it is found that the analogy between the surface of the moon and earth fails in a still more remarkable degree. Some of the immense caverns are nearly four miles deep, and forty in diameter. A high annular ridge, marked with lofty peaks and little cavities, generally encircles them. An insulated mountain frequently rises in their centre, and sometimes they contain smaller cavities of the same nature with themselves. These hollows are most numerous in the south-west part of the moon; and it is from this cause that that portion is more brilliant than any other part of her disc. The ridges which encircle the cavities reflect the greatest quantity of light, and, from their lying in every possible direction, they appear, near the time of full moon, like a number of brilliant radiations. If these hollows be adorned with verdure, they must present to the view of a spectator, placed among them, a more variegated, romantic, and sublime scenery, than is to be found on the surface of our globe. An idea of some of these scenes may be acquired by conceiving a plain of about a hundred miles in circumference, encircled with a range of mountains, of various forms, three miles in perpendicular height, and having a mountain near the centre, whose top reaches a mile and a half above the level of the plain. From the top of this central mountain, the whole plain, with all its variety of objects, would be distinctly visible; and the view would appear to be bounded on all sides by a lofty amphitheatre of mountains, in every diversity of shape, rearing their summits to the sky. From the summit of the circular ridge, the conical hill in the centre, the opposite circular range, the plain below, and some of the adjacent plains which encompass the *exterior* ridge of the mountains, would form another variety of view; and a third variety would be obtained from the various aspects of the central mountain, and the surrounding scenery, as viewed from the plains below.

Astronomers have found it difficult to explain, with any degree of probability, the formation of these immense cavities. Some have thought that our globe would present the same appearance if all the lakes and seas were removed. The lunar cavities, then, may be intended for the reception of water, or they may be the beds of lakes and seas that once existed in the moon.

The deep caverns, and the broken, irregular ground, which appear in almost every part of the moon's surface, have induced several astronomers to believe that these inequalities are of volcanic origin. Their conjectures have received some confirmation from a number of phenomena that have been seen in the dark part of the moon.

During the annular eclipse of the sun, in 1778, Ulloa observed, before the edge of the sun's disc emerged from that of the moon, a bright white spot, which he imagined to be the light of the sun shining through an opening in the moon. This phenomenon continued about one minute and a quarter, and was noticed by different observers. Beccaria observed a similar spot in 1772, and supposed that it, as well as that perceived by Ulloa, was the flame of a burning mountain. Similar bright spots have been seen at various times. We shall not stop to enumerate them, but shall proceed to give, in his own words, Herschel's account of similar phenomena, which he witnessed in 1787.

"April 19th. I perceive three volcanoes in different places of the dark part of the new moon. Two of them are either nearly extinct or going to break out. This may perhaps be decided at the next lunation. The third shows an actual eruption of fire or luminous matter. Its light is much brighter than the nucleus of the comet that Mechain discovered on the 10th of this month.

"April 20th. The volcano burns with greater violence than last night. I believe its diameter cannot be less than three seconds. Hence, the burning or shining matter must be above three miles in diameter. It is of an irregular, round figure, and very sharply defined on the edges. The other two volcanoes resemble large, faint nebulæ, that are gradually brighter in the middle; but no well-defined luminous spot can be discerned in them. I did not perceive any similar phenomena last lunation, though I then viewed the same places with the same instrument.

"The appearance of what I have called the actual fire exactly resembled a small piece of burning charcoal, when covered with a thin coat of white ashes; and it had a degree of brightness about as strong as such a coal would present in faint daylight.

"All the adjacent parts of the volcanic mountain seemed to be faintly illuminated by the irruption, and were gradually more obscure as they lay at a greater distance from the crater."

The formation of craters in different parts of the moon seems also to indicate the existence of volcanoes. With an excellent telescope, five feet long, and with an aperture of three inches and three quarters, Olbers discovered two small craters, which were wanting in Shroeter's charts. Shroeter had frequently examined this part of the moon, but had not perceived the slightest traces. He, however, at last perceived the largest of them, which was uncommonly deep in proportion to its breadth, and was surrounded with a broad annular elevation, of little brightness.

In order to convey an idea of the lunar surface, three plates are here given. Figure 1 is a very brilliant spot, called *Aristarchus*, in the north-east quarter of the moon's surface. Figure 2 represents the spot called *Gassendi*, in the south-east quarter, the dark edge *a b* representing the boundary between the illuminated and obscure portion of her disc. Figure 3 is a spot called *Hevelius*, containing an annular cavity, and a broken elevation resembling an egg.

Fig 1

Fig 2

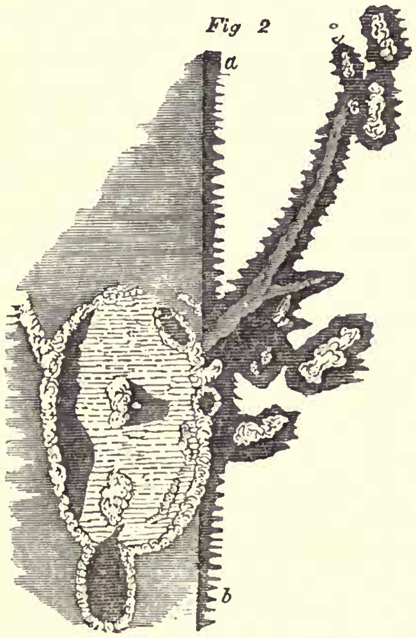
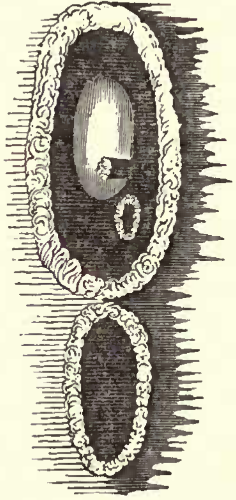


Fig 3



As to the existence of a lunar atmosphere, there is much diversity of opinion among philosophers. The constant serenity of the moon's surface has induced some to believe that she had no atmosphere; and this opinion was confirmed by the brilliancy of light retained by the fixed stars and planets when they were nearly in contact with the limb of the moon, and when their light must have passed through her atmosphere if she had any. Fouchy endeavors to show, that the duration of eclipses and occultations ought to be diminished by means of the refractive power of the moon's atmosphere, and, if its horizontal refraction amounted to eight seconds, that there never could be a total eclipse of the sun. In that which happened in 1724, total darkness continued two and one fourth minutes,—a circumstance which Fouchy maintains could not have happened had the moon been encircled with the rarest atmosphere.

Yet, the appearance of the moon's limb in total and partial eclipses of the sun, has suggested numerous arguments for the existence of a lunar atmosphere. In 1605, Kepler perceived that the moon, in a solar eclipse, was surrounded with a luminous ring, most brilliant on the side nearest the moon. A similar phenomenon was observed in the total eclipse of 1706. An observer of the same eclipse, at Bern, perceived a blood-red streak of light immediately before the emersion of the sun's limb. Fatio, at Geneva, observed the luminous ring round the moon, and Scheuchyer describes the eclipse as appearing annular, in consequence of the refraction of the sun's light by the moon's atmosphere. In the total eclipse of 1715, Halley observed a diminution of brightness in the limb of the sun which was immerging before total darkness. The sharp horns of the solar crescent were blunted at their extremities during total darkness, and a ring of light encompassed the moon. The ring was brightest near the body of the moon, and flashes of light seemed to dart out on all sides from behind the moon a little before the emersion. About two seconds before the emersion, a long, narrow streak of dusky, but strong red light seemed to color the western limb of the moon; but when the sun appeared, the streak and the ring instantly vanished.

Louville saw the same phenomena, and describes the red streak as a piece of a circle, of a lively red, which preceded the emersion.

In an eclipse of the sun, (1748,) when the uncovered part of that luminary resembled the moon in quadrature, the horns of the solar crescent were observed to be bent outward beyond the circle in which every other part of his disc was comprehended. When the eclipse became annular, the sun's disc was dilated beyond the circle that formerly embraced it. This dilation Euler estimated at twenty-five seconds.

In the eclipse of 1778, in which the solar darkness lasted four minutes, several singular appearances were observed. The ring of light about the moon seemed to have a rapid circular motion. This light became more dazzling as the centres of the bodies approached, and, about the middle of the eclipse, its breadth was a sixth part of the moon's diameter. Flashes issued from it in all directions: the light was reddish toward the moon, a deep yellow toward the middle, and a pure white at its circumference.

Experiments were made with the shadows of globes by Maraldi and Fouchy, to show that the luminous ring might arise from another cause than the moon's atmosphere. They found that a ring of light, produced by the inflection of the passing rays, surrounded the shadows of all opaque globular bodies. But as the phenomena of inflection are produced merely by the surfaces of bodies, the breadth of the luminous ring produced by the head of a pin will be as great as that produced by the inflection of the moon at the same distance from both bodies. Thus the ring of light surrounding the moon would not exceed the ring seen by Maraldi around the globes of wood and stone, and therefore could not be discerned at the distance of that luminary.

The appearance of the stars and planets, when eclipsed by the moon, also furnishes proofs of the existence of a lunar atmosphere. It was natural to expect, that when the stars or planets came in contact with the moon's limb they would suffer a change in color, arising from the transmission of their light through the densest part of the moon's atmosphere. When we consider, however, that this atmosphere, if its size were proportional to that of the earth, could not subtend a greater angle than one second, and that the emerging star moves through this space in two seconds of time, we can scarce expect any great change in its brilliancy. The visible limb of the moon may be formed by mountains, and the denser part of her atmosphere may be below their summits; so that the remaining part of her atmosphere, which alone is visible to us, may not have sufficient density to deaden the light of the star. Cassini frequently observed the circular figure of Jupiter, Saturn, and the fixed stars, changed into an elliptical one, when they approached the limb of the moon. In an occultation of Saturn, in 1762, the ring and body of that planet were observed to be affected by their proximity to the moon, and had the appearance of a comet at the moment of emersion.

But the complete discovery of the moon's atmosphere was reserved for Schroeter. He had frequently perceived that the high ridges of certain lunar mountains, when in the dark hemisphere, were less illuminated in proportion to their distance from the boundary of light and darkness, and that the cusps were also more faintly illuminated than the other parts of the disc. He observed, also, changes in the lunar atmosphere, from which he was led to expect that a twilight might be perceived toward her cusps, as had been done in Venus.

By observing the moon when her phases were extremely falcated, Schroeter at last discovered a faint, glimmering light, of a pyramidal form, extending from both cusps into the dark hemisphere. The greatest breadth of this light was two seconds, and its length one minute and twenty seconds; from which Schroeter computed that the breadth of the lunar twilight from the boundary of light and darkness to where it loses itself in, and assumes the faint appearance of, the light reflected from the earth, measures, in a direction perpendicular to the boundary of light and darkness, about two and a half degrees, and, therefore, that the inferior or more dense part of the atmosphere is not more than fifteen hundred feet high, and that the height where it could affect the brightness of a fixed star, or inflect the solar ray, is not so much as six thousand feet. This space subtends at the earth an angle of less than a second, and which would be passed over by a star in less than two seconds of time.

A spectator on the lunar surface would behold the earth, like a luminous orb suspended in the dome of heaven, presenting a surface about thirteen times larger than the moon does to us, and appearing sometimes gibbous, sometimes horned, and at other times with a round, full face. The light which the earth reflects upon the dark side of the moon may be perceived by a common telescope. The lunar surface contains about fifteen millions of square miles, and is, therefore, capable of containing a population equal to that of our globe, allowing fifty-three inhabitants to every square mile. That this planet is inhabited by sensitive and intelligent beings, there is every reason to conclude, from a consideration of the sublime scenery with which its surface is adorned, and of the general beneficence of the Creator, who appears to have left no large portion of his material creation without animated existences; and it is highly probable that *direct proofs* of the moon's being inhabited may hereafter be obtained. Indeed, if we are ever to obtain an ocular demonstration of the habitability of *any* of the celestial orbs, the moon is the only one where we can expect to trace, by our telescopes, indications of the agency of sentient or intelligent beings; and we are convinced, that a long-continued series of observations on this planet, by a number of individuals, in different places, might completely set at rest the question whether the moon be a habitable world. Were a vast number of persons, in different parts of the world, to devote themselves to a particular survey of the moon—were different portions of her surface allotted to different individuals, as the object of their particular research—were every mountain, hill, cavern, cliff, and plain, accurately inspected, and every change and modification in the appearance of particular spots carefully marked and represented in a series of delineations—it might lead to some certain conclusions, both as to her physical constitution and her ultimate destination. It can be demonstrated, that a telescope which magnifies one hundred times will show a spot on the moon's surface whose diameter is twelve hundred and twenty-three yards; and one which magnifies a thousand times will, of course, enable us to perceive a portion of her surface whose size is only one hundred and twenty-two yards: and, consequently, an object, whether natural or artificial, of no greater extent than one of our large edifices, (for example, St. Paul's Church, London,) may, by such an instrument, be easily distinguished. Now, if every minute point on the lunar surface were accurately marked by numerous observers, it might be ascertained whether any changes are taking place, either from physical causes, or from the operations of intelligent agents. If a large forest were cutting down—if a city were building in an open plain, or extending its former boundaries—if a barren waste were changing into a scene of vegetation—or, if an immense concourse of animated beings were occasionally assembled on a particular spot, or shifting from one place to another—such changes would be indicated by certain modifications of shade, color, or motion; and, consequently, would furnish a direct proof of the agency of intelligent beings analogous to man, and of the moon being a habitable globe. For, although we may never be able to distinguish the *inhabitants* of the moon, (if any exist,) yet, if we can trace those *effects* which can flow only from the operations of intelligent agents, it would form a complete demonstration of their existence—on the same ground on which a navigator concludes an unknown island to be inhabited, when he perceives human habitations and cultivated fields.

"That changes occasionally happen on the lunar hemisphere next the earth, appears from the observations of Herschel and Schroeter, particularly from those of the latter. In the Transactions of the 'Society of Natural Philosophy,' at Berlin, Schroeter relates that on the 30th December, 1791, at 5 o'clock, P. M., with a seven-feet reflector, magnifying one hundred and sixty-one times, he perceived the commencement of a small crater on the south-west declivity of the volcanic mountain in the *Mare Crisium*, having a shadow of at least 2″. 5. On the 11th January, at twenty minutes past five, on looking at this place again, he could see neither the new crater nor its shadow. Again, on the 4th January, 1792, he perceived, in the eastern crater of Helicon, a central mountain, of a clear gray color, three seconds in diameter, of which, during many years' observations, he had perceived no trace. 'This appearance,' he adds, 'is remarkable, as, probably, from the time of Hevelius, the western part of Helicon has been forming into its present shape, and nature seems, in that district, to be particularly active.' In making such minute observations as those to which we have alluded, it would be proper, along with an inspection of the moon's luminous disc, to mark the appearances of different portions of her dark hemisphere, when it is partially enlightened by the reflected light from the earth, soon after the appearance of new moon. These researches would require a *long-continued* series of the most minute observations, by numerous observers in different regions of the globe, which could be effected only by exciting, among the bulk of mankind, a general attention to such investigations. But were this object accomplished, and were numerous observations made from the tops of mountains, and in the serene sky of southern climes, where the powers of the telescope are not counteracted by dense vapors, there can be little doubt that direct proofs would be obtained that the moon is a habitable world; or, at least, that the question in relation to this point would be completely set at rest."

The public was once amused by the announcement of a discovery said to have been made by Professor Frauenhofer, of Munich. This gentleman was said to have discovered a *fortification* in the moon, and to have distinguished several lines of road, supposed to be the work of the lunar inhabitants. It is scarcely necessary to say, that such announcements are obviously premature. To perceive distinctly the shape of an object in the moon, which resembles a fortification, it is requisite that that object be of a much larger size than our terrestrial ramparts. Besides, although an object resembling one of our fortifications were perceived on the surface of the moon, there would be no reason to conclude that it served the same purpose as fortifications do among us. We are so much accustomed to *war* in our terrestrial system, and reflect so little on its diabolical nature, that we are apt to imagine that it must form a necessary employment even in other worlds. With regard to the pretended discovery of the lunar *roads*, it may not be improper to remark, that such roads must be at least four hundred feet broad, or ten times the breadth of ours, in order to be perceived as faint lines through a telescope which magnifies a thousand times; which is a higher power, we presume, than Frauenhofer can apply with *distinctness* to any of his telescopes.* It is not at all likely that the lunar inhabitants are of such a gigantic size, or employ carriages of such an enormous bulk, as to require roads of such dimensions, since the whole surface of the moon is only the thirteenth part of the area of our globe.

Schroeter conjectured the existence of a great city to the north of *Marius*, (a spot in the moon,) and of an extensive canal towards *Hygens*, (another spot,) and he represented part of the spot named *Mare Imbrium* to be as fertile as the Campania. Similar remarks to those now stated will apply to these conjectures of Schroeter. We are too apt to imagine that the objects we perceive in the moon must bear a certain resemblance to those with which we are acquainted on the earth; whereas, there is every reason to believe, from the variety we perceive in nature, that no one world resembles another, except in some of its more prominent and *general* arrangements. The moon bears a general resemblance to the earth, in its being diversified with mountains and valleys; but the positions and arrangement of these objects in the moon, and the scenery they exhibit, are materially different from what appears on the surface of our globe.

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* More recently, Professor Gruithausen, of Munich, has publicly declared that he has discovered irrefragable proofs that the moon is inhabited like the earth. All Europe has answered by railleries the declaration of the Bavarian astronomer, but his firmness has been

CHAPTER V.

SECTION I.

The system of the world—Limits of magnitude and minuteness—Theories respecting the world—Ptolemy's—Egyptian—Tycho Brahe's—Copernican—Des Cartes' whirlpools—Number and names of the planets—Origin of their symbols—Their comparative distances from the sun—Their division into inferior and superior—Their periodical times—Their secondaries—Origin of the planets' names—Heliocentric circle of a planet—Aspects, what—Venus both an evening and a morning star—Its phases—Why imperceptible to the naked eye—Inferior planets—Their geocentric motions in looped curves—Mars—The form of its disc—Its orbit without the earth's—Aspects and motions of superior planets—Mode of determining the position of the orbits—Elements of an orbit—Predicting a planet's return to the same situation—Venus sometimes visible at noonday.

To study nature is to search into the works of creation, where every step must lead us to form more exalted ideas of the divine Being who prevails throughout, directs and animates the whole. From the animalcule that is invisible to the unassisted eye, to the magnificent luminaries of heaven, he is everywhere present.

What sublime ideas of this great Being do we obtain by contemplating the vast diversity of his works! How is the mind captivated by the astonishing scenes that are spread out before us! That part of nature which is the immediate object of our senses is very imperfect, and but of small extent; yet, by the assistance of art and the help of reason, it is enlarged till it loses itself in an infinity on either hand. The immensity of things on one side, and their minuteness on the other, carry them equally out of our reach, and conceal from us many of the more admirable parts of physical operations. As magnitude, abstractly considered, is capable of being increased indefinitely, and is also divisible without end, so we find that in nature the limits of dimension are at an immense distance from each other. We can perceive no bounds to the vast expanse in which natural causes operate; and we are no less at a loss when we endeavor to trace things to their elements, and to discover the limits which include the subdivisions of matter.

The objects that we call great vanish when we contemplate the vast body of the earth; and the earth, in its turn, is lost in the solar system. In some parts, it is seen only as a distant star; in others, it is unseen, or seen only at certain times, by vigilant observers, assisted, perhaps, by instruments like our telescopes. The sun itself dwindles into a star—Saturn's vast orbit, and the orbits of the comets, crowd into points—when viewed from numberless places between the earth and the nearest fixed stars. Other suns give light to illuminate other systems, where the rays of our sun are unperceived; but these also are swallowed up in the immeasurable expanse. Even all the systems of the stars which sparkle in the clearest sky, must possess but a small part of that space over which such systems are dispersed, since more stars are discovered in one constellation, by the telescope, than the naked eye perceives in the whole heaven.

And after we have proceeded thus far, and left all definite measures behind us, we find ourselves still no nearer to a limit; for all this is nothing to what may be displayed in the infinite expanse beyond the remotest stars that have ever been discovered.

We shall now proceed to give an account of some of the different theories that have prevailed, at different times, concerning the solar system. They are various and contradictory.

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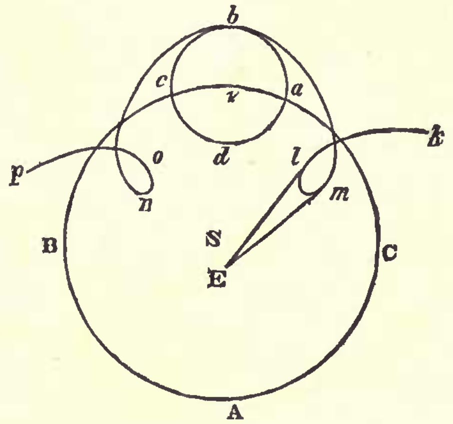
no more shaken than that of Christopher Columbus was when he announced the existence of a new world. The German journals have published the observations of Professor Gruithausen, combined with those of his learned brother, the astronomer Schroeter. Their common conclusions are, 1. That vegetation upon the surface of the moon extends to the fifty-fifth degree of latitude south, and to the sixty-fifth degree of latitude north; 2. That from the fiftieth degree of latitude north to the forty-seventh degree of latitude south may be perceived evident traces of the abode of animated beings; 3. That some signs of the existence of lunar inhabitants are sufficiently apparent to enable a person to distinguish great roads traced in several directions, and particularly a colossal building, situate nearly under the equator of the planet. The *ensemble* presents the aspect of a large town, near to which may be distinguished a building, perfectly resembling that which we call a redoubt.

The most celebrated of those who established a hypothesis among the ancients, and who defended it with a show of reason and argument, was Ptolemy, called "the wisest and most divine among the Greek philosophers." He flourished at Alexandria, in Egypt, in the time of the emperor Adrian, about one hundred and thirty years after Christ. He supposed that the earth was fixed immovably in the centre of the universe, and that the moon, Mercury, Venus, the sun, Mars, Jupiter, and Saturn, revolved around it, according to the order mentioned. Above these, he placed the firmament of the fixed stars, the primum mobile, and cœlum empyrium, or heaven of heavens; all of which were imagined to move round the earth once in twenty-four hours, as also in certain other stated or periodical times, agreeably to their annual changes and appearances. And to account for their different motions, Ptolemy was obliged to imagine a number of curves, called eccentrics and epicycles, which crossed and intersected each other in various directions.

This theory may be explained by reference to the figure below. Let A B C be a circle, S the centre, E the earth; *a b c d* another circle, whose centre, *v*, is in the circumference of the circle A B C. Conceive the circumference of the circle A B C to be carried round the earth every twenty-four hours, according to the order of the letters, and at the same time let the centre *v* of the circle *a b c d* have a slow motion in the opposite direction, and let a body revolve in this circle in the direction *a b c d;* then it is manifest, that, by the motion of the body in this circle, and the motion of the circle itself, the body might describe such a curve as is represented by *k l m b n o p;* and if we draw the tangents E *l*, E *m*, the body would appear stationary at the points *l* and *m*, and its motion would be *retrograde* through *l m*, and then *direct* again. Now, to make Venus and Mercury always accompany the sun, the centre *v* of the circle *a b c d* was supposed to be always very nearly in a right line between the earth and the sun, but more nearly so for Venus than for Mercury, in order to give each its proper elongation. This system, although it will account for all the motions of the bodies, yet it will not solve the phases of Venus and Mercury; for, in this case, in both conjunctions with the sun, they ought to appear dark bodies, and to lose their lights both ways from their greatest elongations; whereas, it appears, from observation, that, in one of their conjunctions, they shine with full faces.



This rude system was soon found incapable of standing the test of observation and experiment, and, notwithstanding the opposition of blind and zealous bigots, it has long been rejected by all mathematicians and philosophers. The planets Mercury and Venus are now well known not to include the earth in their orbits, and the comets move through the heavens in all directions, so that they must infallibly have met with continual obstructions, and would long since have broken to pieces all the imagined crystal spheres, and rendered them totally unfit for the purposes for which they were designed.

The contradictions and perplexities attending the theory of Ptolemy were, indeed, so numerous and evident, that it was impossible they should ever be reconciled upon that hypothesis. Notwithstanding this, mankind were not easily induced to give up their darling prejudices, and embrace the truth in whatever form she might be presented. Many early habits were to be corrected, and vulgar prepossessions eradicated from the mind, before men could be brought to reckon the earth as a planet, and to believe this vast globe, which appears to be the most fixed of all things in nature, to be whirling round the heavens with such rapidity.

The system received by the Egyptians was this: that the earth is immovable in the centre, about which revolve, in order, the moon, sun, Mars, Jupiter, and Saturn—and about the sun revolve Mercury and Venus. This disposition will account for the phases of Mercury and Venus, but not for the apparent motions of Mars, Jupiter, and Saturn.

The next system which we shall mention, though posterior in time to the true, or *Copernican System*, as it is usually called, is that of Tycho Brahe, a Polish nobleman. He was pleased with the Copernican system, as solving all the appearances in the most simple manner; but conceiving, from taking the literal meaning of some passages in Scripture, that it was necessary to suppose the earth to be absolutely at rest, he altered the system, but kept as near to it as possible. And he further objected to the earth's motion, because it did not, as he conceived, affect the motions of comets observed in opposition, as it ought; whereas, if he had made observations on some of them, he would have found that their motions could not otherwise have been accounted for. In his system, the earth is supposed to be immovable in the centre of the orbits of the sun and moon, without any rotation about an axis; but he made the sun the centre of the orbits of the other planets, which, therefore, revolved with the sun about the earth. By this system, the different motions and phases of the planets may be solved, the latter of which could not be by the Ptolemaic system; and he was not obliged to retain the epicycloids, in order to account for their retrograde motions and stationary appearances. One obvious objection to this system is, the want of that simplicity by which all the apparent motions may be solved, and the necessity that all the heavenly bodies should revolve about the earth every day, whereas it is physically impossible that a large body, as the sun, should revolve in a circle about a small body, as the earth, at rest in its centre. If one body be much larger than another, the centre about which they revolve must be very near the large body,—an argument which holds also against the Ptolemaic system. It appears, also, from observation, that the plane in which the sun must, upon this supposition, diurnally move, passes through the earth only twice in a year. It cannot, therefore, be any force in the earth which can retain the sun in its orbit; for it would move in a spiral, continually changing its plane. In short, the complex manner in which all the motions are accounted for, and the physical impossibility of such motions being performed, is a sufficient reason for rejecting this system; especially when we consider in how simple a manner all these motions may be accounted for, and demonstrated, from the common principles of motion. Some of Tycho's followers, seeing the absurdity of supposing all the heavenly bodies daily to revolve about the earth, allowed a rotary motion to the earth, in order to account for their diurnal motion, and this was called the *semi-Tychonic system;* but the objections to this system are, in other respects, the same.

Thus, instead of consulting the heavens, and collecting the history of nature, philosophers were ambitious to gratify their vanity, or their preconceived notions, by inventing whimsical hypotheses, which had no conformity to fact. Cycles and epicycles were multiplied, to answer every appearance, till the universe had lost all its native beauty in their descriptions, and seemed again reduced to chaos by their unhappy labors.

The system which is now universally received is called the *Copernican.* Here the sun is placed in the centre of the system, about which the other bodies revolve, in the following order: Mercury, Venus, the Earth, Mars, Jupiter, Saturn, and Herschel, which was discovered by Dr. Herschel; beyond these, at immense distances, are placed the fixed stars. The moon revolves about the earth, and the earth revolves about an axis. This disposition of the planets solves all the phenomena, and in the most simple manner; for, from inferior to superior conjunction, Venus and Mercury appear first horned, then dichotomised, (halved,) and next gibbous, and the contrary from superior to inferior conjunction. They are always retrograde in their inferior, and direct in their superior, conjunction. Mars and Jupiter appear gibbous about their quadratures; but in Saturn and Herschel this is not sensible, on account of their great distances. The motions of the superior planets are observed to be direct in their conjunction, and retrograde in their opposition. All these circumstances are such as ought to take place in the Copernican system. The motions, also, of the planets are such as should take place upon physical principles. We may also further observe, that the supposition of the earth's motion is necessary, in order to account for a small apparent motion which every fixed star is found to have, and which cannot otherwise be accounted for. The harmony of the whole is as satisfactory a proof of the truth of this system as the most direct demonstration could be: we shall therefore assume this system to be true.

Among the modern philosophers, one, who attempted to explain the phenomena of nature by principles less exceptionable than those of the ancients, and who acquired a great reputation among his followers, claims, at least, a passing notice for his theory respecting the solar system.

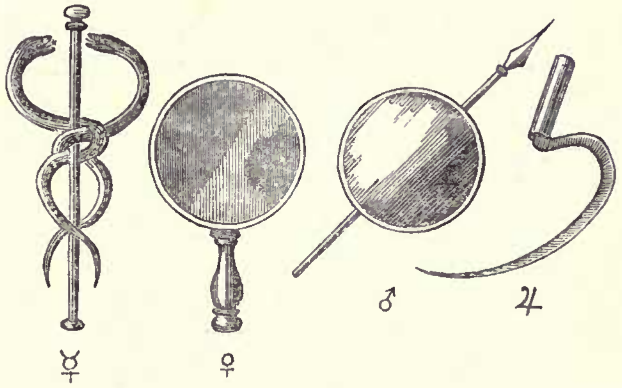
Des Cartes was the author of a new system, which, for a long time, divided the opinions of the learned, and was considered by many as the most extensive and exquisite in its contrivance of any that had been before imagined. Endowed with a bold and elevated genius, he attempted to unveil at once all the mysteries of nature, and thought it beneath him to offer any thing to the world less than a complete and finished system.

To account for the motions of the celestial bodies, he supposes the sun to be placed in the centre of a vast whirlpool of subtle matter, which extends to the utmost limits of the system; and the planets, being plunged into such parts of this vortex as are equal in density to themselves, are continually dragged along with it, and carried round their several orbits, by its constant circulation. Those planets that have satellites are likewise the centres of other smaller whirlpools, which swim in the great one; and the bodies that are placed in them are driven round their primaries in the same manner as those primaries are driven round the sun.

Hence, as the sun turns upon its axis the same way as the planets move, and the primaries turn round their axes the same way as their satellites move round them, it was imagined, that, if the whole planetary region were filled with a fluid matter like that before mentioned, the sun and planets, by a constant and rapid rotation on their axes, would communicate a circular motion to every part of this medium, and by that means drag along the bodies that swim in it, and give them the same circumvolution. This is the celebrated system of vortices, and the world, of Des Cartes. However absurd or romantic this may seem now, when first stated it divided the whole philosophic world into two great parties.

The solar system consists of the sun, with the planets and comets, which perform their revolutions around him. In the midst apparently of a vast concavity, surrounded every way with stars, which are at an immense distance from the sun and from each other, is the great central luminary, whilst eleven planets and several comets perform their revolutions around him, at different distances from him, and in different periods of time.

The planets may be considered as so many earths, enlightened and warmed by the sun in different degrees, inhabited by creatures rational and irrational, and, it may be, very different from those on our globe. To inhabitants of these planets the earth, if visible, would appear like the rest of the primaries. *The names* of the planets, in the order of their distance from the sun, with their respective symbolical characters, are as follows:— ☿ Mercury; ♀ Venus; ⊖ Earth; ♂ Mars; ⚶ Vesta; ⚵ Juno; ⚳ Ceres; ⚴ Pallas; ♃ Jupiter; ♄ Saturn; ♅ Herschel. An origin has been



ascribed to these characters which will be understood by a reference to the accompanying plate. They were taken from the symbols of those heathen deities whose names they bear. Thus, the character of Mercury, ☿, is his caduceus, or rod, with serpents twined about it; that of Venus, ♀, a looking-glass, with a handle, such being the form of the ancient mirrors; that of Mars, ♂, a buckler and spear; that of Saturn, ♄, a sickle; that of Jupiter, ♃, is Z, the first letter of his name in Greek, (Zeus,) with a stroke through it to denote abbreviation. To this we may add that the sun's character, ⊙, represents a buckler, as the ancients kept their bucklers bright to dazzle the eyes of their enemies; ☽, the moon, plainly represents a crescent; ⊖, the earth, seems to represent a sphere, with the equator. As to the other planets, their discovery is of modern date.

The comparative distances of the planets from the sun are as follows, the earth's being considered as unity: that of Mercury is $\frac{4}{10}$; of Venus, $\frac{7}{10}$; of Mars, $1\frac{1}{2}$; of Vesta, $2\frac{4}{10}$; of Juno, $2\frac{7}{10}$; of Ceres, $2\frac{8}{10}$; of Pallas, $2\frac{8}{10}$; of Jupiter, $5\frac{2}{10}$; of Saturn, $9\frac{1}{2}$; of Herschel, $19\frac{2}{10}$. The following may be a more simple method of remembering the distances of the different planets from the sun.

Write in a line the following series of numbers, the law of which is evident:—

0, 3, 6, 12, 24, 48, 96, 192.

Add four to the first six, and we have

4, 7, 10, 16, 28, 52, 96, 192.
☿ ♀ ⊕ ♂ ⚳ ♃ ♄ ♅

It will be seen, by the signs placed under these numbers, that if 10 represents the distance of the earth from the sun, 4 will be the distance of Mercury; 7 that of Venus; 16, 52, 96, and 192, the respective distances of Mars, Jupiter, Saturn, and Uranus.

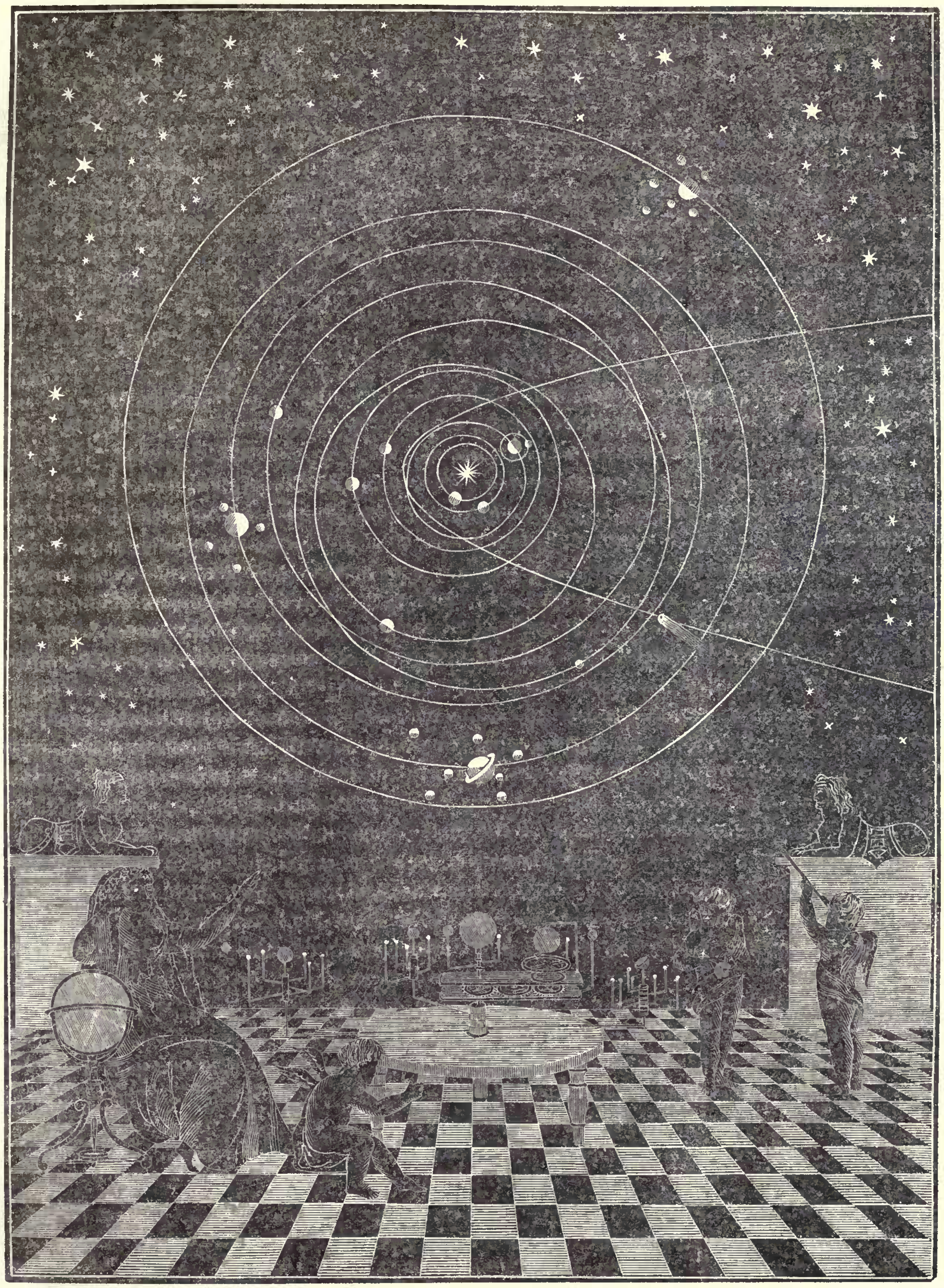
The absolute distances will be given hereafter, and the method of finding those distances. When we compare the distances of the several planets from the sun in a looser and more general way, we call those *inferior* which are nearer the sun than the earth is, those *superior* which are further from the sun than the earth is.

The periodical times in which the planets go round the sun, are as follows, in days and decimals: Mercury, 87.97; Venus, 224.7; Earth, 365.3; Mars, 686.98; Vesta, 1325.74; Juno, 1592.66; Ceres, 1681.39; Pallas, 1686.54; Jupiter, 4332.6; Saturn, 10759.2; Herschel, 30686.8, of our time.

These are called primary planets. The four between Mars and Jupiter, being very small, have been named "asteroids," which signifies "similar to stars." Some of the planets are attended in their courses round the sun by certain smaller spherical bodies, which have been accordingly named secondaries, satellites, or attendants. Thus, our earth has one moon, Jupiter four, Saturn seven, and Herschel six. None of these, except our satellite, are visible without the aid of the telescope.

The name Saturn (synonymous with time) seems to have been given to that planet from the apparent slowness of its motion; Jupiter, from its brightness; Mars, (from the god of war,) because of its red fiery appearance; earth, from its supposed want of splendor; Venus, from its beauty; Mercury, probably, from the rapidity of its motion.

The dominion of the heavenly bodies was fancied by the superstitious among the ancients, and, we grieve to add, by some who ought to know better among the moderns, to be so extensive, that the sun, moon, and planets, had each of them a particular constellation or portion of the heavens assigned it, wherein being posited, they were supposed to be most powerful in their influence, and were therefore said to be in their exaltation; and when in the opposite part of the heaven they were said to be in their fall or detriment, and thought to be weak. Besides this, every one had its peculiar color, metal, stone, tree, flower, animal, number, day, &c., assigned it, whence are derived the supposed virtues of amulets and talismans, for the dealers in these fooleries pretend that there is a sympathy between the heavenly bodies and those things which are under their dominion, so that, for instance, the plant over which any planet presided



had a power of attracting the influences of that planet.

The paths or orbits of the planets round the sun may well enough be considered as concentric circles, having the sun in their common centre. In this view, they are represented in the accompanying plate, where, the sun being the centre, the smallest circle represents the orbit of Mercury, the next that of Venus: the orbits of the earth, Mars, the four small planets, Jupiter, Saturn, follow in their order, and are easily distinguished, as well by their several dimensions, as by being marked with the characters of their respective planets. Each of the elliptical curves represents a portion of the orbit of a comet. The remainders of the ellipses are to be conceived as extending far beyond the paper.

The orbits of the planets are not in the same plane, as they are represented in the plate; though the difference of the inclinations of their orbits is small, excepting those of Pallas, Juno, and Ceres. The mode of expressing the situation of the orbits, in this respect, is to take the plane of the earth's orbit as a standard, and compute the inclination of the several orbits to this.

The heliocentric circle of a planet is that which the planet would appear to describe to a spectator in the sun. All very distant objects appear to us situated in some part of the sphere that we call the heavens. If, then, a spectator at the sun were to observe any planet, it would appear to him situated among the fixed stars; and if he continued to observe it during its entire revolution, though it were in reality at a distance incomparably less than that of the stars, it would seem to him to describe a great circle on the starry sphere. This would be the heliocentric circle of the planet, because it is described by a line (the radius vector) drawn from the eye of an observer at the sun to the planet, and is always in the plane of that planet's orbit.

We may say, generally, that to a spectator in the sun the several planets would appear to describe different circles in different periods of time. If these circles were all in the same plane, they would appear to coincide, that is, one circle would represent them all; but as the planes of the planets' orbits are all different, the circles to represent them must be different; and since the times of their revolutions in their apparent circles are the same as their respective periods in their real orbits, there must be the same difference between the former as between the latter.

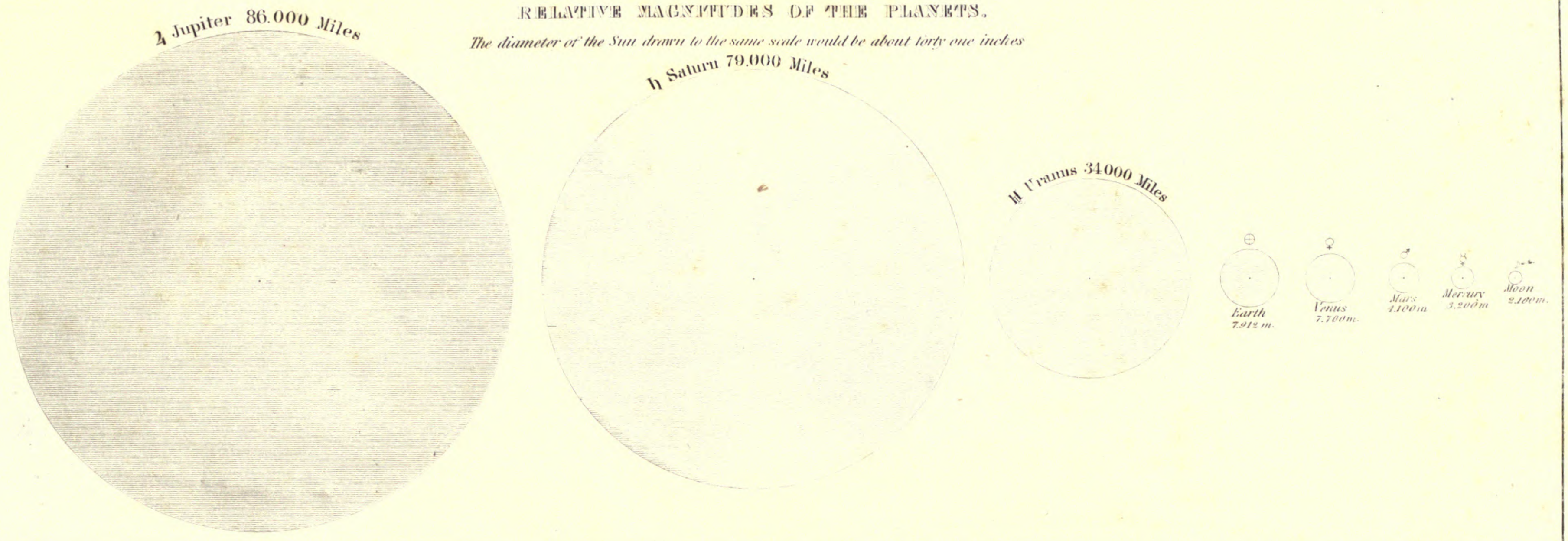
The configurations of the heavenly bodies, arising from their situations with regard to their different longitudes measured on the ecliptic, are called *aspects;* as if they looked at one another in different manners, according to their positions. The term seems to have been adopted from a supposition once entertained that the sun, moon, and planets, were animated beings. The framers of judicial astrology would have us believe that some of the heavenly bodies are of a benign, others of a malignant, nature, having more or less effect according to their aspects. Kepler, therefore, defined an aspect to "be an angle formed by the rays of the planets meeting on the earth, and having power to influence sublunary beings."

We have already treated of the motions of the sun and moon. These two are more interesting to us than all the other heavenly bodies: the first because it is the principal source of life and fruitfulness to the earth; the second because of its proximity, its beauty, its phases; and both, because they furnish us the means of measuring time. Yet the other bodies which compose our planetary system reward our researches with results that are equally curious and useful. By studying them we shall attain a more perfect knowledge of the system of the universe, and this knowledge, in turn, will have an effect upon our first results, either correcting them by more exact measurements, or enabling us to regard them in a more extended connection, or, finally, discovering to us relations that had before escaped our observation; for the comparison of many similar phenomena necessarily developes their analogies, and we learn to see the more, the more we practice observation.

Encouraged by this belief, we enter with zeal upon the study of the planetary motions. We shall seek to discover their laws from a comparison of the phenomena they present.

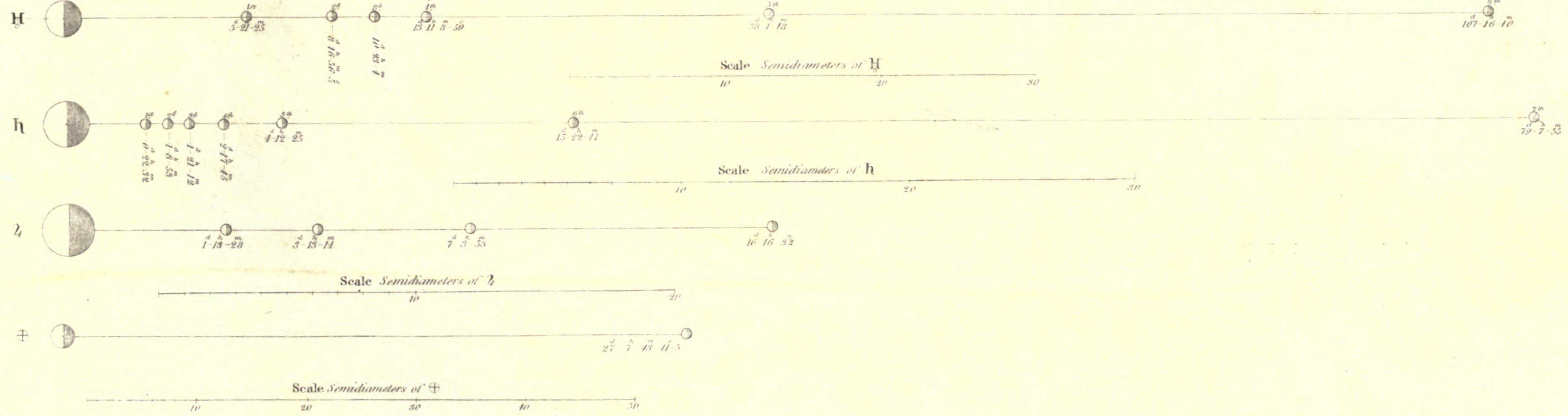
RELATIVE MAGNITUDES OF THE PLANETS.

The diameter of the Sun drawn to the same scale would be about forty one inches



Mean Distances of the Planets from the Sun in Millions of Miles.

Distances of the Satellites from their Primaries in equatorial radii of the latter, and their sidereal periods.



Let us begin with Venus, which is the most conspicuous. There is no one who has not remarked at times a beautiful star shining in the west a little after sunset, and called, for this reason, the *evening star*. This is the planet Venus. On observing it for several successive days, we perceive that it does not remain constantly at the same distance from the sun. It removes until it reaches a certain limit, which is about forty-five degrees, after which it seems to approach the sun again; and as we can commonly see it with the naked eye only when the sun is below the horizon, it is visible for a short time immediately after sunset. After some time has elapsed, it sets with the sun, and then, the splendor of the sun's light preventing us from perceiving it, we lose it entirely from our view.

After some days, we discover in the morning, near the east, a beautiful star, which we had not observed there before. At first it rises but a few moments before the sun, and we name it, from this circumstance, the *morning star*. From day to day it removes further from the sun, and rises earlier and earlier; but after having attained a distance of about forty-five degrees from that luminary, again approaches it, rises with it, and consequently ceases to be visible.

Soon after, the evening star is again seen in the west, at a little distance from the sun. As this distance increases, it escapes from the splendor of the sun's rays. Afterward it approaches again, and again recedes, always following the same laws, and being in turn a morning or an evening star.

These alternate motions, observed during more than two thousand years without interruption, plainly show that the morning and evening star are one and the same body. They also teach us that this star has a proper motion, and that, by reason of this proper motion, it seems to oscillate about the sun, appearing now as if preceding, and now as if following, that luminary.

These are the appearances presented to the unaided eye; but that excellent invention, the telescope, permits us to extend these observations much further. By this instrument that is revealed to us which before was only imagined, viz., that Venus has *phases*, like the moon.

In the evening, when it is approaching the sun, it appears as a luminous crescent, the horns of which are toward the east, that is, in a direction opposite the sun. The apparent size of this crescent diminishes day by day, as the planet approaches the sun. But after it has passed the sun, and reappears, in the morning, on the other side of that luminary, the horns of the crescent are turned in the direction opposite to what they were at the former observation, that is, they are turned toward the west. The luminous phase gradually increases in size, and assumes the form of a semicircle. Venus is then in its first quarter. In proportion as it advances toward the sun, the visible portion of its enlightened disc increases, and when it overtakes the sun it appears to us *full*. After it has passed by the sun, and appears in the west, its disc begins to be hollowed out, and the portion enlightened to us diminishes, gradually passing through the same phases that it presented to us in its augmentation.

These phenomena represent to us Venus as if it were a moon revolving round the sun and enlightened by its rays, and all observations show this to be the case. When Venus appears full, it is beyond the sun in respect to the earth, and its apparent diameter is then very small, not exceeding one sixth of a minute. On the contrary, as its disc diminishes, and its illuminated face turns more and more away from us, its apparent diameter increases. It must then be nearer to the earth. Finally, during the time elapsed between its disappearance in the evening and its reappearance in the morning, it may be seen, though rarely, to pass over the disc of the sun, looking like a round and black spot. It is then between the sun and earth, and its apparent diameter is greater than in any other part of its revolution, amounting to nearly one minute of a degree.

These variations are not perceptible by the naked eye, because of the irradiation, which enlarges somewhat the apparent diameters of the heavenly bodies, and the more so the more illuminated they are. The phases of Venus increasing in size when it is beyond the sun, the increase of its light compensates for its greater distance. But the telescope destroys the illusion, and teaches us its real variations in distance by those of its apparent diameter.

The orbit of Venus is not without that of the earth; for if it were this planet would sometimes be seen in opposition to the sun, and the earth would be between them. This never happens. Nor is its orbit entirely beyond the sun in respect to the earth; if it were so, Venus would never be seen between the earth and sun—but it sometimes eclipses that luminary. In fine, while the sun seems to move in the ecliptic, Venus never removes beyond certain limits, and its oscillation about the sun, or its *elongations*, are always nearly of the same extent. These facts, united, evidently prove that Venus moves around the sun in an orbit returning into itself, and that it is carried onward with the sun by that body's apparent motion in the ecliptic.

The progressive changes in the phases of that planet prove, moreover, that it is opaque, not shining by its own light, and that it is nearly spherical.

The orbit of Venus, in its various positions, appearing to us under different points of view, there necessarily results quite a number of apparent irregularities and anomalies when we choose to refer its motions to the centre of the earth. But these complications in its movement disappear if we consider them in reference to the sun, which is the true centre of them. Observations confirm this statement.

Venus is not the only planet that presents the phenomena of which we have thus spoken. *Mercury* exhibits perfectly similar appearances; but its excursions are confined within narrower limits. This planet revolves around the sun like Venus, but in a smaller circle. The observation of its phases proves that it is opaque, being enlightened by the sun, and that it is nearly spherical. Its greatest apparent diameter is about eleven seconds, its least five seconds.

These two planets (Mercury and Venus) are called *inferior* planets, because, the radius of their orbits being less than that of the earth's orbit, they are nearer than the earth is to the sun. To an observer on the earth, the motion of the planets appears sometimes direct, or from west to east, sometimes retrograde, and both of these with great inequalities of velocity. Sometimes they appear stationary for a time, not sensibly changing their places in the sphere of the heavens. This diversity in their appearance is owing to the several combinations of the motions of the planets and the earth in their orbits; and therefore, in order to give a full explanation, both these motions must be taken into the account. But it will not be amiss first to consider them separately. And since the earth is longer in going round the sun than either of the inferior planets, let us consider the earth as at rest in some part of its orbit, whilst an inferior planet (Mercury, for example) revolves round the sun, and see what its appearances would be on this supposition.

Whilst an inferior planet is moving in its superior * semicircle, its motion, seen from the earth, is direct, or from west to east; whilst moving in its inferior † semicircle, it is retrograde, or contrary to the order of the signs of the zodiac. When the earth is in the line of the nodes of an inferior planet, its orbit, in a perspective view, is represented by a straight line, because the plane of that orbit passes through the eye of an observer on the earth, and therefore the planet's *apparent* motion is in a straight line. Let the earth be in the line of Mercury's nodes, the projection of that planet's orbit is a straight line, extending on each side of the sun to the planet's greatest distance from that luminary. If Mercury at this time be in its superior semicircle, its apparent motion is direct, but unequal, passing over unequal portions of the line in equal times, and the faster the nearer to the sun. If a conjunction happens, it passes behind the sun. But if, on the other hand, Mercury be in its inferior semicircle, its apparent motion is retrograde,

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* The superior semicircle is the part of the planet's orbit which is further from the earth than the sun is.

† The inferior semicircle, that part which is nearer to the earth than the sun is.

in the same straight line, but more unequal than before, going the faster the nearer to the sun; and in the case of a conjunction, passing between the sun and our eye, it appears on the sun's disc. The transits of Mercury are not unfrequent: those of Venus seldom happen, occurring but twice in one hundred and twenty years. When the earth is out of the line of the nodes of an inferior planet, its orbit appears an ellipse, more or less eccentric according as the eye is elevated above its plane. Suppose the earth ninety degrees out of the line of Mercury's nodes, the projection of its orbit will be an elliptic curve, and in superior conjunction it will be above the sun, and its motion direct—at inferior conjunction below the sun, and its motion retrograde. In these cases its apparent motions will be unequal, faster the nearer conjunction, most unequal in the inferior semicircle, going through unequal arcs in equal times.

Thus the geocentric motions of the inferior planets is sometimes swifter and sometimes slower,—swifter the nearer to the sun, slower the nearer to their greatest elongations. This inequality is not owing to the small real inequality of their motions in their orbits, but to their orbits being viewed obliquely, and, by this means, projected into long ellipses, or straight lines, with the sun in the middle of them; in which projections a body moving with a uniform velocity round a circle will appear to move irregularly, swifter the nearer to the middle, slower the nearer to the extremities.

An inferior planet is stationary while its motion is changing from direct to retrograde, or from retrograde to direct; that is, it will appear not to change its place sensibly for some time. If the earth stood still, the places where the planets were stationary would be at their greatest elongations; for, though it be the nature of a tangent to touch its circle only in one point, yet, when the circle is large, the receding of the curve from the tangent is not perceptible in the parts very near the point of contact. To an observer on the earth, the inferior planets appear always near the sun, alternately departing from and advancing towards it, first on one side and then on the other, sometimes so near the sun as to be rendered invisible by its strong light: sometimes, when in or near their nodes, they pass behind the sun, or between the earth and sun.

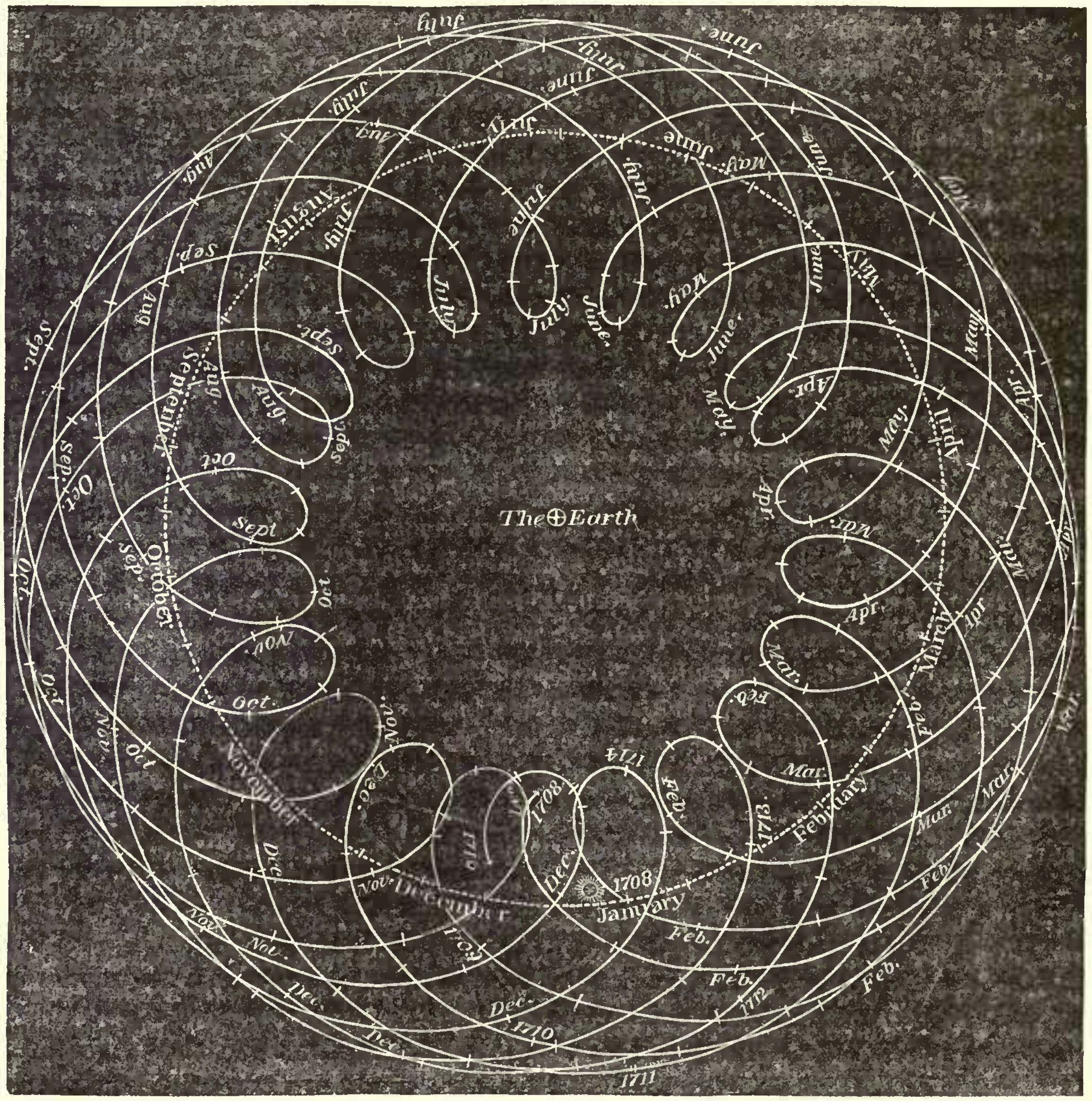
We have thus far considered the earth as stationary, while the inferior planets go round the sun. If the earth were really without motion, the places of the conjunctions, of the stations, of the direct and retrograde motions, of the planets, would always be in the same parts of the heavens. But the places where these appearances happen are continually advancing in the ecliptic, by the motion of the earth in its orbit.

The geocentric motions of Venus are similar to those of Mercury, only, as Mercury goes through its orbit quicker than Venus, its changes are more frequent.

An inferior planet in inferior conjunction with the sun is said to be in perigee, (nearest the earth,) in superior conjunction to be in apogee, (most distant from the earth.) These distances are, however, variable, and their variation is owing partly to the eccentricities of the planets' orbits, and partly to their motions, by which it happens that they are in perigee when in different parts of their orbits, as well as when the earth is in a different part of its orbit. Since the difference between the perihelion and aphelion distances is greater in the orbit of Mercury than in that of the earth, Mercury will be at its least possible distance from the earth when it is in perigee and at the same time in aphelion; because, Mercury being then between the earth and the sun, its attaining its greatest distance from the sun brings it nearer the earth. Again, Mercury is at its greatest possible distance from the earth when in apogee at the same time that it is in aphelion. With Venus it is not so, because the difference between its perihelion and aphelion distances is less than that of the earth's.

The inferior planets, revolving in orbits nearer the sun than the orbit of the earth, and being sometimes nearer to us than at others, present apparent diameters sometimes greater than at others; and, conversely, from the difference of their apparent diameters, we might conclude that their distances were different.

A common spectator may observe an inferior planet alternately approach nearer the sun till in conjunction, and recede further till at its greatest elongation; and this will be first on one side of the sun and then on the other. But if we observe the change of its apparent place in the sphere of the heavens, its stations, direct motions, and retrogradations, and measure its disc frequently with the micrometer, we shall find that the planet at times comes nearer to us, and at others recedes further from us, in such a manner that, taking the whole of its apparent motion into account, its course round the earth appears to be a complicated curve; and such a curve must it actually describe if the earth remain stationary.



The plate below will best exhibit what the motions of Mercury must be if the earth has no real motion. The earth is placed in the centre, as it always appears to be. The curved and looped line, marked with the names of the months abbreviated, shows the motion of Mercury, such as it appears to an observer on the earth, for seven successive years. The short strokes crossing the curved line show the place of the planet for aliquot parts of the month. The years, as well as the months, are set down in their proper places. Thus the curve exhibits the direct motions, the stations, and retrogradations of Mercury, with the times of the same. It shows, also, its least and greatest distances from the earth, with the several intermediate distances. The apparent motions of Venus are so similar to those of Mercury (the difference consisting in the less number of the loops) that it will be unnecessary to describe them. All the planets, except Mercury and Venus, come into *conjunction* and *opposition* with respect to the sun; that is, at certain times they are in the same direction as the sun from the earth, and at other times in a contrary direction. But this last circumstance never happens to Mercury and Venus. We are led by other analogies, however, to examine if the other planets do not revolve about the sun like Mercury and Venus, but in larger orbits. By following out this idea, we perceive that the phenomena observed all declare the existence of such a motion.

For example, take Mars. If we observe it with a telescope, we shall see its disc constantly round (or nearly so) and enlightened; it is never a crescent, like that of Venus. Yet it presents very perceptible variations in its apparent form. This form is completely circular in conjunction and opposition. In passing from one of these positions to the other, it contracts a little, and assumes the form of an oval, more or less narrow. This change always takes place in a slow and gradual manner.

These phenomena teach us that Mars is an opaque body, and nearly spherical, reflecting the light of the sun. They are well represented by supposing this planet in motion in an orbit returning upon itself, and surrounding the sun and earth. In fact, the connection of this circumstance with the phenomena exhibited, is so necessary that they cannot be true without its being equally so. If the orbit of Mars did not embrace that of the earth, it would never appear in opposition; and if it did not surround the sun, so that it could at conjunction pass between the earth and sun, its disc would become a crescent, like those of Venus and the moon—instead of which it always appears nearly round.

A superior planet, going round the sun in an orbit larger than the earth's, can only be in conjunction with the sun when the latter is between the earth and the planet. It is in opposition to the sun when the earth is between it and the sun, and in quadrature to the sun when its geocentric place differs ninety degrees from that of the sun.

As the earth goes round the sun in less time and in a less orbit than any of the superior planets, it will not be amiss to suppose one of these last to stand still, in some part of its orbit, while the earth goes once round the sun, and to consider the *apparent* motions of the planet on this supposition. While the earth is in its most distant semicircle, the apparent motion of the planet would be direct; while in its nearest semicircle, the planet's apparent motion would be retrograde; and while the earth is near the points of contact of a line drawn from the planet tangent to the earth's orbit, the planet would appear stationary.

The direct motion of a superior planet is swifter the nearer it is to conjunction, and slower the nearer it is to quadrature, with the sun; and the retrograde motion is swifter the nearer the planet is to opposition, slower the nearer it is to quadrature.

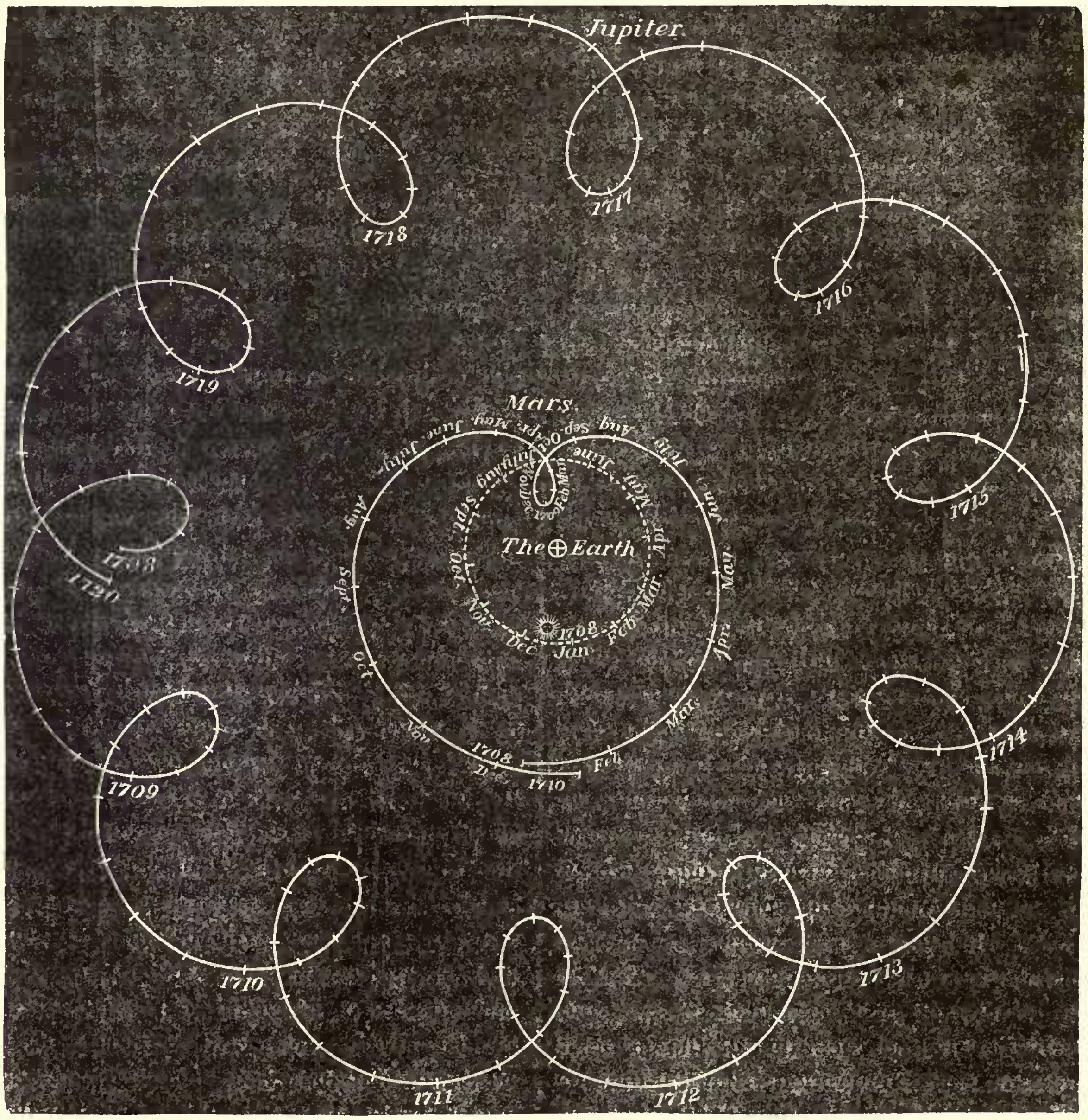
All the changes in the motions of the superior planets, caused by the earth's motion in its orbit, will happen in the same manner if we suppose the planet to go on slowly in its orbit, only they will happen every year when the earth is in a different part of its orbit, and, consequently, at different times of the year.

A superior planet in conjunction with the sun is said to be in apogee: in opposition, it is said to be in perigee.

The distance of each of the superior planets from the earth at apogee is variable, as is also their distance at perigee. This variation is owing partly to the eccentricities of their orbits, and of the orbit of the earth, and partly to the motions of the planet and the earth; by which it happens that they are in apogee or perigee when in different parts of their orbits, as well as when the earth is in a different part of its orbit.

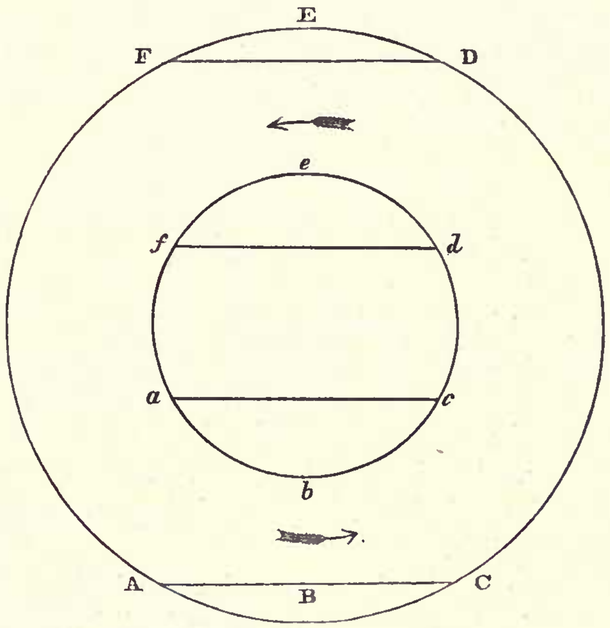
Since the superior planets go round the sun in orbits larger than that of the earth, they must be sometimes nearer to us than they are at others, and, consequently, their apparent diameters are variable.

If we observe the apparent change of place of the superior planets in the sphere of the heavens, their direct motions, stations, and retrogradations, and measure their discs with the micrometer, we shall find, by the difference of their apparent diameters at different times, that their apparent courses are in complicated looped curves; and in such curves must their real motions be if the earth be fixed in the centre. In the figure, the motion of Mars during two years is laid down; that of Jupiter for twelve years.



The motions of the planets, as seen from the earth, being some of the most difficult appearances to represent to the imagination, we shall endeavor to illustrate them by ships in motion on the sea.

A body moving along the same way with the eye, with a velocity equal to that of the eye, will appear to be at rest. Thus, if two ships are sailing eastward, in parallel lines, at the same rate, to a spectator in one of the ships the other will appear constantly in the same place, and he will have the same view of it as if both ships stood still. But if the body move with a greater velocity than the eye, it will appear to go forward, but with a less velocity than if the eye were at rest: if two ships sail, in parallel lines, eastward, with unequal velocities, the swifter will, to a spectator in the slower ship, appear to sail eastward, but with a slower motion than if he stood on the land. A body moving the same way with the eye, but with a less velocity, will appear to move in a direction contrary to its real motion: if two ships sail eastward with unequal velocities, to a spectator in the swifter ship the slower will appear to move westward. If a body move in a direction contrary to the motion of the eye, that body will seem to move in the direction of its real motion, but with a greater velocity than if the eye were at rest: if two ships sail, in parallel lines, one eastward, the other westward, to a spectator in the ship sailing east the other ship will appear to move west, but with a greater velocity than it really does. If a body at rest be viewed by the eye carried along, the body will appear to move with a velocity equal to that of the eye, but in a contrary direction: thus, to a spectator in a ship sailing eastward, the shore seems to go westward with a velocity equal to that of the ship. And if a body move round in one circle, and the eye be carried round in another concentric with the first, when the eye and the body are in the semicircles on the same side, they may be considered as going in parallel lines in the same direction; but when the eye and the moving body are in opposite semicircles, they may be considered as moving in parallel lines in opposite directions. In the figure, if two ships sail in the concentric circles *a b c d*, &c., and A B C D, &c., according to the order of the letters, while they are in the curves A B C and *a b c* they may be considered as moving eastward in the parallel lines A C and *a c*, and while in the semicircles D E F and *d e f*, as both going westward in the parallel D F and *d f*. When the ships are in the opposite semicircles, A B C and *d e f*, they may be considered as moving in parallels, but in different directions, one eastward in A C, and the other westward in *d f*. By considering what has been said of the ships in motion, we hope the reader will be assisted in understanding the apparent motions of the planets.



The apparent diameter of Mars increases in coming from conjunction to opposition, and diminishes in going from opposition to conjunction. Therefore, in the first instance Mars must be approaching the earth, and in the second receding from it. The variation of its apparent diameter is very considerable. Its greatest value is about eighteen seconds, its least about four seconds. The distances, then, are to each other as four to eighteen, or as four and a half nearly; that is, Mars is nearly four and a half times more distant from the earth in the second case than in the first.

These great differences teach us that the earth is not the centre of the motions of Mars. If we trust ourselves to the guidance of analogy, we shall find it most natural to conclude that this planet, like Mercury and Venus, revolves around the sun, which carries the orbit of Mars along with it in its annual motion through the ecliptic. The greatest and the least distances of Mars from the earth would happen when the sun was at its greatest distance from the earth. It would be at that time, therefore, we should find the apparent distance of that planet greatest or least; and observing this, we are obliged to conclude that Mars revolves around the sun.

The succession of phenomena that is presented by the other planets whose orbits include the earth's, and which, for that reason, are called *superior* planets, is precisely the same, and therefore leads to the same conclusions; only the variations that the apparent form of their disc presents are much less perceptible, and that form varies less from a circle. This proves that their distances from the sun are much more considerable than that of Mars; for if there were a planet placed so far from the sun that the sun's orbit could be regarded as a point in comparison to that distance, and this planet could be seen from the earth, the appearances presented to us would be the same as if we were at the sun's centre, and this planet revolved about us. Its disc would appear to us always as a circle, the variation of its phases being too small to be perceptible.

We are led by these reflections to believe that the sun is placed near the centre of all the planetary orbits, and that it carries them along in its annual motion on the ecliptic.

Shall we believe that this heavenly body really revolves in the ecliptic, or shall we regard this motion as an appearance produced by the real motion of the earth, which, carrying us successively to different points of the ecliptic, causes the sun, and the planetary orbits of which it is the centre, to appear to revolve about us? Assuredly, if we permit ourselves to be guided by analogy, always so evident in the works of God, we shall be led irresistibly to embrace the latter opinion, for in that, the sun being the common centre of our planetary system, symmetry will be established through all.

Let us forget the earth, and, imagining ourselves at the centre of the sun, endeavor to consider our observations as made at that point.

It first occurs to the mind as most simple to regard the planetary orbits as curves, whose planes pass through the centre of the sun. This supposition is confirmed by the analogy existing between the motions of the planets round the sun, and those of the moon round the earth. We will examine if it agrees with observations.

If the planets move in orbits whose planes pass through the centre of the sun, the points where each planet passes the plane of the ecliptic are opposite each other and in the same straight line, —a line drawn through the centre of the sun, and movable with it in the ecliptic. These points, then, determine the place where the orbit crosses the ecliptic, and the line joining them is called the *line of the nodes.*

An observer at the sun might easily decide if this condition were fulfilled. He would determine, by a series of observations, the moments when the latitude of the planet was nothing, and he would calculate if, at the same moments, the heliocentric longitudes were the same, or if they differed by half a circumference. We can also determine, by observations from the earth, the moment when the planet passes its nodes; but, not being at the centre of the planetary motions, these nodes will not appear to be at opposite points on the celestial sphere, for the line that joins them, being carried by the sun along the ecliptic, will appear to us successively under different degrees of obliquity, and thus render the opposition imperceptible.

Still, among all the situations which the plane of the orbit can assume, as regards us, there are two (very rarely happening, however,) in which the difficulty may be avoided. These are when the planet is without latitude, and at the same time in opposition to or conjunction with the sun; for then we see it in the same right line as if we were at the centre of the sun. Many observations of this kind would decide if the node of the planet has always the same longitude seen from the sun.

This method is quite practicable in regard to Mercury and Venus. As the revolutions of these two planets are very short, it follows that they must pass their nodes very often, as they must evidently pass through each in the course of every revolution. The frequency of these phenomena must therefore render the occurrence in question very frequent. The transit of these planets over the sun's disc is a particularly favorable opportunity for these observations; for then we see them in the same right line with the sun, while their latitude is necessarily very small, and they are very near one of their nodes. The observation of these transits would then determine the constancy of the nodes as seen from the sun.

All the observations of Mercury's transits unite to prove that this planet has a very small latitude, when its longitude, as seen from the sun, is about forty-five degrees. Consequently, it is then near that point which we call the *descending node*, because, when the planet passes it, it is descending toward the south pole of the ecliptic. This conclusion is confirmed by Delambre's calculation of the heliocentric longitude of Mercury's descending node at the transit in 1799. He found it, after applying certain necessary corrections, to be very nearly the same as the geocentric longitude given by the mean of the transits. Besides, its nodes are not strictly fixed. This will affect the results. Thus, by making such allowances as ought to be made in the calculation, we shall find that the longitude of the descending node of Mercury is nearly constant.

The same constancy is noticeable in Mercury's passage through another point, called the *ascending node*, because the planet then is approaching the north pole of the ecliptic.

The longitude, as seen from the sun, of the ascending node, exceeds that of the descending node by six signs nearly, that is, by a semicircumference. The two, then, as seen from the sun, are opposite each other, as they must be if all the points of the orbit be in the same plane. They are also nearly constant.

The passages of Venus through its descending node present the same agreement.

The agreement, however, of these phenomena, are not sufficient to permit us to extend the same conclusion to the other planets, which, because of the slowness of their revolutions, are much more rarely to be seen with small latitude at the time of conjunction. We must therefore find some method that may prove the constancy of the node, without the necessity of observing it under circumstances so rare. Geometry furnishes, for this purpose, a method very general, as well as very simple, which, however, it is unnecessary to detail here.

In the present state of astronomy, the motions of the planets may be regarded as pretty accurately known. Observers of the present age are seeking to determine them with still greater exactness. Yet, in adopting the motions as they have been laid down, we may consider them as sufficiently accurate for our purpose.

The place of the node being found, it may be used to determine the inclination. For this purpose, we observe when the sun *is in the node* of the planet, that is, when its longitude is the same as that of the node; then we calculate, from observation, the planet's latitude as seen from the sun, and a trigonometrical calculation gives us the inclination of the plane of the orbit.

It is difficult, or we might say impossible, to seize the exact moment when the sun is in that node; but by observing both bodies many days in succession before and after the time of the sun's passage through the node, we may, by calculations founded on the results, determine quite accurately the moment when this phenomenon must have happened. Then we determine, for this moment, the respective positions of the two bodies, according to the law of the observed motions. From these positions we calculate the inclination of the orbit. This method, however, supposes the node already known. But if there still remains some small error in the element, it would have but a trifling effect upon the amount of the inclination; particularly if we select, for the observation of the phenomena, the times when the planet is near its quadrature.

We ought to inform the reader, that all these isolated determinations of the elements of the orbit are but approximations, to be rectified afterward.

When we determine the longitude of the nodes at times quite distant from each other, and refer the origin of these longitudes to the same point of the ecliptic, having regard to the motion of the equinoxes, we find that the nodes are not fixed. They all have retrograde motions on the ecliptic, that is, in a direction contrary to the proper motion of the planet. These variations are very slow, and of the nature of those which are called secular. The inclinations of the different orbits also experience some variations in regard to each other and to the ecliptic.

The retrogradation of the nodes of the lunar and planetary orbits is a necessary consequence of universal attraction. The same is true in respect to the variations of inclination.

Analysis, besides making known this connection, has enabled us to calculate their effects.

The position of the plane of the orbit being determined, it remains to find the law of the planet's motions, and the form of the curve that it describes. Each of these would be known if we could determine for every instant the length of the radius vector, (i. e. the line drawn from the sun's to the planet's centre,) and the angle formed by this radius with a fixed right line drawn in the plane of the orbit and passing through the centre of the sun.

The first element to be determined is the length of a complete sidereal revolution of the planet round the sun. To discover this, the most simple and direct method is to observe the interval of time between two successive passages of the planet through the same node. As the plane of the ecliptic moves slowly in the heavens, it will be necessary to make allowance for this motion during the time elapsed between the observations compared, that is, it will be necessary to reduce them to a fixed ecliptic.

As we must be prepared to find disturbances in the motions of the planets, so we can greatly diminish their effect by deducing the mean motions from observations which comprehend a great number of revolutions, in order that, the periodic inequalities being compensated several times in the interval, the error which remains in the final result may be inappreciable by a division among so many revolutions. In this manner was determined the length of the mean year, independently of the periodic inequalities in the sun's motion.

The mean motion being known, we must next deduce from observation the angular motion of the planet round the sun, and the variations of its distance from that luminary. For this purpose, conjunctions and oppositions are extremely favorable. In fact, under these circumstances, the radius vector drawn from the earth to the planet, and that which is drawn to it from the sun's centre, are projected upon the plane of the ecliptic in the same right line. Thus the point of the ecliptic to which we refer the planet is either the same as that to which an observer at the sun's centre would refer it, or it is directly opposite. In these two cases the longitude of the planet as seen from the sun, (heliocentric,) is derived from its longitude as seen from the earth, (geocentric;) for in conjunctions these two are equal to each other; in oppositions they differ by two right angles, (or one hundred and eighty degrees.) And as the position of the orbit upon the plane of the ecliptic is known, and that of the planet's node, we can determine by calculation the distance of the planet from its node, and the distance of the planet from the sun, expressed in parts of the earth's distance from the sun.

The oppositions and conjunctions of the planets happen successively in different points of the heavens; and they do not always correspond to the same points of their orbits. Thus, making many similar observations, we shall find successively different angles and different radii vectores. Then we can measure these radii, place them around the sun in their true positions, and trace, by means of them, the form of the curve which the planet describes. In order to obtain these results, it is not even necessary that the planet be observed at the time of its opposition and conjunction. One geocentric longitude and latitude, observed at any time, will suffice, with the aid of calculation, to find the radius vector and the planet's distance from its node.

The curve traced in this way for each of the planets is very similar to an ellipse, having the sun in one of its foci. Analogy induces us to examine if the laws of elliptic motion will not agree with the conclusions to which observation leads us.

The method of proof is very simple. Three points, given in position on a plane, will be sufficient to determine satisfactorily an ellipse, one of whose foci is known. If, therefore, we find an ellipse which satisfies three observations of the planet, we must examine whether it satisfies all other observations that may be or have been made.

In this manner it has been found that the *orbits of all the planets are ellipses, with the sun in one of their foci. Around this point the radii vectores describe equal areas in equal times.* These are the first and second *laws of Kepler;* so called because they were discovered by that great astronomer.

The eccentricities of the planetary ellipses experience small variations in a long course of time. Theory teaches us the laws and the extent of these changes. Those of Mercury, Mars, and Jupiter, at present, are increasing; those of the other planets are diminishing.

The perihelia of the planets are not fixed unchangeably in the heavens. They move slowly in the planes of the orbits.

For all the planets, except Venus, these motions are direct, (that is, from west to east.) But the perihelion of Venus moves from east to west, or retrograde. Exact observations are, as yet, too few and recent to determine with precision the amount of these small variations. The theory of attraction determines it with much greater nicety.

To know the absolute quantity of these motions, and their direction, we refer them not to the equinoxes, which are movable, but to some point on the ecliptic that is fixed and determined.

The knowledge of the elliptic motions of the planets depends on seven elements for each of them. Two serve to determine the position of the orbit: these are the inclination of the orbit, and the longitude of the node. The others relate to the motion in the ellipse: these are the length of the sidereal revolution; half the greater axis of the orbit, or the mean distance of the planet from the sun; the eccentricity; the mean longitude of the planet at a given time; the longitude of its perihelion at the same time. As there are eleven planets known at present, it is necessary to have seventy-seven elements determined, before we can have a complete knowledge of our planetary system in the present state of astronomy.

Although the determination of these elements may be made, and has been made by the above-described procedure, it is very evident that, being applied to each element separately and successively, it could furnish only approximations. Astronomers of the present day are sufficiently advanced in that science, and have reflected on the causes that affect the accuracy of calculations long enough, to perceive the necessity of considering all the elements simultaneously, if they would estimate their mutual influences in the disturbances they experience. We must determine their amounts, not by a single observation, but by many, if we would perfect the calculations, and give the stamp of accuracy to our first approximations.

Those planets move the slowest, that are most distant from the sun. By comparing their velocities with their distances, Kepler discovered this remarkable relation:—*The squares of the times of their revolutions are as the cubes of their mean distances.* This is called Kepler's third law.

This law, being shown to be true as respects all the planets, ought to be regarded as more exact than observation itself. Wherefore, instead of deriving from observation the ratios of the planets' distances from the sun, (ratios always difficult to find with accuracy,) it is better to deduce them, by this law, from the length of their sidereal revolutions, for we can measure these last with the greatest precision, from the returns of each planet to the same node. Reciprocally, if we knew the planet's distance from the sun, but did not know the time of its sidereal revolution, we might calculate the latter by means of the same law.

This is the case with regard to the newly-discovered planets; for observation enabled astronomers to determine their greater axes, and all the elements of their orbits, long before they had finished a sidereal revolution.

The earth is also subject to this law, like all the other planets. If we admit its annual motion, the orbit becomes that of a planet revolving round the sun, conformably to Kepler's laws. The time of its revolution, calculated from its solar distance, according to this theory, is exactly equal to a sidereal year.

This fact shows that there is a striking analogy between the earth and the other planetary bodies. The motion of our globe, imperceptible to the senses, could not have been indicated to us in a more decided manner.

Kepler's laws are the foundation of all theoretic astronomy. They conduct us to the law of universal gravitation, which is a consequence of them.

The motions of the planets are not made exactly in ellipses. They are subject to a great number of minute irregularities, which observation and theory have discovered and determined with much accuracy.

The most considerable changes are those which affect the motions of Jupiter and Saturn. On comparing modern and ancient observations, a diminution in the time of Jupiter's revolution, and an increase in that of Saturn's, is detected. Modern observations compared with each other give a contrary result. These variations indicate in the motions of these planets great inequalities, whose periods are very long and whose effect upon the two planets is opposite, so that the motion of the one increases, while that of the other is retarded. These phenomena have been completely developed by La Place, who has made known their laws and given to the tables of Jupiter and Saturn an unexpected degree of accuracy.

It is quite remarkable that the distance from the sun of the four smallest planets, (Ceres, Pallas, Vesta, Juno,) are almost exactly the same. From this results the slight difference in the times of their sidereal revolutions, which are deduced from their distances by the third law of Kepler. This equality is particularly striking as respects Ceres and Pallas. Ceres and Juno, though they differ more in their distances, agree almost exactly in their eccentricities, and in the position of their nodes. From these facts, some astronomers have imagined that these four might have been formerly united, forming a large planet, which was separated by the effect of some internal explosions,—a theory, which, however incredible it may seem, has (to say the least) some plausible arguments in its favor. With these we may furnish the reader before closing this treatise.

When we wish to make observations on the motions of the planets, it is often essential that we should know the time they occupy in returning to the same situation with respect to the sun. This is called their *synodic revolution.*

We may deduce this from the preceding results. It is sufficient that we rely upon the general fact, that all the known planets make their revolutions in the same direction, that is, from west to east, a conformity which is one of the most remarkable phenomena of the solar system.

If we find the difference between the daily motion of the earth and that of any other planet, this difference will express the quantity by which the two planets, seen from the sun, remove from each in the course of twenty-four hours; and, supposing their motion uniform, we can deduce from it, by a simple proportion, the number of days necessary for their attaining a distance from each other of three hundred and sixty degrees, that is, for their arriving again at the same relative position in their revolution round the sun, which is the time of the planet's synodic revolution.

By comparing the mean motion of the planets with the mean motion of the sun, we can calculate the time at which these bodies ought to be found again in the same position with regard to the earth. These periods differ from those of a synodic revolution, which only bring the planet to the same angular distance from the sun. It is useful to know them, because, at these epochs, the hours of the rising, meridian transits, and setting of the planets, and all the inequalities that affect their motions, are found nearly the same as at the preceding epoch; so that the phenomena that depend on the position of these bodies begin again, and take place in the same order, affording an easy method of predicting them.

We may, therefore, know all the times of the mean conjunctions of Mercury with the sun, which are phenomena very important to be observed.

If the orbit of Mercury were wholly in the plane of the earth's orbit, the former planet, in each of its inferior conjunctions, would transit the sun's disc. But the inclination of the planet's orbit prevents the frequent return of these phenomena, and they are less frequent than conjunctions.

It is evident, indeed, that Mercury at conjunction cannot be projected on the sun's disc, except when its latitude, as observed from the earth, is less than the sun's apparent semidiameter. In every other case it passes above or below the sun.

Many circumstances operate against the fulfilment of this condition, and cause a variation in the times of Mercury's transits over the sun. Among these may be reckoned the great eccentricity of that planet's orbit, which renders its motion very unequal; the motion of the nodes, which prevents the planet from having the same latitude when it returns to the same conjunction; and, above all, the annual motion of the orbit, which, being carried forward on the ecliptic by the sun, appears under different elongations and aspects, whence result considerable variations in the geocentric latitude of that planet.

In the midst of so many inequalities, the only method that is left us of predicting accurately all the transits, consists in finding the epochs when they may take place, and then calculating by the tables all the conjunctions corresponding to these epochs, to determine those in which the transits will really happen. Tables have been formed in this way, which contain the transits that have happened, and those that will happen during several centuries.

We can find in these tables the effect of the different periods which have been ascertained. They also show that the transits of Mercury always take place in May or November. They are much more frequent in the latter month, owing to the position of Mercury's ellipse on the plane of the ecliptic. This ellipse is at present situated in such a way, that its perihelion is toward us in winter, its aphelion in summer; and, as the orbit is very eccentric, Mercury is much nearer the sun in the month of November than in the month of May. And if we imagine a luminous cone, formed by visual rays drawn from any point of the earth's surface to the sun, this cone, having for its vertex a point on the earth, and for its base the sun's disc, will be the more likely to be met by Mercury the nearer that planet is to the sun, and consequently the transits will be most frequent in the autumn. The preceding considerations, and the methods with which they furnish us, apply also to the orbit of Venus.

The transits of Venus over the sun's disc are much more rare than those of Mercury, because Venus is much more distant from that luminary.

Venus is sometimes visible to the naked eye in broad daylight. This remarkable phenomenon takes place when the planet is in a position to reflect to us the most rays. But the phases of Venus increase in extent, as the planet departs from the earth. This tends to increase its splendor, while the increase of distance tends to diminish it, for the intensity of rays of light diminishes in proportion to the square of the distance. There is a middle point at which the planet will appear to us most brilliant. The time elapsed between the returns of Venus to this situation is about eight years; but in many other positions Venus may be seen at noonday, and this phenomenon happens frequently.

SECTION II.

Individual planets—Mercury—Period of its revolution—Method of finding its rotation—Motion in its orbit per hour—When visible—Its diameter and distance from the sun—Its telescopic appearances—Its mountains—Its atmosphere—Venus—Its distance from the sun, diameter, and rate of motion—Its period—Inclination of its orbit—Telescopic appearances—Atmosphere—Rotation—Mountains—Mars—How the earth and moon appear there—Its irregularities, the subject of Kepler's studies—Peculiarities in its appearance—Effects of its atmosphere on the color of the planet—Its luminous zone, and the cause of the same—Mars supposed phosphorescent—Ultra zodiacal planets—Seemingly disturb the harmony of the system—Their feeble powers of gravitation—Peculiarities of Ceres—of Pallas—of Juno—of Vesta—Olber's theory respecting the small planets.

We have purposely delayed, thus far, to speak of the planets individually, in order that their general relations might be presented in an unconfused manner, and that we might devote some pages to a separate consideration of their physical constitutions, and to the varieties in their appearance and condition.

Very careful observations have been made to discover spots on the discs of the planets, in order to determine whether, like the sun, they have a motion of rotation. Such a motion has been found to exist with respect to all those upon which spots have been discovered. These are Venus, Mars, Jupiter, and Saturn. The method is the same as for the sun and moon. It has been proved, by another method, that Mercury also turns on its axis.

MERCURY

Is the nearest planet to the sun, and goes round it in a little less than eighty-eight of our days, or one fourth of our year nearly. But being seldom seen, and no spots appearing on its surface, (it being so enveloped in the sun's rays that nothing can be perceived but a sparkling disc of light,) some other method was necessary to reveal to us that it revolved on its axis. The method used by Schroeter was a continued observation of the variation in the *horns* of the planet. In its course round the sun, it moves at the rate of one hundred and fifty thousand miles an hour. Its light and heat from the sun are nearly seven times as great as ours; and the sun appears to its inhabitants nearly seven times as large as to us. Yet the great heat is not a sufficient argument against its being habitable; since the Creator could as easily suit the constitutions of its inhabitants to the heat of their planet, as ours to that of the earth. And it is probable that the inhabitants of that planet think the same of us as we do of the people of Jupiter, Saturn, and Herschel, viz. that we must be in a melancholy condition, suffer intolerable cold, and be poor, benighted souls, at such a distance from the sun. Mercury appears to us with all the various phases of the moon, when viewed, at different times, through a good telescope, except that it never appears quite full, because its enlightened side is turned directly toward us only when it is so near the sun as to be lost from our view in his beams. As its enlightened side is always toward the sun, it evidently shines by no light of its own, for if it did it would constantly appear round. That it moves round the sun in an orbit within the earth's is also plain, because it is never seen opposite the sun, nor more than fifty-four times the sun's breadth from his centre. Its orbit is inclined seven degrees to the ecliptic, and that node, from which it ascends northward, is in the fourteenth degree of "the Bull," the opposite in the fourteenth degree of "the Scorpion." The earth is in these points on the sixth of November and the fourth of May, and when Mercury comes to either of its nodes at inferior conjunction about these times, it will appear to pass over the sun's disc like a round dark spot. But in all other parts of its orbit the conjunctions are invisible, because it goes either above or below the sun.

When this planet becomes visible, it remains so only a few successive evenings or mornings, because of the rapidity of its daily motion. When it begins to appear in the evening, it is with difficulty distinguished in the rays of twilight. It disengages itself more and more the following days, and, after having departed nearly twenty-three degrees from the sun, it returns toward him again. In this interval, its motion with respect to the stars is direct; but when in returning it comes within eighteen degrees of the sun, it seems stationary, after which its motion appears retrograde. It continues to approach the sun, and is again lost in his rays in the evening. After continuing invisible for some time, it is seen again in the morning disengaging itself from the sun's rays, and receding from the sun, its motion being still retrograde as before its disappearance. Arriving at the distance of eighteen degrees, it is again stationary; then resumes its direct motion, till its distance amounts to twenty-two and a half degrees; then it returns, and, disappearing in the light of the dawn, is soon after seen again in the evening, producing the same phenomena as before.

The best time to see Mercury in the evening is in spring, at the time the planet is east of the sun, and at its greatest distance from that body. It will then be visible for several minutes, and will set about an hour and fifty minutes after the sun. But if the planet is west of the sun, and at its greatest distance, it will rise about one hour and fifty minutes before that body, and will be most advantageously seen in the morning at the latter part of summer or the beginning of autumn.

The planet Mercury is about three thousand one hundred and fifty miles in diameter, and revolves round the sun at the distance of thirty-seven millions of miles. It emits a brilliant white light, and twinkles like the fixed stars. The dazzling splendor of its rays, the shortness of the interval during which observations can be made upon its disc, and its proximity to the vapors of the horizon when it is observed, have prevented astronomers from making any interesting discoveries respecting this planet. When Mercury is viewed with a telescope of high magnifying power, it exhibits nearly the same phases as the moon does, being sometimes horned, and sometimes nearly full. Dr. Herschel frequently examined Mercury with telescopes magnifying two hundred and three hundred times; but it always appeared equally luminous in every part of its disc, without any dark spot or ragged edge. Schroeter was more successful. He maintains that he has seen, not only spots, but even mountains, in Mercury; and that he succeeded in measuring the altitude of two of them. One of these mountains was about a mile and a fifth in height, the other ten miles and three quarters, which last is nearly three times as high as Chimborazo, one of the highest mountains on the earth. The highest mountains are situated in its southern hemisphere. By examining the variation in the daily appearance of Mercury's horns, Schroeter found the period of its diurnal rotation about its axis to be twenty-four hours, five minutes, twenty-eight seconds. Wallot imagined that Mercury had a horizontal refraction of two hundred and seventy-six seconds; but Bugge, when observing the transit of this planet in 1802, could perceive no traces of an atmosphere.

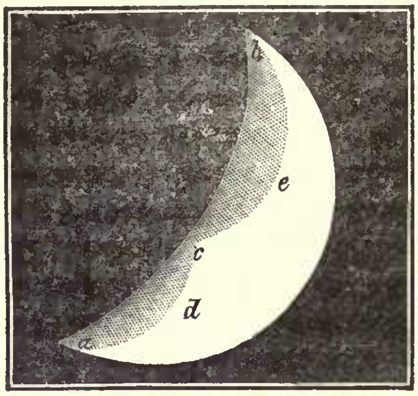
VENUS.

Venus is computed to be sixty-eight millions of miles from the sun, and goes round in its orbit in about two hundred and twenty-four days and seventeen hours of our time, moving at the rate of seventy-six thousand miles an hour. According to Bianchini's observations, its day is as long as twenty-four and one third of our days. This however is probably an error, as we shall see hereafter. Its diameter is seven thousand seven hundred miles.

Its orbit includes that of Mercury within it; for, at its greatest elongation, or apparent distance from the sun, it is ninety-six times his breadth from his centre, which is almost double the distance of Mercury. Its orbit is included by the earth's, for, if it were not, it might be seen as often in opposition to the sun, as it is in conjunction with him; but it was never seen ninety degrees, or a fourth part of a circle, from the sun.

When Venus appears west of the sun, it rises before him in the morning, and is called the *morning star;* when it appears east of the sun, it shines in the evening after he sets, and is then called the *evening star;* being each, in turn, for two hundred and ninety days. It may perhaps be surprising, at first, that Venus should keep longer on the east or west of the sun than the whole time of its period round him. But the difficulty vanishes when we consider that the earth is all the while going round the sun the same way, though not so quick, as Venus; and therefore its relative motion to the earth must in every period be as much slower than its absolute motion in its orbit, as the earth during that time advances forward in the ecliptic, which is two hundred and twenty degrees. To us Venus appears, through a telescope, with all the various shapes of the moon.

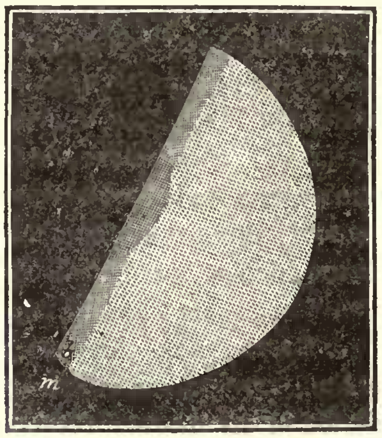
Venus's orbit is inclined three and a half degrees to the earth's, and crosses it in Gemini and Sagittarius; and, therefore, when the earth is about these points of the ecliptic at the time that Venus is in its inferior conjunction, it will appear like a spot on the sun, and afford a more certain method of finding the distances of all the planets from the sun, than any other yet known. But these appearances happen very seldom. Excepting such transits as these, this planet shows the same appearances to us regularly every eight years, its conjunctions, elongations, and times of rising and setting, being very nearly the same, on the same days, as before.



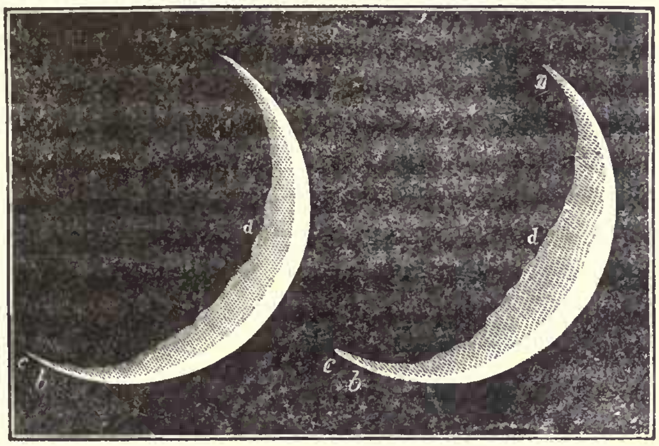
The powerful telescopes of Herschel and Schroeter were employed in examining the various appearances of this planet. On the nineteenth of June, 1780, Herschel observed spots on its surface, as represented in the figure: *a d c* is a bluish spot, and *c e b* a brighter spot. They met in an angle at a point *c*, distant from the cusp *a* about one third of the planet's diameter. This astronomer also observed that Venus was much brighter round its limb than in that part which separates the enlightened from the obscure portion of the disc. As this brightness round its limb diminishes pretty suddenly, it resembles a narrow, luminous border, and therefore does not seem to be the result of any optical deception. The light seemed to decrease gradually between this border and the boundary of the illuminated part of the planet's disc. Schroeter had before observed that the light appeared strongest at the outward limb, whence it decreased gradually, and in a regular progression, toward the interior edge; but he differed from Herschel with regard to the sudden diminution of this marginal light. Herschel ascribed the appearance to the atmosphere of Venus, which, like our own, is probably replete with matter that reflects and refracts light copiously in all directions. Therefore, on the border, where we have an oblique view of it, there will be an increase of this luminous appearance. Herschel considered the real surface of Venus to be less luminous than its atmosphere, and this accounts for the small number of visible spots on its disc; for the planet will commonly be enveloped by its dense atmosphere, so as not to present us with any variety of appearances. This also shows the reason why the spots, when there are any visible, seem generally darker than the rest of the body. The observations of this astronomer did not enable him to ascertain the diurnal rotation or the position of the axis of the planet; but he was of opinion that it could not be so slow as twenty-four days, the period assigned by Bianchini.

The atmosphere of Venus appears to be very dense, not merely from the changes which take place in the dark spots, but, as Schroeter inferred, from the illumination of its cusps when it is near its inferior conjunctions, when the enlightened ends of its horns reach far beyond a semicircle.

This astronomer's observations led him to some results different from Herschel's. He discovered several mountains, and found that, like those of the moon, they were always highest in the southern hemisphere, their perpendicular height being nearly as the diameters of their respective planets. From the eleventh of December, 1789, to the eleventh of January, 1790, the southern horn *b* of Venus appeared much blunted, with an enlightened mountain *m* in the dark hemisphere near twenty-two miles high.

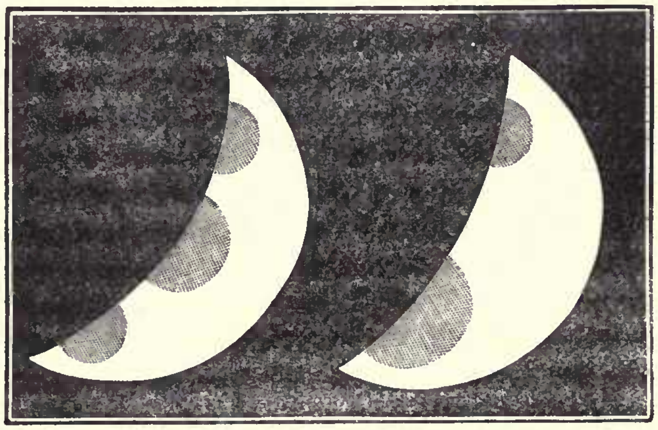


In order to determine the time of the planet's rotation, Schroeter observed the different shapes of the horns. Their appearance generally varied in a few hours, and became nearly the same again about half an hour sooner each day. Hence he concluded that its period of rotation must be about twenty-three and a half hours, that its equator is considerably inclined to the ecliptic, and the pole at a considerable distance from the point of the horn. On the thirtieth of December, 1791, at eight o'clock in the morning, the southern horn appeared with the same bluntness, and with the same enlightened mountain in the dark hemisphere, as it had done on the twenty-eighth of December, 1789, at five o'clock in the morning. Hence the period of Venus's rotation must be twenty-three hours, twenty minutes, fifty-nine seconds—only about one minute less than the time given by Cassini. The alternate bluntness and sharpness of the horns of this planet, Schroeter supposes to arise from the shadow of a high mountain. The appearance of Venus, with its ragged edge, and blunt horn, is shown in the figures.



The luminous margin, which we have already mentioned, induced Schroeter to believe that Venus had an atmosphere of considerable extent. At the interior edge, the light becomes dim till it loses itself in a faint bluish gray, and forms a ragged margin, (as in the above plate,) which it is difficult to perceive even with the best telescopes. This diminution of light is much more sensible near the middle *d* than at the cusps *a*, *b*.

On the ninth of September, 1790, he observed that the southern cusp disappeared, and was bent, like a hook, about eight seconds beyond the luminous semicircle into the dark hemisphere. The northern cusp had the same tapering termination, but did not encroach upon the dark part of the disc. A streak, however, of the glimmering bluish light proceeded about eight seconds along the dark limb, from the point of the cusp *b* to *c*, (figure above,) *b* being the extremity of the diameter *a b*, and consequently the natural termination of the cusp. The streak *b c*, verging to a pale gray, was faint when compared with the light of the cusp at *b*. Schroeter considered this appearance as the twilight of Venus. "That it is a real twilight is evident from the relative appearances of the cusps." On the ninth and twelfth of March, 1790, when the southern cusp extended in a hooked direction into the dark hemisphere, the pale blue light appeared only at the point of the northern cusp, and proceeded in a spherical curve into the dark part. On the tenth of March, when the southern cusp did not proceed so far, the pale streak was perceptible at poth points, but more sensible at the northern. The bright prolongation of the southern cusp on the tenth and twelfth of March, must be ascribed to the solar light on a ridge of mountains, whence it could not be strictly spherical. When the bright prolongation was not considerable, twilight had its due effect, and the true spherical arc of the dark limb appeared faintly illuminated. From these observations, Schroeter calculated that the *dense part* of Venus's atmosphere is about sixteen thousand feet, or over three miles, high; and he concluded, that its upper strata must be far above the highest mountains, that the atmosphere is more opaque than that of the moon, and that its density is a sufficient reason why we do not discover, on the surface of the planet, those shades and varieties



of appearance which are to be seen on the other planets.

The preceding plate represents Venus as seen by Bianchini.

MARS.

This planet is the next to the earth in the order of distance from the sun, which distance is equal to one hundred and forty-four millions of miles. It moves at the rate of fifty-five thousand miles an hour, and goes through its orbit in one year and ten months of our time, which is of course the length of its year. The time of its rotation (or length of its day) is twenty-four hours and forty minutes. Its diameter is four thousand one hundred miles. The quantity of light and heat at Mars is but one half as much as ours, if we consider their amount as wholly depending on the sun. That luminary appears but half as large at Mars as at the earth. Mars is much smaller than the earth, and if any moon attends it, it must be very small, since the most powerful telescopes have been repeatedly directed that way for the purpose of making such a discovery, but without success.

To the inhabitants of Mars, the earth and the moon must appear like two moons, changing places continually with each other, and appearing sometimes horned, sometimes half and sometimes three quarters enlightened, but never full, and never more than a quarter of a degree asunder.

The earth must appear to Mars about as large as Venus does to us. It can never be seen more than forty-eight degrees from the sun, and sometimes passes over the sun's disc, as do also Mercury and Venus. But Mercury cannot be seen there by such eyes as ours, unaided by instruments, and Venus will be seen as seldom as we see Mercury. Jupiter and Saturn are as visible to Mars as to us. The axis of Mars is inclined thirty degrees eighteen minutes, and the plane of its orbit about two degrees, to the plane of the ecliptic.

At its nearest approach to the earth its distance from us is about fifty millions of miles, and its greatest distance is about two hundred and forty millions of miles; so that in the former case, it appears twenty-five times larger than in the latter. To an observer in this planet, the earth will appear alternately as a morning and evening star, and will exhibit all the phases of the moon, just as Venus does to us, but with a less degree of apparent magnitude and splendor.

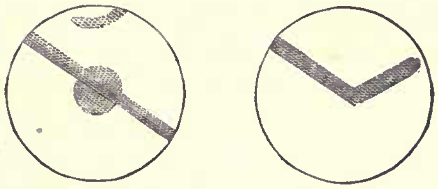
The irregularities of Mars in its orbit being the most considerable of all the primary planets, Kepler fixed upon it as the first object of his investigations respecting the nature of the planetary orbits; and, after extraordinary labor, he at last discovered that the orbit of this planet is elliptical, that the sun is situated in one of the foci of the ellipse, and that there is no point round which the angular motion is uniform. In the pursuit of this inquiry, he found the same true as to the earth's orbit; and it was reasonable to conclude from analogy that all the planetary orbits are elliptical, having the sun in one of their foci.

Continued observations show that the figure of Mars is not an exact sphere, but an oblate spheroid, whose polar diameter is to its equatorial as fifteen to sixteen nearly. The planet Mars is remarkable for the redness of its light, the brightness of its polar regions, and the variety of spots on its surface. The atmosphere of this planet, which astronomers have long considered as of an extraordinary extent and density, is the cause of the remarkable redness of its light. When a beam of white light passes through any medium, its color inclines to red, in proportion to the density of the medium, and the space through which it has travelled. The momentum of the red (or least refrangible) rays being greater than that of the violet (or most refrangible) rays, the former will make their way through the resisting medium, while the latter are either reflected or absorbed. The color of the beam, therefore, when it reaches the eye, must partake of the color of the least refrangible rays, and this color must increase with the number of the violet rays that have been obstructed. Hence we see that the morning and evening clouds are beautifully tinged with red; that the sun, moon, and stars, appear of the same color when near the horizon; and that every luminous object seen through a dry mist is of a ruddy hue. The planet Mars has an atmosphere of great density and extent, as is evident from the dim appearance of fixed stars, even at a distance from its disc. Cassini observed a star in the constellation of the *Water-Bearer*, which, at the distance of a tenth of a degree from the disc, became so faint as to be invisible even with a telescope of three feet. The same phenomenon was observed at Paris by Roemer. The dim light, therefore, by which Mars is illuminated, having to pass twice through its atmosphere before it reaches the earth, must be deprived of a great proportion of its violet rays, and consequently the color of the resulting light, by which Mars is visible, must be red. As there is a considerable difference of color among the other planets, and likewise among the fixed stars, are we not entitled to conclude that those in which the red color predominates are surrounded with the most extensive, or the densest, atmosphere? According to this principle, the atmosphere of Saturn must be the next to that of Mars in density or extent.

After Galileo had discovered the phases of Mars, Dr. Hook and Cassini discovered upon the disc of this planet a number of dark spots. Hook perceived some trifling changes in their position, but Cassini had the merit of determining from these changes that the diurnal revolution of the planet was performed in twenty-four hours and forty minutes.

The luminous zone at the southern pole of Mars, which had before been often noticed by astronomers, was particularly observed by Maraldi. During six month's observations he found it subject to many changes. Sometimes it appeared bright, at other times faint, and, after completely disappearing, it returned with its original brightness. When the spot was most luminous, the disc of the planet did not appear exactly round, but the bright part of the southern limb, that terminated this spot, appeared to project like a bright cap, whose exterior arch was a portion of a circle of a larger radius than the rest of the planet's limb. This appearance resembled that of the new moon surrounding the old, spoken of before, and seems to be an optical deception arising from the same cause.

In 1719, a favorable opportunity occurred for observing the spots upon Mars. When within two degrees of its perihelion, it was in opposition to the sun, and appeared superior to Jupiter in magnitude and brightness. Maraldi observed it at that time, through a refracting telescope thirty-four feet long, and saw the appearance represented in the adjoining figures. A long belt, extending half-way round its disc, was joined by a shorter belt, forming with it an obtuse angle. By the motion of this angular point, Maraldi found its daily period to be twenty-four hours and forty minutes—the very same with that of Cassini. These luminous spots were observed, from 1777 to 1783, by Herschel, who, by ascertaining the changes in their position, has determined the inclination of the axis, and the place of the nodes, of Mars. The polar spots are represented in the several figures accompanying, in



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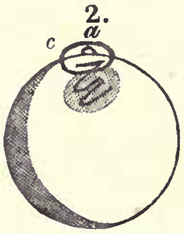

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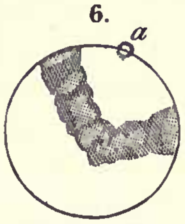

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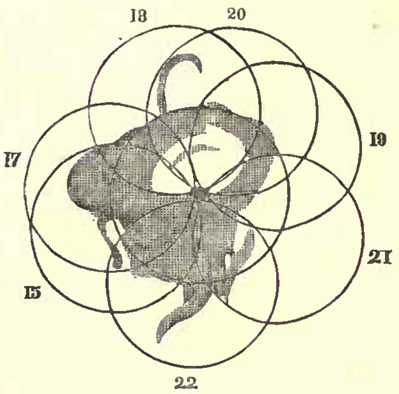
which *a* is the south polar, and *b* the north polar, spot. In the second figure, the south polar spot has a singular appearance, similar to what was observed by Maraldi. In consequence of its great splendor, it seems to project beyond the disc of the planet, producing a break at *c*, increased by the gibbous appearance of the planet. The south polar spot is represented in the other figures, which complete the whole equatorial circle of appearances, as they were observed in immediate succession. These figures are all connected in one projection. The centre of the circle marked 17 is placed on the circumference of the inner circle, by making its distance from the centre of the circle marked 15 answer to the interval of time between the two observations, properly calculated and reduced to sidereal measure. The same has been done with regard to the circles marked 18, 19, 20, &c. And it will be found, by placing any of these connected circles so as to have its contents in a similar situation with the figures in the single representation which bear the same number, that there is a sufficient resemblance between them; but some allowance must be made for the distortion of this kind of projection.



From the similarity between Mars and the earth, in their diurnal motion, and in the position of their equators, Dr. Herschel imagined that the bright spots at the poles of this planet are produced by the reflection of the sun's light from its frozen regions, and that the melting of masses of polar ice is the cause of the variation in the magnitude of the spots. Hence, in 1781, when the antarctic glaciers had not felt for twelve months the thawing influence of the sun, the south polar spot was extremely large, and in 1783 it had suffered a considerable diminution from an exposure of eight months to the solar rays.

As the diurnal rotation of Mars has been accurately established by the motion of its spots, it was natural to expect that, in conformity to the laws of gravity, it should exhibit a spheroidal form. Owing to its gibbous appearance, there is difficulty in taking accurate measures of its diameters. Dr. Herschel finally succeeded in the attempt, and found its figure to be an oblate spheriod, whose equatorial diameter is to its polar nearly as sixteen to fifteen; that the inclination of its axis to the ecliptic is fifty-nine degrees forty-two minutes; that the node of the axis is in seventeen degrees forty-seven minutes of the *Fishes;* that the obliquity of its ecliptic is twenty-eight degrees forty-two minutes; and that the time of its diurnal rotation is twenty-four hours thirty-nine minutes. The remarkable flattening at the poles of Mars probably arises from a considerable variation in the density of its different parts. La Place computed its density to be about three fourths of that of the earth.

From the circumstance of this planet's having no satellite, and appearing to require light in the sun's absence, it has been imagined that Mars is phosphorescent, and gives out during the night the light it has imbibed during the day.

ULTRA ZODIACAL PLANETS.

Four very small planets have been discovered since the commencement of the nineteenth century, lying between the orbits of Mars and Jupiter, and have been named respectively Ceres, Pallas, Juno, and Vesta.

These additions do not merely present us with a few insulated facts similar to those with which we were before acquainted. They exhibit to us new and unexpected phenomena, that seem to destroy the harmony of the solar system, as far as it depends on the magnitudes and distances of the planets, or on the form and position of their orbits.

The planets which were before considered as composing the system, were placed at somewhat regular distances from the sun. They moved from west to east, and at such intervals as to prevent any extraordinary derangements which might arise from their mutual action.

The magnitudes, too, of the four nearest the sun increased with their distance from that centre, and the eccentricity, as well as the inclination of the orbits was comparatively small. In the system as now known, however, we find the four small planets placed as above stated, all of them at nearly the same distance from the sun, and moving in very eccentric orbits, which intersect each other, and are greatly inclined to the plane of the ecliptic. The satellites of the planet Herschel are another exception, for they move nearly at right angles to the plane of his orbit; and the direction of their motion is opposite to that in which all the other planets, whether primary or secondary, circulate in their respective orbits. The most remarkable peculiarity of these small planets must consist in their feeble power of gravitation. A man placed on one of them would spring, with ease, *sixty feet high*, and sustain no greater shock in his descent than he does on the earth from leaping a yard. On such planets, *giants might exist;* and those enormous animals, which on earth require the buoyancy of water to sustain them, might there be dwellers on the land.

CERES

Was discovered at Palermo, Sicily, on the first of January, 1801, by Piazzi, an ingenious observer, who afterward distinguished himself by his astronomical labors. This new celestial body was then situated in the *Bull*, and was observed by Piazzi till the twelfth of February, when a dangerous illness compelled him to discontinue his observations. It was, however, again discovered by Olbers, at Bremen, on the first of January, 1807, nearly in the place where it was expected from calculation. The nebula with which it was surrounded gave it the appearance of a comet.

Ceres is of a ruddy color, and appears about the size of a star of the eighth magnitude. It seems to be surrounded with a large, dense atmosphere, and plainly exhibits a disc when examined with a magnifying power of two hundred. This planet performs its revolution round the sun in four years seven months and ten days; and its mean distance from that luminary is nearly two hundred and sixty-three millions of miles The eccentricity of its orbit is a little greater than that of Mercury, while its inclination to the ecliptic exceeds that of all the old planets. The observations which have been made upon this celestial body do not seem sufficiently correct to enable us to determine its magnitude with any degree of accuracy. According to the measurements of Herschel, the diameter of Ceres does not exceed *one hundred and sixty-three miles*, while the observations of Schroeter make is about *sixteen hundred miles.*

PALLAS

Was discovered at Bremen, on the twenty-eighth of March, 1802, by Olbers, the same astronomer who rediscovered Ceres. It is nearly of the same apparent magnitude with Ceres, but of a less ruddy color. It is surrounded with a nebulosity of almost the same extent, and performs its annual revolution in nearly the same period.

The planet Pallas, however, is distinguished in a remarkable manner from Ceres, and all the other primary planets, by the great inclination of its orbit. While these bodies are revolving round the sun in almost circular paths, rising only a few degrees above the plane of the ecliptic, Pallas ascends above this plane at an angle of about thirty-five degrees, which is nearly five times greater than the inclination of Mercury. From the eccentricity of Pallas being greater than that of Ceres, or from a difference of position in the line of their apsides, while their mean distances are nearly equal, the orbits of these two planets mutually intersect, a phenomenon altogether anomalous in the solar system.

The diameter of Pallas has not been determined with accuracy. Herschel made it only *eighty miles*, while Schroeter made it between two and three thousand miles, which is much larger than the magnitude he assigned to Ceres. Its mean distance from the sun is over two hundred and sixty-three millions of miles.

JUNO

Was discovered by Harding, on the first of September, 1804. While this astronomer was forming an atlas of all the stars which are near the orbits of Ceres and Pallas, he observed, in the constellation of the *Fishes*, a small star, (as he thought,) of the eighth magnitude, which was not mentioned in the catalogue by La Lande; and, being ignorant of its longitude and latitude, he put it down in his chart as nearly as he could estimate with the eye. Two days after the star had disappeared; but he perceived another, which he had not seen before, resembling the first in size and color, and situated a little to the south-west of its place. He observed it again on the fifth of September, and, finding that it had moved a little farther to the south-west, he concluded that it belonged to the planetary system. The planet Juno is of a reddish color, and is free from that nebulosity which surrounds Pallas. Its diameter is less, and its distance greater, than those of the other new planets. It is distinguished from all the other planets by the great eccentricity of its orbit; and the effect of this is so very sensible, that it passes through the half of its orbit which is bisected by its perihelion in half the time that it employs in describing the other part, which is farther from the sun. From the same cause, its greatest distance from the sun is double the least distance, the difference between the two distances being about one hundred and twenty-seven millions of miles. Its mean distance from the sun is two hundred and fifty-three millions of miles.

VESTA.

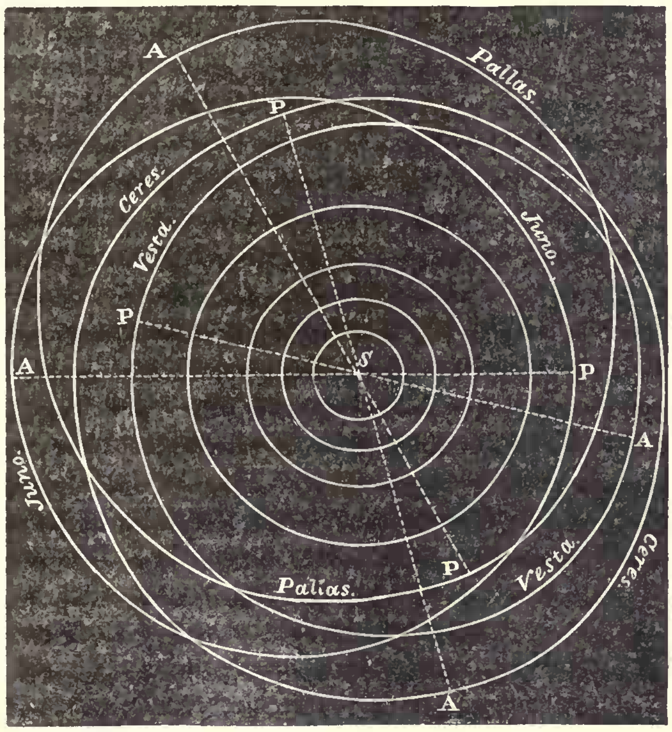
From the regularity observed in the distances from the sun of the planets formerly known, some astronomers supposed that a planet existed between the orbits of Mars and Jupiter. The discovery of Ceres confirmed this happy conjecture; but the opinion which it seemed to establish respecting the harmony of the solar system, appeared to be completely overturned by the discovery of Pallas and Juno. Olbers, however, imagined that these small celestial bodies were merely the fragments of a larger planet, that had been burst asunder by some internal convulsion, and that several more might yet be discovered between the orbits of Mars and Jupiter. He therefore concluded, that, though the orbits of all these fragments might be differently inclined to the ecliptic, yet, as they all must have diverged from the same point, they ought to have two common points of reunion, or two nodes in opposite regions of the heavens, through which all the planetary fragments must pass sooner or later. One of these nodes Olbers found to be in the Virgin, the other in the Whale; and it was actually in the latter region that Harding discovered the planet Juno. With the intention, therefore, of detecting other fragments of the supposed planet, Olbers examined, three times a year, all the little stars in the opposite constellations of the Virgin and the Whale, till his labors were crowned with success, on the twenty-ninth of March, 1807, by the discovery of a new planet, to which he gave the name Vesta.

As soon as this discovery was made known in England, the planet was observed by Groombridge, who continued his observations, from the twenty-sixth of April to the twentieth of May, 1807, with an astronomical circle, when, from its having ceased to be visible on the meridian, he had recourse to equatorial instruments. On the eleventh of August, the meridional observations were renewed, from which Groombridge computed part of the elements of its orbit, and had the good fortune to observe the ecliptic opposition of the planet.

Vesta is of the fifth or sixth magnitude, and may be seen in a clear evening with the naked eye. Its light is more intense, pure, and white, than any of the other three. It is not surrounded with any nebulosity, and has no visible disc. The orbit of Vesta cuts the orbit of Pallas, but not in the same place where it is cut by that of Ceres. According to the observations of Schroeter, the apparent diameter of Vesta is only 0·488 of a second, or one half of what he found to be the apparent diameter of the fourth satellite of Saturn; and yet it is remarkable that its light is so intense that Schroeter saw it several times without the aid of an instrument. Vesta is two hundred and twenty-five millions of miles from the sun.

It has been supposed that this planet had been previously observed, and mistaken for a fixed star, since a small star, situated in the same place and observed by Monnier, has since disappeared.

The orbits of these four small planets, projected from the places of their perihelia, are represented in the figure. These orbits appear to intersect each other in various places, and it is obvious that the points of intersection must be perpetually shifting, according to the changes in the aphelia of the planets.

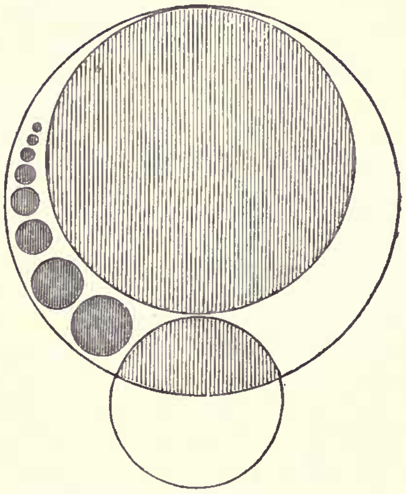


SECTION III.

Jupiter's form—Its situation—Length of its year—Rapidity of rotation—Small change in its seasons—Alternately morning and evening star—Its belts—Degree of oblateness—Cause of the belts—Jupiter's satellites—Particulars respecting them—Velocity of light—Saturn's size compared with the earth's—Surrounded by a ring—Singular form of Saturn—Its spots and belts—Why this planet is more oblate than Jupiter—Saturn's satellites—Position of their orbits—Theories concerning the rings—Their different appearances—Their revolution—How they are sustained—Herschel, particulars of—Its satellites—Their peculiarities—How kept in their orbits.

JUPITER.

The planet Jupiter revolves about its axis in ten hours nearly. Its form, like that of Mars and of the earth, is an oblate spheroid, the equatorial being to the polar diameter as fourteen to thirteen; so that its poles are three thousand miles nearer its centre than its equator is. This results from its quick motion round its axis; for the fluids, together with the light particles which they can carry or wash away with them, recede from the poles, which are at rest, towards the equator, where the motion is quickest, until there be a sufficient number accumulated to make up the deficiency of gravity lost by the centrifugal force which always arises from a quick motion round an axis: and when the deficiency of weight or gravity of the particles is made up by a sufficient accumulation, there is an *equilibrium*, and the equatorial parts rise no higher. The ratio (fourteen to thirteen) was obtained from observations by Herschel, and it is a remarkable coincidence between theory and observation, that, from the influence of the equatorial parts of the planet upon the motion of the nodes of the satellites, La Place found the proportion very nearly the same.



Jupiter, the largest of all the planets, is still higher in the system than Pallas, being about four hundred and ninety millions of miles from the sun, and, going at the rate of twenty-nine thousand miles an hour in its orbit, completes its revolution in a little less than twelve years of our time. This planet is *thirteen hundred times larger than the earth,* its diameter being nearly eighty-six thousand miles, which is nearly eleven times the diameter of the earth. In the figure, Jupiter's surface is compared to that of all the other planets taken together.

Jupiter's year contains more than ten thousand days, and the diurnal velocity of the parts near its equator is nearly as great as the swiftness with which the planet moves in its annual orbit. By this rapid rotation, the equatorial inhabitants are carried twenty-eight thousand miles an hour, beside the twenty-nine thousand above mentioned, which is common to all parts of its surface by the annual motion.

Jupiter is the brightest of all the planets, except Venus. It shines with a bright white light, and does not vary in apparent size and brightness so much as Mars. It is the largest planet in the solar system. A body weighing one pound at the earth, if removed to the surface of Jupiter would weigh two and a half pounds nearly.

The axis of Jupiter is so nearly perpendicular to its orbit that it has no sensible change of seasons, which is a great advantage, and wisely ordered by the Author of nature; for, if the axis of this planet were inclined any considerable number of degrees, just so many degrees round each pole would in their turn be almost six of our years together in darkness; so that vast tracts of land would be rendered uninhabitable by any considerable inclination of its axis.

When Jupiter is in conjunction, it rises, sets, and comes to the meridian, with the sun, but is never observed to transit the sun's disc; when in opposition, it rises at sunset, sets at sunrise, and comes to the meridian at midnight. This is a sufficient proof that Jupiter revolves round the sun in an orbit including that of the earth.

When viewed in opposition, Jupiter appears larger and more luminous than at other times, being then much nearer the earth than a little before or after conjunction. When its longitude is less than that of the sun, it will appear in the east before the sun rises, and will then be a *morning star.* When its longitude is greater than that of the sun, it will appear in the west after sunset, and will then be an *evening star.*

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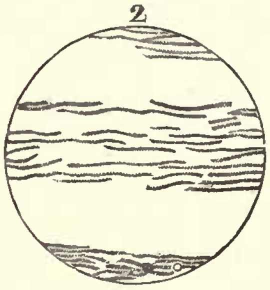

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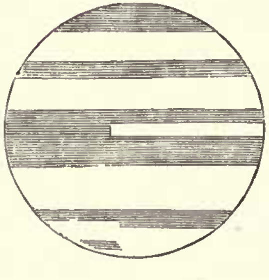

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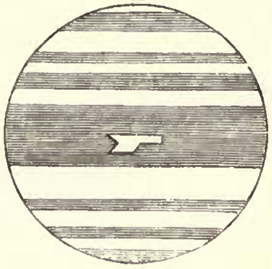

When Jupiter is observed with good telescopes, several belts or bands are perceived extending across its disc in lines parallel to its equator. These belts are by no means alike at all times, either in number, distance, or position. They have even been seen broken up and distributed over the whole face of the planet; but this phenomenon is very rare. Branches running out from them, and subdivisions, as well as dark spots like strings of clouds, are not uncommon, and from these attentively watched it has been concluded that this planet revolves on an axis perpendicular to the direction of the belts. It is very remarkable, and forms a satisfactory comment on the reasoning by which the spheroidal figure of the earth was deduced from its diurnal rotation, that the outline of Jupiter's disc is not circular, but elliptic, being much flattened in the direction of its axis of rotation. This appearance is no illusion, but is confirmed by measures with the micrometer, which assign one hundred and seven to one hundred as the proportion of the equatorial to the polar diameters.* And, to confirm in the strongest manner the truth of those principles on which former conclusions were founded, and fully to authorize their extension to this remote planet, it appears, on calculation, that this is really the degree of oblateness, which corresponds, on those principles, to the dimensions of Jupiter, and to the time of its rotation.

Herschel perceived the whole disc of Jupiter covered with small curved belts, or rather lines, that were not continuous across the disc. This appearance is represented in figures 1 and 2. The parallel belts are most common, and, in clear weather, may be seen with a magnifying power of forty. The appearance they presented when viewed through Herschel's instruments, is shown in figures 3 and 4. Sometimes they are interrupted in their length, as in figure 3; at others they seem to increase and diminish alternately, to run into one another, or to separate into others of a smaller size. Bright and dark spots are frequently visible, as in figure 4. Some of these revolve with greater rapidity than others, from which it appears that they are not permanent spots upon the planet itself.

When Jupiter was in perihelion, in 1785 and 1786, Schroeter observed the belts with a telescope magnifying one hundred and fifty times. He perceived upon the disc several new spots, which were black and round. In 1787, he saw two dark belts in the middle of the disc, and near them two white and luminous belts, resembling those observed by Campani. The equatorial zone, which was comprehended between the two dark belts, had assumed a dark gray color, bordering upon yellow. The northern dark belt then received a sudden increase of size, while the southern became partly effaced, and afterwards increased into an uninterrupted belt. The luminous belts also suffered several changes, growing sometimes narrower, and sometimes one half larger, than their original size.

Different opinions have been entertained respecting the cause of these belts and spots. By some they have been regarded as clouds, or as openings in the atmosphere of the planet. Others regard these appearances as indications of great physical revolutions, which are perpetually agitating and changing the surface of the planet. The first of the above opinions sufficiently explains the variations in the form and magnitude of the belts, but does not account for the permanence of some of the spots, and for the parallelism of the belts.

The spot first observed by Cassini, which rëappeared eight times between the years 1665 and 1708, could not possibly have been occasioned by any atmospherical variations; and its disappearance for five years is a presumptive, though not a decisive, argument that it arose from some changes in the body of the planet. Brewster, however, was disposed to think, from the frequent appearance of this spot, that it was permanent on the body of Jupiter, and that its disappearance was owing to the interposition of clouds in the atmosphere of the planet. If it were the effect of an earthquake or inundation, or if it were the mark of a new island or continent, as some have conjectured, how should we account for its reappearance after five years in the same form and position? May we not suppose that the clouds of Jupiter, partaking of the great velocity of its diurnal motion, are formed into strata parallel with the equator, that the body of Jupiter reflects less light than the clouds, and that the belts are the body of the planet seen through the parallel interstices which lie between the different strata of clouds? The spot seen by Cassini will, of course, only be seen when it is immediately below one of these interstices, and will therefore always appear as if it accompanied one of the belts.

Herschel the younger has the following on this subject. The parallelism of the belts to the equator of the planet, their occasional variations, and the appearances of spots seen upon them, render it extremely probable that they subsist in the atmosphere of the planet, forming tracts of comparatively clear sky, determined by currents analogous to our trade winds, but of a much more steady and decided character, as might indeed be expected

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* The younger Herschel. This ratio differs but little from that before given.

from the immense velocity of its rotation. That it is the comparatively darker body of the planet which appears in the belts, is evident from this, that they do not come up in all their strength to the edge of the disc, but fade away gradually before they reach it.

By directing a telescope to Jupiter, it is found to be attended by *four small stars*, ranged nearly in a right line parallel to the plane of its belts. These stars are the moons of Jupiter, which move round their primary in different periods, and at unequal distances. The third and fourth have been sometimes seen with the naked eye; but only when the air is uncommonly pure can we expect to be gratified with so rare a sight.

The discovery of these satellites was made by Galileo, in 1610; and this may be considered as one of the first fruits of the invention of the telescope. They are distinctly visible with a telescope of a moderate power. Their relative situation with regard to Jupiter, as well as to each other, is constantly changing. Sometimes they may be all seen on one side of Jupiter, and sometimes all on the other. They are designated by their distances from Jupiter, that being called the *first* whose distance from Jupiter is the least when at the greatest elongation, and so on with the others. They are of very different magnitudes, some of them being greater than our earth, while others are not so large as the moon. Their apparent diameters being insensible, their real magnitudes cannot be exactly measured. The attempt has been made, by observing the time they enter the shadow of Jupiter; but there is a great discordance in the observations which have been made to obtain this circumstance, and, of course, the result of these observations must be very discordant. The *third*, however, is the greatest; the *fourth* is the second in magnitude; the *first* the third in magnitude; and the *second* is the least.

These satellites were observed with great assiduity during the last century, and the tables of their motions have been brought to a degree of perfection which the most sanguine expectations could not have anticipated. To geographers and astronomers the system of Jupiter and its moons is equally interesting. Though but a short time comparatively has elapsed since their discovery, yet, from the extreme shortness of their revolutions, they present in a short period those great and interesting changes which are not effected in the course of many centuries in the planetary system.

The moon nearest Jupiter revolves in its orbit in forty-two and a half hours: the most remote in about seventeen days of our time. The satellites of Jupiter revolve from west to east, (following the analogy of the primaries, and of our moon,) in planes nearly coincident with that of the planet's equator. This latter plane is inclined about three degrees to the orbit of the planet, and is therefore but little different from the plane of the ecliptic. Accordingly, we see their orbits projected very nearly into straight lines, in which they appear to oscillate to and fro, sometimes passing before the planet and casting shadows on its disc, (which shadows are very visible in good telescopes, like small, round ink spots,) and sometimes disappearing behind the body, or being eclipsed in its shadow at a distance from it.

The four moons must afford many curious phenomena to the inhabitants of the primary, in their nightly course through the heavens. The first moon, or that nearest the planet, is two hundred and thirty thousand miles from its centre, and will appear from its surface four times larger than our moon does to us; the second, being further distant, will appear about the size of our moon; the third, somewhat less; and the fourth, which is distant a million of miles, will appear about one third the size of our moon.

The planet, if seen from its nearest moon, will present a surface a thousand times as large as our moon does to us, and will appear in the form of a crescent, a half-moon, a gibbous phase, and a full moon, in regular succession, every forty-two and a half hours.

When the satellites are on the right hand, or west of Jupiter, approaching it, or east of Jupiter, receding from it, they are then in the superior parts of their orbits or furthest from the earth. On the contrary, when the satellites are on the right hand, or west of Jupiter, receding from it, or east of Jupiter, approaching it, they are then in the inferior part of their orbits, or nearest the earth.

An extremely singular relation subsists between the mean angular velocities, or *mean motions*, (as they are termed,) of the three first satellites of Jupiter. If the mean angular velocity of the first satellite be added to twice that of the third, the sum will equal three times that of the second. From this relation it follows, that, if from the mean longitude of the first added to twice that of the third be subtracted three times that of the second, the remainder will always be the same, or constant, and observation informs us that this constant is one hundred and eighty degrees, or two right angles; so that, the situations of any two of them being given, that of the third may be found. It has been attempted to account for this remarkable fact on the theory of gravity by their mutual action. One curious consequence is, that these three satellites cannot be all eclipsed at once; for, in consequence of the last-mentioned relation, when the second and third lie in the *same* direction from the centre, the first must lie on the *opposite*, and, therefore, when the first is eclipsed, the other two must lie between the sun and planet, throwing its shadow on the disc, and *vice versa*. One instance only is on record when Jupiter has been seen *without satellites*, viz. by Molyneux, November, 1681.

The discovery of Jupiter's satellites by Galileo, forms one of the most memorable epochs in the history of astronomy. The first astronomical solution of the great problem of "*the longitude*" (the most important for the interests of mankind which has ever been brought under the dominion of strict scientific principles) dates immediately from their discovery. The final and conclusive establishment of the Copernican system of astronomy may also be considered as referable to the discovery and study of this exquisite miniature system, in which the laws of the planetary motions, as ascertained by Kepler, and especially that which connects their periods and distances, were speedily traced, and found to be satisfactorily maintained. And (as if to accumulate historical interest on this point) it is to the observation of their eclipses that we owe the grand discovery of the aberration of light, and the consequent determination of the enormous velocity of that wonderful element. This we must explain.

The earth's orbit being concentric with that of Jupiter, and interior to it, their mutual distance is continually varying, the variation extending from the *sum* to the *difference* of the radii of the two orbits, and the difference of the greater and least distances being equal to a diameter of the earth's orbit. Now, it was observed by Roemer, on comparing together observations of eclipses of the satellites during many successive years, that the eclipses at and about the opposition of Jupiter (or its nearest point to the earth) took place *too soon*—sooner, that is, than, by calculation from an average, he expected them; whereas those which happened when the earth was in the part of its orbit most remote from Jupiter were always *too late*. Connecting the observed error in their computed times with the variation of distance, he concluded, that, to make the calculation on an average period correspond with fact, an allowance in respect of time behooved to be made proportional to the excess or defect of Jupiter's distance from the earth above or below its average amount, and such that a difference of distance of one diameter of the earth's orbit should correspond to 16m. 26s.6 of time allowed. Speculating on the probable physical cause, he was naturally led to think of the gradual, instead of the instantaneous, propagation of light. This explained every particular of the observed phenomenon; but the velocity required (*one hundred and ninety two thousand* miles per second) was so great as to startle many, and, at all events, to require confirmation. This has been afforded since, and of the most unequivocal kind, by Bradley's discovery of the aberration of light. The velocity of light deduced from this last phenomenon differs by less than one eightieth of its amount from that calculated from the eclipses, and even this difference will no doubt be destroyed by nicer and more rigorously reduced observations.

The orbits of Jupiter's satellites are but little eccentric. Those of the two interior, indeed, have no perceptible eccentricity: Their mutual action produces in them perturbations analogous to those of the planets about the sun, and which have been diligently investigated by Laplace and others. By assiduous observation it has been ascertained that they are subject to marked fluctuations in respect of brightness, and that these fluctuations happen periodically, according to their position with respect to the sun. From this it has been concluded, apparently with reason, that they turn on their axes, like our moon, in periods equal to their respective sidereal revolutions about their primary.

SATURN.

This planet is about nine hundred millions of miles from the sun, and, travelling at the rate of twenty-two thousand miles an hour, performs its annual circuit in twenty-nine and a half of our years, which make only one of its years. The planet's diameter is seventy-nine thousand miles, and, therefore, it is nearly *ten hundred times larger than our globe.* It is surrounded by a broad thin ring, as an artificial globe is by a horizon. But of this hereafter.

Saturn shines with a very feeble light compared with that of Jupiter, partly on account of its greater distance, and partly from its dull red color. In size, it is the next planet to Jupiter in the solar system. A body weighing a pound at the earth's surface, would weigh a little more than one pound and one third at the surface of Saturn. The apparent motion of Saturn in its orbit is subject to irregularities similar to those of Jupiter and Mars. It commences and finishes its retrograde motion when the planet is about one hundred and nine degrees from the sun, before and after opposition. The arc in which it retrogrades is about six and one third degrees, and the time of its retrograde motion is nearly one hundred and thirty-one days.

When we look at the body of Saturn with a good telescope, it appears, like most of the other planets, to be of a spheroidal form, arising from a rapid rotation round its axis. Herschel measured the diameters, and at first found that the equatorial was to the polar as eleven to ten nearly. However, he afterwards corrected this result by new observations, and found the proportion to be more nearly as twelve to eleven. Until the year 1805, Herschel regarded Saturn as an accurate spheroid; but on the 12th of April, of that year, he was struck with a very singular appearance presented by the planet. The flattening at the poles did not seem to begin till a very high latitude; so that the real figure of the planet resembled a square, or rather a parallelogram, with the four corners rounded off deeply, but not enough to make a spheroid. After examining Saturn with his telescopes, and comparing it with the form of Jupiter, Herschel concluded that this was the real form of the planet. He also found that the latitude of the *longest* diameter was about forty-three and a half degrees.

The surface of Saturn is diversified, like that of some of the other planets, with dark spots and belts. Huygens observed five belts, which were nearly parallel to the equator. Herschel also observed several belts, which were, in general, parallel with the ring. On the 11th of November, 1793, immediately south of the shadow of the ring upon the planet, he perceived a bright, uniform, and broad belt, and close to it a broad and darker belt, divided by two narrow white streaks; so that he saw five belts, three of which were dark, and two white. The dark belts had a yellowish tinge. These belts generally cover a larger zone of the disc of Saturn, than the belts of Jupiter occupy on the surface of that planet.

Herschel also perceived dark spots on Saturn's disc, and, by the changes in their position, determined the diurnal rotation of the planet to be performed in about ten hours and a quarter, round an axis perpendicular to the plane of the rings.

It has been made known already that the flattening at the poles of the planets arises from the centrifugal force of their equatorial parts. On account of the great diameter of Jupiter, and the rapidity of its daily motion, its equatorial parts move with immense velocity, and, in consequence of their great centrifugal force, this planet is more flattened at its poles than either the earth or Mars. It is remarkable, however, that Saturn should be more flattened at its poles than Jupiter, though the velocity of the equatorial parts of the former is much less than that of the latter. When we consider, however, that the ring of Saturn lies in the plane of its equator, and that its density is equal to, if not greater, than that of the planet, we shall find no difficulty in accounting for the great accumulation of matter at the equator of Saturn. The ring acts more powerfully upon the equatorial regions of Saturn, than upon any other part of its disc, and, by diminishing the gravity of these parts, it aids the centrifugal force in flattening the poles of the planet. Had Saturn never revolved on its axis, the action of the ring would of itself have been sufficient to give it the form of an oblate spheroid.

Satellites of Saturn.—The planet Saturn is surrounded with no fewer than seven satellites, which supply it with light during the absence of the sun. The importance of these moons will be at once perceived, when it is stated that the sun appears at Saturn only one ninetieth as large as to us.

The fourth of the satellites was discovered by Huygens, on the 25th of March, 1655. Cassini discovered the fifth, in October, 1671; the third on the 23d of December, 1672. The sixth and seventh, were discovered by Herschel, in 1789, and are nearer to Saturn than the rest, though, to avoid confusion, they are named in the order of their discovery.

These satellites are all so small, and situated at such distances from the earth, that they cannot be seen except with powerful telecopes. Wargentin saw the five old satellites with an achromatic telescope of ten feet, and Herschel saw them distinctly with a power of sixty applied to his ten-feet reflector. The sixth and seventh are the smallest of the whole; the first and second are the next smallest; the third is greater than the first and second; and the fourth is the largest of them all. The fifth surpasses all of them, except the fourth, in brightness, when it is at its western elongation from Saturn, but at other times it is very small, and entirely disappears at its eastern elongation. This phenomenon, which was at first observed by Cassini, appears to arise from one part of the satellite being less luminous than the rest. In consequence of the satellite's rotation on its axis, this obscure part of the disc, is turned toward the earth when it is in the part of its orbit east of Saturn; and the luminous part of its surface becomes visible while it is in the western part of its orbit. Herschel observed this satellite through all the variations of its light; and concluded, that, like our moon, and the satellites of Jupiter, it turned round its axis in the same time that it performed its revolution round the primary. When he used his twenty-feet telescope, he never lost sight of the satellite, even when its light was most faint.

The theory of the satellites of Saturn is less perfect than that of the satellites of Jupiter. The difficulty of observing their eclipses, and of measuring their elongations from Saturn, have prevented astronomers from determining, with their usual precision, the mean distances and the revolutions of these secondaries.

In the position of their orbits there is something quite remarkable: while the orbits of the six inner satellites all lie nearly in the plane of the ring, the orbit of the fifth (most distant) moon deviates considerably from this plane. The fourth moon is probably not much inferior to Mars in size. The fifth is the only one whose theory has been examined further than suffices to verify Kepler's laws of the periodic times, which, under certain reservations, holds good of this, as of the system of Jupiter. It exhibits, as has been stated, periodic defalcations of light, which prove its revolution on its axis in the time of its sidereal revolution about Saturn. The next in order (proceeding inwards) is tolerably conspicuous; the three next very minute, and requiring pretty powerful telescopes to see them; while the two interior satellites, which just skirt the edge of the ring, and move exactly in its plane, have never been discerned but with the most powerful telescopes which human art has yet constructed, and then only under peculiar circumstances. At the time of the disappearance of the ring (to ordinary telescopes) they have been seen threading like beads the almost infinitely thin fibre of light to which it is then reduced, and for a short time advancing off it at either end, speedily to return, and hastening to their habitual concealment. Owing to the obliquity of the ring, and of the orbits of the satellites, to Saturn's ecliptic, there are no eclipses of the satellites (the interior ones excepted) until near the time when the ring is seen edgewise.

The inequalities in the surface of the ring are considered by La Place as absolutely necessary for maintaining it in equilibrium around Saturn; and he has shown, that, if the ring were a regular body, similar in all its parts, its equilibrium would be disturbed by the slightest force, such as the attraction of a comet or a satellite, and that it would finally be precipitated upon the surface of the planet. Hence, that philosopher concluded that the different rings with which Saturn is encircled are irregular solids, of unequal breadth in different parts of their circumference, so that their centres of gravity do not coincide with their centres of figure; and that these centres of gravity may be considered as so many satellites circulating round Saturn, at distances dependent on the inequality of the parts of each ring, and with periods of rotation equal to those of their respective rings. Hence, the ring will turn round its centre of gravity in the same time that it revolves round Saturn. It is obvious that the action of the sun and the satellites of Saturn upon these rings, ought to produce motions of precession analogous to those of the earth's equator; and that, as these motions ought to be different for each ring, they ought finally to move in different planes. This result is, however, contrary to observation; and La Place discovered that the action of the equator is the cause that retains all the rings in one plane.

Not content with explaining the various phenomena presented by the rings, astronomers have attempted also to account for their formation. Maupertuis maintained that this luminous girdle was the tail of a comet, which the attraction of Saturn had compelled into its service. Mairan asserted that the diameter of the planet was originally equal to that of its outer ring, and that by some cause the external shell of Saturn was broken in pieces, which were attracted by its body; but that the equatorial parts of the shell remained entire, and thus formed a ring about the planet. Buffon imagined that the ring is a part of the equator, which has been detached by the centrifugal force. It may be sufficient to observe that we might as well attempt to account for the formation of the satellites as the ring; that none of them seem to have been the effect of any accidental cause; and that the most rational solution of the difficulty is, to suppose that when Saturn was created and launched into the heavens, it was at the same instant encircled with a luminous ring, to answer some important purpose.

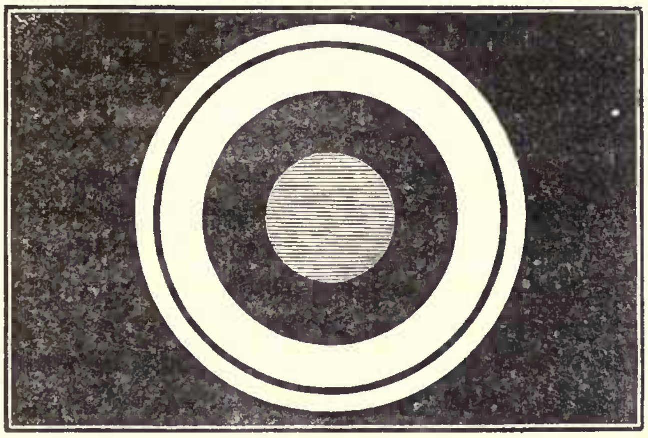
The edge of the ring reflects but little of the sun's light to us: the planes of the ring reflect the light of the sun, in the same manner as the planet does. If we suppose the diameter of Saturn to be divided into three equal parts, the diameter of the ring is equal to about seven of these parts. The ring is detached from the body of the planet in such a manner that the distance from its innermost edge, to the body of the primary, is equal to the breadth of the ring. Stars have been seen through the intervening space, though rarely, as the opening, in reality of large dimensions, appears quite small to us by reason of the distance.

Galileo was the first who discovered any thing uncommon in Saturn. Through his telescope he thought that the planet appeared like a large globe, with a smaller one on each side of it. In the year 1610, he gave out his discovery in a Latin sentence, the meaning of which was, that he had seen Saturn with three bodies; but the letters of the sentence were transposed, to keep his discovery secret for a time, lest some other person should pretend to the same. After viewing the planet in this form for two years, he was surprised to see it become quite round, without its adjacent globes, for some time. But afterwards he again discovered the globes on each side, which, in process of time, appeared to change their form; sometimes appearing round, sometimes oblong like an acorn, sometimes semicircular, then with horns towards the globe in the middle, and growing, by degrees, so long and wide as to encompass it, as it were, with an oval ring.

And now Saturn was observed by several others, some of whom, either from want of skill in drawing what they saw, or of good telescopes to make observations with, published figures not very like to what it appears through powerful glasses.

About forty years after this, Huygens, having greatly improved the art of grinding object glasses, first with a telescope of twelve, and afterward with one of twenty-three feet, that magnified a hundred times, (Galileo's magnified but thirty times,) discovered the true shape of Saturn's ring.

If we had a view of Saturn and its ring, with our eye perpendicular to one of the planes of the ring, we should see them as in the figure. But our eyes are never elevated so much above either plane as to have the visual ray stand at right angles to it: our eye, indeed, is never elevated more than thirty degrees above the plane of the ring. For the most part we view the ring at an oblique angle, so that it appears of an oval form, more or less oblong according to the different degrees of obliquity with which it is viewed.



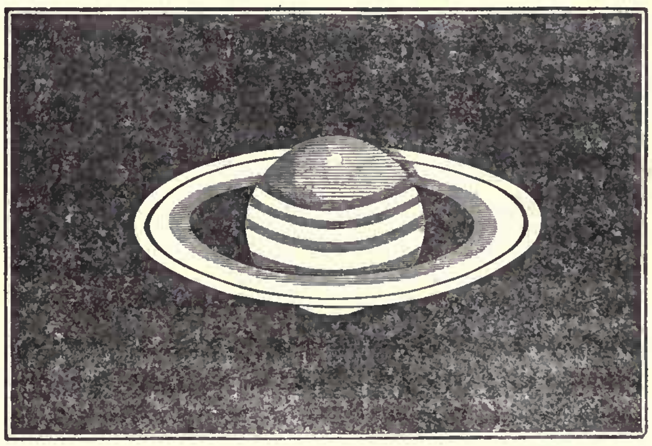
When the ring appears as an ellipse, the parts about the extremities of the longer axis, reaching beyond the disc of the planet, are called "handles," (ansæ.) They are unequal in size a little before and after the ring disappears. The larger handle is longer visible before the planet's round phase, and appears sooner again after it. As the ellipse of the ring grows narrower, the handles appear shorter; their extremities disappear first, either because of their narrowness, or because the outward parts of the rings are less bright than the inward.

The appearances above described constantly succeeding each other in a regular manner, we must conclude, then, that the cause producing them is constant; and they are ascribed to a solid body surrounding the planet, appearing and disappearing in succession. As it would not be natural to conclude that this body acquires and loses by turns the power of reflecting light, we must suppose that it is opaque, and that the variations in its appearance result from its position and form.

Thus, it will be bright when it turns toward us that face which is illuminated by the sun, and cease to be visible when it turns the opposite face. We must also lose sight of it when we are so situated that its plane passes through the earth's centre; for then it can reflect no light to us. Again, we cannot see it when its plane passes through the sun; for then only its edge is illuminated, and, as it is very thin, it cannot reflect light enough to render it visible to us. Yet, if very powerful telescopes be used, the edge can be seen, and it appears like a luminous line on the disc of the planet.

These phenomena afford strong confirmation to the hypothesis of an annular surface surrounding Saturn.

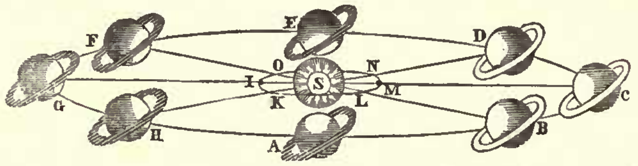
It can be demonstrated that the ring, like the planet, is an opaque body; for when the illuminated surface of the ring is inclined to the earth, as in



the figure, it projects a perceptible shadow on the globe of Saturn. This figure represents the planet surrounded by its rings, and having its body striped with dark belts, somewhat similar, but broader and less strongly marked, than those of Jupiter, but owing doubtless to a similar cause. That the ring is a solid opaque substance, is shown by its shadow on the planet on the side nearest the sun, and by its receiving that of the planet on the other side, as shown in the figure. From the belts being parallel with the plane of the ring, it may be conjectured that the axis of rotation of the planet is perpendicular to that plane; and this conjecture is confirmed by the occasional appearance of extensive dusky spots on its surface, which, when watched, like the spots of Mars and Jupiter, indicate a rotation in ten and a half hours about an axis so situated. The dimensions of Saturn's rings are as follows:—

	Miles.
Exterior diameter of exterior ring	=176,418
Interior ditto	=155,272
Exterior diameter of interior ring	=151,690
Interior ditto	=117,339
Equatorial diameter of the body	=79,160
Interval between the planet and interior ring	=19,090
Interval of the rings	=1,791
Thickness of the rings not exceeding	=1,000

The axis of rotation, like that of the earth, preserves its parallelism to itself during the motion of the planet in its orbit; and the same is also the case with the ring, whose plane is constantly inclined at the same, or very nearly the same, angle to that of the orbit, and, therefore, to the ecliptic, viz. twenty-eight degrees and forty minutes, and intersects the latter plane in a line which makes an angle with the line of equinoxes of one hundred and seventy degrees; so that the *nodes of the ring* lie in one hundred and seventy degrees and three hundred and fifty degrees of longitude. Whenever, then, the planet happens to be situated in one or other of these longitudes, the plane of the ring passes through the sun, which then illuminates only the edge of it; and as, at the same moment, owing to the smallness of the earth's orbit compared with that of Saturn, the earth is necessarily not far out of that plane, and must, at all events, pass through it a little before or after that moment, it only then appears to us a very fine straight line, drawn across the disc, and projecting out on each side: indeed, so very thin is the ring, as to be quite invisible, in this situation, to any but telescopes of extraordinary power. This remarkable phenomenon takes place at intervals of fifteen years; but the disappearance of the ring is generally double, the earth passing *twice* through its plane before it is carried past our orbit by the slow motion of Saturn. As the planet, however, recedes from these points of its orbit, the line of sight becomes gradually more and more inclined to the plane of the ring, which, according to the laws of perspective, appears to open out into an ellipse which attains its greatest breadth when the planet is ninety degrees from either node.



Let S be the sun, A B C D E F G H Saturn's orbit, and I K L M N O the earth's orbit. Both Saturn and the earth move according to the order of the letters, and when Saturn is at A its ring is turned edgewise to the sun S, and it is then seen from the earth as if it had lost its ring, let the earth be in any part of its orbit whatever, except between N and O; for, whilst it describes that space, Saturn is apparently so near the sun as to be hid in his beams. As Saturn goes from A to C, its ring appears more and more open to the earth. At C the ring appears most open of all, and seems to grow narrower and narrower as Saturn goes from C to E; and when it comes to E, the ring is again turned edgewise both to the sun and earth: and as neither of its sides are illuminated, it is invisible to us, because its edge is too thin to be perceptible, and Saturn appears again as if it had lost its ring. But as it goes from E to G, its ring opens more and more to our view on the under side, and seems just as open at G as it was at C; and may be seen in the night-time from the earth in any part of its orbit, except about M, when the sun hides the planet from our view. As Saturn goes from G to A, its ring turns more and more edgewise to us, and, therefore, it seems to grow narrower and narrower; and at A it disappears as before. Hence, while Saturn goes from A to E, the sun shines on the upper side of the ring, and the under side is dark; and whilst it goes from E to A, the sun shines on the under side of the ring, and the upper side is dark.

If we take the dimensions of the ring with a micrometer, we shall find that its apparent breadth, as has been stated, is equal to the distance of its interior border from the surface of the planet. This distance is a third of the diameter of the planet, and its mean value is 5″. 4. The real dimensions are probably rather smaller. They would naturally appear enlarged on account of irradiation. The best telescopes enable us to observe on the surface of the ring concentric lines, extremely fine and dark, that appear to divide it into many parts. There is, therefore, probably many distinct rings. The telescope must be very powerful to permit us to discover these lines of division. With other than powerful instruments the whole appears as one ring, increased somewhat in breadth by irradiation.

These rings cast a deep shadow upon the planet, which proves that they are not shining *fluids*, but composed of *solid* matter. They appear to be possessed of a higher reflective power than the surface of Saturn, as the light reflected by them is more brilliant than that of the planet. One obvious use of this double ring is, to reflect light upon the planet in the absence of the sun: what other purposes it may be intended to subserve in the system of Saturn, is, at present, to us unknown. It will naturally be asked how so stupendous an arch, composed of solid and ponderous materials, can be sustained without collapsing and falling in upon the planet. The ring has a rapid rotation in its own plane, which observation has detected owing to some portions of its surface being a little less bright than others.

The period of the ring's revolution presents to us quite a singular relation. If a satellite be supposed to describe an orbit round the planet, having the mean circumference of the ring for its circumference, and its sidereal revolution be computed, it will be found equal to that of the ring. This relation answers the question above stated as to the manner in which the ring is sustained without touching the planet; or it refers the phenomenon to the general cause by which all satellites are sustained in their orbits. We may view in the light of a small satellite each particle of the ring, or its whole as a multitude of satellites connected inseparable together. If these small supposed bodies were independent of each other, their velocities would differ according to their distances from the centre of the primary. Those situated nearest the centre would have the greatest, those furthest from the centre the least, velocity; and if we take for the mean term the velocity that belongs to the mean circumference of the ring, the velocities of the other particles would deviate from it each way by equal quantities, the greater counterbalancing the smaller. Now, if the particles were united and attached to each other so as to form one solid body, a sort of compensation would take place in their motions: the most rapid would tend to impart greater rapidity to the slowest, and the slowest would tend to retard the motion of the most rapid; and as these efforts would balance each other, there would remain the mean motion common to all the particles, which would be that of the mean circumference, and the rings would be sustained about Saturn in the same way as the moon is sustained about the earth, or like the arches of a bridge when the centre of gravity is at the centre of the voussoirs. It is the centrifugal force (arising from the rotation) which sustains the ring; and although no observations nice enough to exhibit a difference of periods between the outer and inner rings have hitherto been made, it is probable that such a difference does exist as to place each, independently of the other, in a similar state of equilibrium.

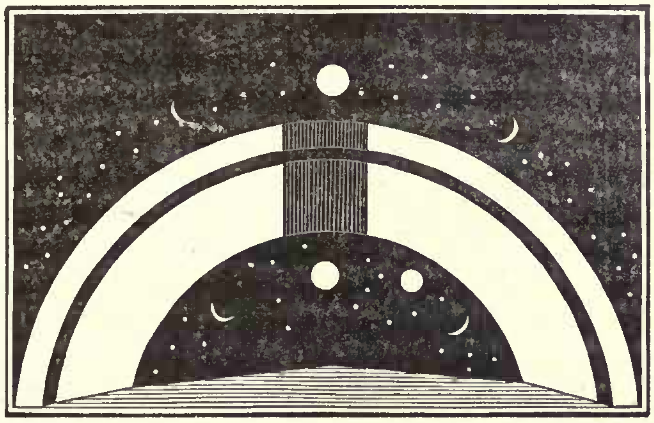
This theory would hold good were the ring composed, as that of Saturn's seems to be, of *several* detached and concentric circles, only it must be applied separately to each. The periods of their rotations would then be different.

Although the rings are, as we have said, very nearly concentric with the body of Saturn, yet recent micrometrical measurements of extreme delicacy have demonstrated that the coincidence is not mathematically exact, but that the centre of gravity of the rings oscillates round that of the body, describing a very minute orbit, probably under laws of much complexity. Trifling as this remark may appear, it is of the utmost importance to the stability of the system of the rings. Supposing them mathematically perfect in their circular form, and exactly concentric with the planet, it is demonstrable that they would form (in spite of their centrifugal force) a system in a state of *unstable equilibrium*, which the slightest external power would subvert, not by causing a rupture in the substance of the rings, but by precipitating them, *unbroken*, on the surface of the planet. For the attraction of such a ring or rings on a point or sphere eccentrically situate within them, is not the same in all directions, but tends to draw the point or sphere towards the nearest part of the ring, or away from the centre. Hence, supposing the body to become, from any cause, ever so little eccentric to the ring, the tendency of their mutual gravity is, not to correct, but to increase, this eccentricity, and to bring the nearest parts of them together. Now, external powers, capable of producing such eccentricity, exist in the attractions of the satellites, and in order that the system may be *stable*, and possess within itself a power of resisting the first inroads of such a tendency while yet nascent and feeble, and opposing them by an opposite or maintaining power, it is sufficient to admit the rings to be *loaded* in some part of their circumference, either by some minute inequality of thickness, or by some portions being denser than others. Such a load would give to the whole ring to which it was attached somewhat of the character of a heavy and sluggish satellite, maintaining itself in an orbit with a certain energy sufficient to overcome minute causes of disturbance, and establish an average bearing on its centre. But even without supposing the existence of any such load—of which, after all, we have no proof—and granting, therefore, in its full extent, the general instability of the equilibrium, we think we perceive, in the periodicity of all the causes of disturbance, a sufficient guarantee of its preservation. However homely be the illustration, we can conceive nothing more apt in every way to give a general conception of this maintenance of equilibrium under a constant tendency to subversion, than the mode in which a practised hand will sustain a long pole resting on the finger in a perpendicular position by a continual and almost imperceptible variation of the point of support. Be that, however, as it may be, the observed oscillation of the centres of the rings about that of the planet is in itself the evidence of a perpetual contest between conservative and destructive powers, both extremely feeble, but so opposing one another as to prevent the latter from ever acquiring an uncontrollable ascendency, and rushing to a catastrophe.

This is also the place to observe, that, as the smallest difference of velocity between the body and rings must infallibly precipitate the latter on the former, never more to separate, (for they would, once in contact, have attained a position of *stable equilibrium*, and be held together ever after by an immense force,) it follows, either that their motions in their common orbit round the sun must have been adjusted to each other by an external power with the minutest precision, or that the rings must have been formed about the planet while subject to their common orbitual motion, and under the full and free influence of all the acting forces.

The rings of Saturn must present a magnificent spectacle from those regions of the planet which lie above their enlightened sides. On the other hand, in the regions beneath the dark side, a solar eclipse of fifteen years in duration, under their shadow, must afford (to our ideas) an inhospitable asylum to animated beings, ill compensated by the faint light of the satellites. But we shall do wrong to judge of the fitness or unfitness of their condition from what we see around us, when, perhaps, the very combinations which convey to our minds only images of horror, may be in reality theatres of the most striking and glorious displays of beneficent contrivance. When viewed from the middle zone of the planet, in the absence of the sun, the rings will appear like vast luminous arches, extending along the canopy of heaven from the eastern to the western horizon, having an apparent breadth equal to a hundred times the apparent diameter of our moon, and will be seen darkened about the middle by the shadow of Saturn.

The figure beneath presents a view of the appearance which the rings and moons of Saturn will exhibit, in certain cases, about midnight, when beheld from a point twenty or thirty degrees north from its equator. The shade on the upper part of the rings represents the shadow of the body of Saturn. The shadow will appear to move gradually to the west as the morning approaches.



There is no other planet in the solar system whose firmament will present such a variety of splendid and magnificent objects as that of Saturn. The various aspects of the seven moons, one rising above the horizon while another is setting, and a third approaching to the meridian; one entering into an eclipse, and another emerging from it; one appearing as a crescent, and another with a gibbous phase; and sometimes the whole of them shining in the same hemisphere, in one bright assemblage;—the majestic motions of the rings, at one time illuminating the sky with their splendor, and eclipsing the stars; at another, casting a deep shade over certain regions of the planet, and unveiling to view the wonders of the starry firmament;—are scenes worthy of the majesty of the Divine Being to unfold, and of rational creatures to contemplate. Such magnificent displays of wisdom and omnipotence lead us to conclude that the numerous splendid objects connected with this planet were not created merely to shed their lustre on naked rocks and barren sands, but that an immense population of intelligent beings is placed in those regions to enjoy the bounty and to adore the perfections of their great Creator.

HERSCHEL.

From inequalities in the motions of Jupiter and Saturn, which could not be accounted for from the mutual action of these planets, it was supposed by some astronomers that there existed, beyond the orbit of Saturn, another planet, by whose action these irregularities were produced.

This happy conjecture was confirmed on the 13th of March, 1781, when Herschel discovered a new planet, which, in compliment to his patron, he named the *Georgium Sidus*, (the Georgian.) It has been called by some *Uranus*, and by others *Herschel.* This last name has been in popular use in this country, and we hope it may ever continue to be so. The new planet, which had been previously observed as a small star, and introduced into catalogues of the fixed stars, is situated beyond the orbit of Saturn, at the distance of *one thousand nine hundred millions of miles* from the centre of the system, and performs its sidereal revolution round the sun in eighty-four of our years nearly, which is one year to that planet. Its diameter is more than four times that of the earth, being over thirty-three thousand miles. As the distance of the planet Herschel from the sun is twice as great as that of Saturn, it can scarcely ever be distinguished by the naked eye. When the sky, however, is serene, it appears like a fixed star of the sixth magnitude, with a bluish white light, and a brilliancy between that of Venus and the moon; but with a power of two hundred or three hundred, its disc is visible and well defined.

On January 11th, 1787, as Herschel was observing this planet, he perceived, near its disc, some very small stars, whose places he noted. The next evening, upon examining them, he found that two of them were missing. Suspecting, therefore, that they might be satellites which had disappeared in consequence of having changed their situation, he continued his observations, and in the course of a month discovered them to be satellites, as he had first conjectured. Of this discovery he gave an account in 1787.

In 1788, he published a further account of this discovery, containing their periodic times, their distances, and the positions of their orbits, so far as he was then able to ascertain them. The most convenient method of determining the periodic time of a satellite, is, either from its eclipses, or from taking its position in several successive oppositions of the planet; but no eclipses have yet happened since the discovery of these satellites, and it would be waiting a long time to put in practice the other method. Dr. Herschel, therefore, took their situations whenever he could ascertain them with some degree of precision, and then reduced them, by computation, to such situations as were necessary for his purpose. In computing the periodic times, he has taken the synodic revolutions, as the positions of their orbits, at the times when their situations were taken, were not sufficiently known to get very accurate sidereal revolutions. The mean of several results gave the synodic revolution of the first satellite eight days and seventeen hours, and of the second, thirteen days and eleven hours. The results, he observes, of which these are a mean, do not much differ among themselves, and therefore the mean is probably tolerably accurate.

The next thing to be determined in the elements of the satellites was their distances from the planet, to obtain which he found one distance by observation, and then the other from the periodic times. Now, in attempting to discover the distance of the second, the orbit was seemingly elliptical. On March 18th, 1787, at eight hours, he found the elongation to be forty-seven seconds, this being the greatest of all the measures he had taken. Hence, at the mean distance of this planet from the earth, this elongation will be forty-four seconds. Admitting, therefore, for the present, says Herschel, that the satellites move in circular orbits, we may take forty-four seconds for the true distance without much error; hence, as the squares of the periodic times are as the cubes of the distances, the distance of the first satellite comes out thirty-three seconds. The synodic revolutions were here used instead of the sidereal, which will make but a small error.

The last thing to be done, was to determine the inclinations of the orbits, and the places of their nodes. And here a difficulty presented itself which could not be got over at the time of his observation; for it could not be determined which part of the orbit was inclined *to* the earth, and which *from* it, and it is still undecided. So that, we may believe, there is an optical illusion in the case, and that these secondaries in reality describe their orbits by a motion from west to east, preserving unbroken the analogy which is found to exist with respect to all the other planetary worlds, secondary as well as primary. Their orbits are very nearly perpendicular to the ecliptic. The six were all discovered by Herschel, as well as the planet they accompany, and he further suspected, from the result of his observations, that *the planet was surrounded by two rings perpendicular to each other.* This, if it were established as a fact, would be a very remarkable one; but it cannot be considered as at all certain.

There are no means, like those used in the case of Jupiter and Saturn, of ascertaining the distance and actual magnitude of this planet: the determination of these elements rests on the observation of its periodic time, and the law by which the periodic times and the distances are connected.

According to La Place, the five satellites nearest the planet Herschel may be retained in their orbits by the action of its equator, and the sixth by the action of the interior satellites; and hence he concluded that this planet revolves about an axis very little inclined to the ecliptic, and that the time of its diurnal rotation cannot be much less than that of Jupiter or Saturn.

When the earth is in its perihelion, and Herschel in its aphelion, the latter becomes stationary when its elongation or distance from the sun is two hundred fifty-seven and a half degrees, and its retrogradations continue nearly one hundred and fifty-two days. When the earth is in aphelion, and Herschel in its perihelion, it becomes stationary at an elongation of two hundred fifty-six and a half degrees, and the retrogradations continue nearly one hundred and fifty days.

The celestial globes which we have now described, are all the planets which are at present known to belong to the solar system. It is probable that other planetary bodies may yet be discovered between the orbits of Saturn and Herschel, and even far beyond the orbit of the latter; and it is also not improbable that planets may exist in the immense interval of thirty-seven millions of miles between Mercury and the Sun. These, if any exist, can be detected only by a series of *day observations*, made with equatorial telescopes; as they could not be supposed to be seen after sunset, on account of their proximity to the sun. Five *primary* planets, and eight *secondaries*, have been discovered within the last fifty-six years; and, therefore, we shall have no reason to conclude that all the bodies belonging to our system have been detected, till every region of the heavens be more fully explored.

The plate facing this page is intended to represent the relative magnitudes of the seven principal planets in the system, the sun's diameter being considered as three feet and five inches. Their diameters in miles are also appended, as well as their mean distances from the sun in millions of miles, and the distances of the secondaries from their primaries in thousands of miles.

In closing this section, we will add an illustration calculated to convey to the minds of our readers a general impression of the relative magnitudes and distances of the parts of the system. Choose any well levelled field. On it place a globe two feet in diameter, which will represent the sun. Mercury will be represented by a grain of mustard seed, on the circumference of a circle one hundred and sixty-four feet in diameter for its orbit; Venus a pea, on a circle two hundred and eighty-four feet in diameter; the earth also a pea, on a circle of four hundred and thirty feet; Mars a rather large pin's head, on a circle of six hundred and fifty-four feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from one thousand to one thousand two hundred feet; Jupiter a moderate-sized orange, in a circle nearly half a mile across; Saturn a small orange, on a circle of four fifths of a mile; and Herschel a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter. As to getting correct notions on this subject from those toys called orreries, it is out of the question. To imitate the motions of the planets in the above-mentioned orbits, Mercury must describe its own diameter in forty-one seconds; Venus, in four minutes and fourteen seconds; the earth, in seven minutes; Mars, in four minutes and forty-eight seconds; Jupiter, in two hours and fifty-six minutes; Saturn, in three hours and thirteen minutes; and Herschel, in two hours and sixteen minutes.

CHAPTER VI.

SECTION I.

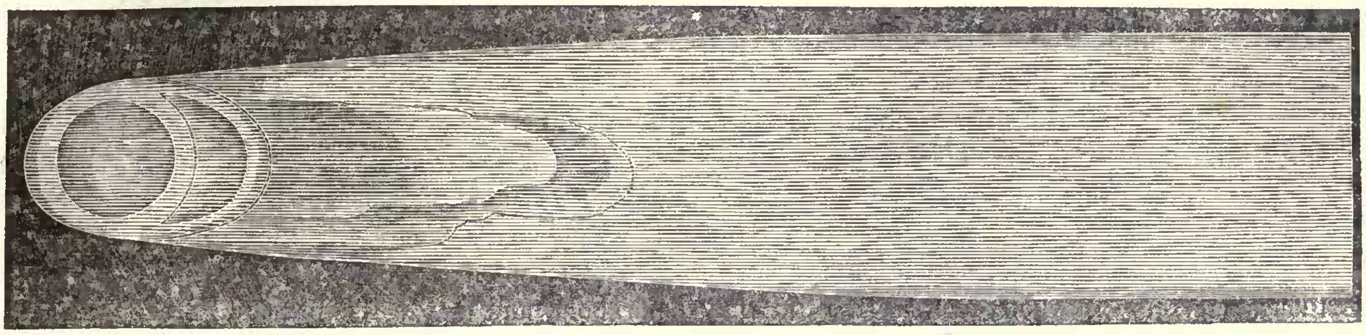
Comets—Little known of their nature or purposes—Their number—Comet of 1680—The tail not an invariable appendage—What are the essentials of a comet—How distinguished from a planet—Anciently considered as meteors—Proof to the contrary—Elements of a cometary orbit—Motions of a comet—How recognised—Halley's comet—Lexell's—Encke's—Biela's—Do comets affect the temperature of our seasons?—Physical constitution—The envelope—Nucleus—Tail—Do comets have phases?—Variation in the size of the envelope.

Besides the planetary globes of which we have treated, there is a class of celestial bodies that occasionally appear in the heavens to which the name of *Comets* (hairy stars) has been given. Their extraordinary aspect, their rapid and seemingly irregular motions, the unexpected manner in which they often burst upon us, and the imposing magnitudes which they sometimes assume, have in all ages rendered them objects of astonishment not unmixed with superstitious dread to the uninstructed, and an enigma to those most conversant with the wonders of nature and the operations of natural causes. Even now that we have ceased to regard their movements as irregular, or as governed by other laws than those which retain the planets in their orbits, their intimate nature, and the offices they perform in the economy of our system, are as much unknown as ever. No account, to which we can give full credence, has been rendered of the many singularities that they present. They are distinguished from the other heavenly bodies by their ruddy appearance, and in general by the accompaniment of a long train of light, known by the name of the *tail*, though improperly, since it often precedes them in their motions. This train sometimes extends over a considerable portion of the heavens, and is so transparent that stars may be seen through it. The number of comets which have been astronomically observed, or of which notices have been recorded in history, is very great. In a list cited by La Lande, *seven hundred* are enumerated. When we consider, that, in the earlier ages of astronomy, and, indeed, in more recent times, before the invention of the telescope, only large and conspicuous ones were noticed, and that since due attention has been paid to the subject scarcely a year has passed without the observation of one or two of these bodies, and that in some years four and even five have been observed, (two or three at once,) it will be readily conceded that their number may be many thousands.

Multitudes, indeed, must escape all observation, by reason of their paths traversing only that part of the heavens which is above the horizon in the daytime. Comets so circumstanced can only become visible by the rare coincidence of a total eclipse of the sun,—a coincidence which happened, as related by Seneca, sixty years before Christ, when a large comet was actually observed very near the sun. Several, however, stand on record as having been bright enough to be seen in the daytime, even at noon, and in bright sunshine. Such were the comets of 1402, and 1532, and that which appeared a little before the assassination of Caesar, and was supposed to have predicted his death.

That feelings of awe and astonishment should be excited by the sudden and unexpected appearance of a great comet, is no way surprising; being, in fact, according to the accounts we have of such events, one of the most brilliant and imposing of all natural phenomena. Comets consist, for the most part, of a large and splendid, but ill-defined, nebulous mass of light, called the head, which is usually much brighter towards the centre, and offers the appearance of a vivid *nucleus*, like a star or planet. From the head, and in a direction *opposite to that in which the sun is situated* from the comet, appear to diverge two streams of light, which grow broader and more diffused at a distance from the head, and which sometimes close in and unite at a little distance behind it—sometimes continue distinct for a great part of their course, producing an effect like that of the trains left by some bright meteors, or like the diverging fire of a sky-rocket, only without sparks or perceptible motion. This is the tail. This magnificent appendage attains occasionally an immense apparent length. Aristotle relates of the tail of the comet of 371 A. C., that it occupied a third of the hemisphere, or sixty degrees: that of A. D. 1618 is stated to have been attended by a train no less than one hundred and four degrees in length. In the figure of the comet of 1680, the most celebrated of modern times, we distinguish the nucleus with its surrounding atmosphere or nebulosity; above is a sort of half-ring, largest at the top, and narrower at the sides; on the other side is an appearance which has been denominated *a beard;* then comes a long tail, in the form of a cone, with a light less lively than that of the head. This comet, with a head not exceeding in brightness a star of the second magnitude, covered with its tail an extent of more than seventy degrees of the heavens, or, as some accounts state, ninety degrees. Its length exceeded *ninety-six millions of miles.*

The tail is by no means an invariable appendage of comets. The smallest, such as are visible only in telescopes, or with difficulty by the naked eye, and which are by far the most numerous, offer very frequently no appearance of such an accompaniment, but appear only as round or somewhat oval vaporous masses, most dense toward the centre; and some of the brightest have been observed to have short and feeble tails, or to be wholly without them. Those of 1585, and 1763, offered no trace of such an appendage; and Cassini describes the comet of 1682 as being round and bright like Jupiter.



Every hairy star which passed successively through different constellations, was formerly called a comet; but modern astronomers give this name, notwithstanding its etymology, to bodies that have not this hairy appearance. We may define a comet by the following characteristics. 1. *It must have a proper motion, or a motion of its own.* 2. *It must move in a very elongated curve*, so that it will pass, in certain parts of its course, to such a distance from the earth as to be invisible.

The very elongated form of the orbit makes a marked distinction between a comet and a planet. When Herschel discovered the heavenly body that has since taken his name, it was for some time supposed to be a comet, although it had neither tail nor hairy appearance, for its proper motion among the constellations was manifest; and, in order to explain why it had not before been seen and recognised, it was supposed that it had now made its appearance for the first time, and that its great distance had hitherto rendered it invisible. But when it was proved, by careful and continued observation, that it passed round the sun nearly in a circle, and was visible at all seasons in the absence of daylight, it was ranked among the planets.

Comets were considered by most of the ancient philosophers as mere meteors, formed in the earth's atmosphere; but they are now known to be celestial bodies. To ascertain this, it was only necessary to compare together several observations made at the same time in different parts of the earth very remote from each other.

From the time of Tycho Brahe, to whom we are indebted for this discovery, comets have been known to move round the sun according to certain laws, similar to those which regulate the motions of the planets, in orbits that are very elongated ellipses, the sun being always in one of the foci of the ellipse.

By a calculation, of which it would be impossible to give an exact idea in this place, it may be shown that three positions of a comet, seen from the earth, are sufficient to determine its orbit. The several particulars or *elements* which constitute this determination are:—

The *inclination of the orbit*, and the *longitude* of the node necessary to determine the position of the plane of the orbit; the *longitude of the perihelion*, showing the situation of that curve in its own plane; the *perihelion distance*, which shows the form of the orbit, because the focus necessarily coincides with the sun's centre; and last, the *direction of the motion*, expressed by one of these words, *direct*, *retrograde*.

To calculate the *elements* is the first object of astronomers when a comet appears. In order to do this, three observations are necessary. If only two can be obtained, the form and the position of its orbit must remain unknown. If many observations can be had, they all tend to establish the final result, and it is the more exact.

We come now to speak of the motions of comets.

These are apparently most irregular and capricious. Sometimes they remain in sight for only a few days, at others for many months; some move with extreme slowness, others with extraordinary velocity; while not unfrequently the two extremes of apparent speed are exhibited by the same comet in different parts of its course. The comet of 1472 described an arc in the heavens of one hundred and twenty degrees in extent in a single day. Some pursue a direct, some a retrograde, and others a tortuous and very irregular, course; nor do they confine themselves, like the planets, within any certain region of the heavens, but traverse indifferently every part. Their variations in apparent size, during the time they continue visible, are no less remarkable than those of their velocity. Sometimes they make their first appearance as faint and slow-moving objects, with little or no tail, but by degrees accelerate, enlarge, and throw out from them this appendage, which increases in length and brightens till (as always happens in such cases) they approach the sun, and are lost in his beams. After a time they again emerge on the other side, receding from the sun with a velocity at first rapid, but gradually decreasing. It is after thus passing the sun, and not till then, that they shine forth in all their splendor, and that their tails acquire their greatest length and development; thus indicating the action of the sun's rays as the exciting cause of that extraordinary emanation. As they continue to recede from the sun, their motions diminish, and the tail fades away, or is absorbed into the head, which itself grows continually feebler, and is at length altogether lost sight of, never, in by far the greater number of cases, to be seen more.

Without the clue furnished by the theory of gravitation, the enigma of these seemingly irregular and capricious movements might have remained forever unresolved. But Newton, having demonstrated the possibility of any conic section whatever being described about the sun by a body revolving under the dominion of that law, immediately perceived the applicability of the general proposition to the case of cometary orbits; and the great comet of 1680, (which we have represented above,) one of the most remarkable on record, both for the immense length of its tail and the nearness of its approach to the sun, (within one sixth of the diameter of that luminary, or about ninety thousand miles nearer than the moon is to the earth,) afforded him an excellent opportunity for the trial of his theory. The success of the attempt was complete. He ascertained that this comet described about the sun, as its focus, an ellipse of so great an eccentricity as to be undistinguishable from a parabola, and that in this orbit the areas described about the sun were, as in the planetary ellipses, proportional to the times. Hence it became a received truth, that the motions of the comets are regulated by the same general laws as those of the planets, the difference of the cases consisting only in the extravagant elongations of their ellipses, and in the absence of any limit to the inclinations of their planes to that of the ecliptic, or any general coincidence in the direction of the motions from west to east, rather than from east to west, like what is observed among the planets.

For the most part, it is found that the motions of comets may be sufficiently well represented by parabolic orbits; that is to say, ellipses whose axis are of infinite length, or, at least, so very long that no appreciable error in the calculation of their motions, during all the time they continue visible, would be incurred by supposing them actually infinite. The parabola is that conic section which is the limit between the ellipse on the one hand, which returns into itself, and the hyperbola on the other, which runs out to infinity. A comet, therefore, that should describe an elliptic path, however long its axis, must *have* visited the sun before, and must again return, unless disturbed, in some determinate period: but should its orbit be of the hyperbolic character, when once it has passed its perihelion, it could never more return within the sphere of our observation, but must run off to visit other systems, or be lost in the immensity of space. A very few comets have been ascertained to move in hyperbolas, but many more in ellipses. These, then, in so far as their orbits can remain unaltered by the attractions of the planets, must be regarded as permanent members of our system.

After learning how much the form of the tail, of the envelope, and the nucleus, vary in the course of two or three days, as well as the intensity of light from all these parts, no one would expect to recognise such a body on its second appearance, after a lapse of many years, by any description founded on those physical characteristics of size, form, or brightness. At any rate, no astronomer would rely on these marks. They would leave them all out of the question, and confine their attention wholly to the course of the comet in the heavens.

When three observations have been made of a comet, with sufficient exactness, the *elements* are calculated, and then search is diligently made in the *catalogue of comets*, in which the elements are recorded, to ascertain whether it is like any of those already observed.

Let us first suppose that all the sets of elements contained in the catalogue, or table, differ from that of the new comet. We must still refrain from drawing any positive conclusion, because observation and theory prove that a comet, in passing near a planet, may be so perceptibly deranged in its course, that the curve it makes *after* that approach cannot be considered as the continuation of the curve it was describing before.

Now let us suppose a contrary case, and that the elements of the new comet differ very little from a set of elements found in the table, and which belong to a comet seen at some former period. In this case there is *great probability* that they are one and the same, and that it is the reappearance of a comet returning to its perihelion. We say there is great probability only, because, mathematically speaking, it is not impossible that two comets should traverse the heavens in two equal curves, and be similarly placed. But when we consider that the similitude must relate, at the *same time*, to the inclination of the plane of the orbit, which may vary from 0° to 180°; to the longitude of the node, that is, to a number susceptible of taking all possible values from 0° to 360°; to the longitude of the perihelion, which, in like manner, may vary 360°; finally, to the perihelion distance, which, for comets already known, is comprehended between twenty and four hundred millions of miles;—when we take all these particulars into consideration, we can scarcely hesitate to conclude that two comets, which, at two different epochs, have appeared with all these elements nearly the same, are one and the same body. Hitherto, at least, we have been justified in this inference by the event.

Having explained that the different circumstances in the proper motion of a comet are the only means of recognising it when it reappears, we proceed to apply these principles to the only three comets whose periodical return has been satisfactorily determined.

THE COMET OF 1759, OR HALLEY'S COMET.

In 1682, there appeared a comet, with great splendor, and with a tail of thirty degrees in length. It was observed by the celebrated astronomer Edmund Halley, who calculated its elements from its perihelion passage. Having also calculated the elements of a comet of 1607, from observations made by Kepler and Longiomontanus, and allowing for the inaccuracies that must necessarily occur in calculating the orbits, and for the errors into which the ablest observers are liable to fall when using instruments so much less perfect than those of the present day, remembering also that the attraction of the planets must produce a real change in a comet's orbit at each successive revolution, Halley came to the conclusion, that, from the great similarity in the elements, the comets of 1607, and 1682, were one and the same.

Here was an interval of seventy-five years. Therefore, in going back about that time from 1607, there ought to have been seen, if Halley's conjecture were founded in truth, a similar comet. This was actually the case. In 1531, that is, seventy-six years before 1607, Apian had observed a comet whose course through the constellations he watched very attentively. His observations, calculated by Halley, gave, as results, elements which differed very little from those of the comets of 1607, and 1682. A comet had been seen also in 1456. From the few precise observations in the authors of that period, Pingre found the elements to be very similar to those of the comets of 1531, 1607, and 1682.

Before the year 1456, we find no good observations. The chroniclers thought it enough to say that a comet was seen in such and such a constellation. Not a word do they give as to its relative position to known stars, or the hour at which it was seen. Consequently the elements of the orbit cannot be calculated. When this infallible method of recognising a comet fails, the period of its revolution is the only guide that remains. We have already seen how much this period varies, and, consequently, how uncertain the results must be. It is, therefore, with some doubt that we give the comet of 1305, that of 1230, the comet mentioned by Haly-ben Rodoan in 1006, that of 855, and a comet seen in the year 52 before the Christian era, as former appearances of that of 1759. As to the comet of 1006, the identity may be inferred from the similarity of their limits, if not from their elements. In 1305, it was termed " the comet of terrible magnitude."

Some have pretended to trace it as far back as 230 years before the Christian era, when a comet is said to have appeared of considerable magnitude and brilliancy, shining with a brightness that surpassed the splendor of the sun. It was supposed to have signalized the birth of Mithridates. In 1456, this comet was beheld by all Europe with fear and astonishment, partly on account of its great brilliancy, and partly because at that time the public mind was enslaved by astrological superstitions.

The Turks were then engaged in a successful war, in which they destroyed the Greek empire: *they*, therefore, might have regarded it as an auspicious omen. The Christians thought that destruction was portended by its appearance, especially as its tail was turned towards the east. The Pope Calixtus regarded it as at once the sign and the instrument of divine wrath. He ordered public prayers to be offered up, and granted a year's indulgence to all who, at the tolling of the noon bell, should say three pater nosters, and three ave marias, to propitiate the mercy of Heaven. In this very circumstance originates the custom, still prevalent in Catholic countries, of ringing the bells at noon. The popular terror can scarcely be wondered at, for the comet at that time exhibited a tail curved like a sabre, sixty degrees in length, or two thirds of the distance between the zenith and horizon. Its whole appearance was described as singularly splendid, and of a vivid brightness. At this return, it was in its most favorable position relative to the earth and sun for observation of its magnitude and brilliancy.

In the year 1531, it appeared of a bright gold color. It pursued the same apparent path through the heavens which it traced in 1835. The celebrated Kepler observed it on his return from a convivial party on the 26th of September. It continued visible about five weeks.

The identity of the comets of 1531, 1607, and 1682, could not be doubted, and accordingly Halley was encouraged to *predict* that a *comet* would be visible toward the end of the year 1758, or the beginning of 1759, having elements differing but little from the three last mentioned.

So remarkable a prediction could not fail to attract the attention of all astronomers, as its fulfilment would form a new era in the astronomy of comets; and therefore it was thought advisable, in order to convince the most incredulous, to do away as far as was possible with the indefiniteness in which Halley had very properly left the date of its precise return; for, in his time, it was impossible to determine exactly the amount of disturbances or perturbations. It became extremely interesting to know whether the attractions of the larger planets might not materially interfere with its orbitual motion. The computation of their influence from the Newtonian law of gravity, a most difficult and intricate piece of calculation, was undertaken and accomplished by Clairaut, who found that the action of Saturn would retard its return by one hundred days, and that of Jupiter by no less than five hundred and eighteen, making in all six hundred and eighteen days. It might be expected, therefore, to reach its perihelion about the middle of April, 1759. Clairault also gave notice to the public, that, being much hurried in his calculations, he had not time to consider many smaller causes, which might together make a difference of thirty days, more or less, in the period of seventy-six years. The event justified all he had said, for the comet appeared according to the prediction, and passed its perihelion, March 12th, 1759, within the assigned limits. Its parabolic elements, a little changed since its preceding appearance, were such as the calculations of Clairault had made them.

No doubt could now be entertained as to the periodical return of Halley's comet. It remained to calculate its next appearance. Damoiseau and Pontecoulant did not shrink from the immense labor. They carried their approximations much further than those who preceded them. They even calculated the disturbing force of Herschel, the existence of which was unknown in the time of Clairault. The following is the result obtained by Damoiseau. "The interval between the passage of the comet through its perihelion in 1759 and its approaching return to that point, will be seventy-six years and two hundred and thirty-seven days, which, reckoned from the 12th of March, 1759, will be accomplished on the 4th of November, 1835." Pontecoulant fixed it on the 13th of the same month, and Lubbock on the 30th of October.

The comet became visible (being first seen at Rome) on the fifth of August, at three o'clock in the morning. Its position was at that time in right ascension five hours and twenty-six minutes, and in declination twenty-two degrees and seventeen minutes north. It was seen again on the next morning, and had sensibly advanced to the east. From about this time the presence of the moon interfered with observations, and we hear that the comet was next seen at Dorpat, Russia, on the 20th of August. In this vicinity it was not seen until the 31st of August. When first discovered, the comet appeared to be merely a faint nebulous mass. By the last of August it was nearly circular, brightest in the middle, and fading away upon the border. On the 11th of October, the train had a length of nine degrees. The nucleus had much the appearance of one of Jupiter's satellites, but with scarcely any sensible magnitude. It passed its perihelion on November 15th,* twenty-two hours and thirty minutes, Greenwich mean time, and was not seen again until January, 1836, emerging from the sun's beams. Mr. J. Muller, assistant in the observatory at Geneva, discovered the comet on its return from its nearest approach to the sun. It was very faint. Its situation was precisely in accordance with the previous calculations of the director of the observatory. The assistant directed his telescope at the minute given toward the spot designated by the calculations, and saw the comet really make its appearance, and pass across the object glass. This was on the morning of the 1st of January, 1836, five hours and fifty-six minutes. The right ascension of the comet was then sixteen hours and eighteen and a half minutes, and its declination twenty-four degrees and forty-four minutes south.

The comet was also seen at Ormskirk, on the 15th and 16th of January, 1836. Its place on January 15th, eighteen hours and fifty minutes, was noted, and found to be fifteen hours fifty-nine minutes and forty-six seconds of right ascension, twenty-seven degrees and twenty-two and a half minutes of south declination. On the 19th, it was seen again by the same observer; but the haze allowed only a momentary glimpse. The comet was so faint that it was impossible to see it without a very powerful instrument. The place calculated by Shatford's Ephemeris for the moment of the above observation, is right ascension fifteen hours fifty-nine minutes and forty-three and one fifth seconds, and south declination twenty-seven degrees twenty-two minutes and forty-two seconds—a very near coincidence. This comet is evidently wasting away. It retains nothing of its ancient "terrible magnitude," but is quite a modest, unobtrusive body. On its next return, in 1912, it will probably not be visible without the aid of powerful telescopes.

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* Differing about two days from Pontecoulant's calculation.

LEXELL'S COMET.

Messier discovered a comet in the month of June, 1770. As soon as three good observations could be obtained, the astronomers hastened, as usual, to compute its parabolic elements. These elements were found to be unlike those of any comet previously observed.

This comet continued to be visible for a long while, which gave an excellent opportunity for ascertaining how far its last positions agreed with the parabola formed by the means of the early observations. Strange to say, the disagreement was enormous, and could not be got rid of by any possible combination of the parabolic elements. In this particular case, therefore, hitherto without example, the ellipse could not properly be assimilated to the parabola; hence the real ellipse must be supposed to have a very short transverse axis.

Accordingly, Lexell found that the comet of 1770 had described round the sun an *ellipse*, of which the transverse axis was only three times the diameter of the earth's orbit, and which corresponds to a revolution of *five years and a half*. He represented also all the positions of this body, during the long time it was visible, with the exactness of the observations themselves.

There was, however, one great objection to this important result: it would seem that the comet of 1770, with so short a revolution, ought to have been frequently seen. Now there was no account of it to be found in any catalogue of comets before the time of Messier; nay, more, it has not been observed since, although it has been diligently sought in those places where, according to the elliptic orbit of Lexell, it ought to have appeared.

It may be easily imagined how many sarcasms and jokes, good or bad, were levelled at astronomers for their *lost comet*, and how much they were laughed at for having supposed that they had found out an infallible method of calculating the return of these bodies. There was, to be sure, something very mysterious in the non-appearance of the comet—a real problem to be solved; for the bright light with which it shone in 1770, forbade the supposition of its having returned several times without being observed. In our day, the whole difficulty has been cleared up; and the laws of universal attraction have derived from this circumstance, which seemed at first to invalidate them, a new proof of their stability.

Why was not this comet visible every five years and a half before 1770? Because its orbit was then quite different from what it has been *since*.

Why has not this comet been seen since 1770? Because its passage through the perihelion in 1776 took place by daylight, and before another return the form of its orbit was so changed, that, if the comet had been seen from the earth, it would not have been recognised.

Lexell had remarked, that, according to his calculation of the elements in 1770, the comet must have passed very near Jupiter in 1767, within a fifty-eighth part of its distance from the sun; that in 1779, when it was again returning to us, it was, towards the end of August, about 500 times nearer to that planet than to the sun. So that notwithstanding the immense size of the solar globe, its attractive force upon the comet was not a two-hundredth part of that of Jupiter. Thus it could not be doubted that the comet had experienced considerable perturbations in 1767 and in 1779; but it was still necessary to prove that those perturbations were *numerically* sufficient to account for its non-appearance both before and after 1770.

The formulas of the fourth volume of the *Mécanique Céleste* give the analytical solution of this problem: The *actual* elliptical orbit of a comet being known, what has it before been, and what will it be afterwards, in consequence of the disturbing influence of the planets?

Now it is found, by translating these formulas into numbers, and substituting the particular elements of the comet for the indeterminate letters, that, in 1767, before this comet had approached Jupiter, the elliptical orbit it described corresponded to a revolution about the sun, not of five years, but of fifty years; and that in 1779, when it escaped from the sphere of that planet's attraction, the orbit was such as to require at least a period of twenty years. It results, moreover, from the same researches, that, before 1767, during the whole of its revolution, the least distance of the comet from the sun was four hundred and eighty millions of miles; and that, after 1779, this least distance became three hundred and fourteen millions of miles. This interval is too great for the comet to be visible from the earth.

With respect to the comet of 1770, therefore, however strange it may appear, we are nevertheless fully justified in saying, that the influence of Jupiter in 1767 brought it within our view, and that the same influence in 1779 produced a contrary effect, and carried it out of our sight.

ENCKE'S COMET.

This comet was discovered at Marseilles, November 26, 1818, by Pons.

Bouvard presented its parabolic elements to the Board of Longitude, on the 13th of January, 1819. A member immediately remarked that the results of Bouvard's calculation resembled so much the elements of a comet observed in 1805, that he could not doubt they were one and the same comet.

The periodical return appeared, by this single comparison, to be determined beyond all doubt; but the length of its period remained unsettled, as it was possible, if not probable, that in thirteen years this comet might have returned several times.

It happened, in this instance, as it often does in scientific researches, that what appears improbable turns out to be true; for Encke, of Berlin, proved, by indisputable calculations, that this comet required for its whole course round the sun but *twelve hundred days*, or three years and three tenths.

But, say those who believe that the time of a comet's revolution must *necessarily* be very long, how happens it that this body, which comes to its perihelion in less than three years and a half, was never observed before 1805? The answer is, It is a very small comet, its light is feeble, and it cannot be seen with the naked eye. This did not account satisfactorily for the want of observations in some of its returns; but it was not long before it was found that, among the collections of the Academy, there were observations of this comet made in 1786 and 1795. The table of comets contains, moreover, the elements of an orbit, at those two epochs, so much like those of 1818, that persons who have any knowledge of the disturbances to which these bodies are liable, can have no doubt of their identity. The points of difference, however, were sufficiently remarkable to prevent a hasty decision.

If doubts were entertained as to the length of the revolution of this singular body round the sun, on account of its performing its elongated orbit in less time than some of the planets employ in their circular orbits, it is needless now to discuss them. The short period of the comet of 1818, is now an undisputed fact, for its reappearance in the southern hemisphere in June, 1822, took place in the parts of the heavens which the calculations had pointed out beforehand. The agreement was not less remarkable in 1825; and in 1829, the epoch of its third predicted return, it appeared in the places which Encke assigned for it a year before, with only very slight variations.

This comet has returned twice since 1829, viz. in 1832 and 1835. These returns have been applied to a valuable purpose, which will be seen by and by. Its next return will be in the latter part of 1838.

BIELA'S COMET.

This comet was discovered at Johannisburg, on the 27th of February, 1826, by Biela, and ten days afterwards at Marseilles, by Gambart. The latter calculated the parabolic elements without delay by means of his own observations, and immediately perceived, on consulting the table of the elements of comets, that this was not its first appearance, but that it had been already observed in 1805, and in 1772.

It was accordingly necessary to change the parabolic elements into elliptical elements, in order to discover the length of the comet's orbit left undetermined by the former. Clausen and Gambart undertook this calculation, and each found, in nearly the same time, that the new comet made a revolution round the sun in about seven years.

This result was adopted without dispute, (for, in 1826, astronomers were cured of their old notion that the revolution of a comet must *necessarily* be very long,) while, from the example of the comet of 1770, it was deemed imprudent to venture to determine the time of the future reappearance of a new comet, before all the derangements and perturbations to which it was liable in its whole course had been thoroughly studied. The last apparition having taken place according to the prediction in 1832, the next will be in 1838. It is a small insignificant comet, without a tail, or any appearance of a solid nucleus whatever. Its orbit, by a remarkable coincidence, very nearly intersects that of the earth; and had the latter, at the time of its passage in 1832, been a month in advance of its actual place, it would have passed through the comet—a singular rencontre, perhaps not unattended with danger.

It was this possibility of danger that made Biela's comet an object of interest to astronomers, and of dread to others. The former calculated its path, and found that there would be in reality no danger of a contact, and were at rest.* The latter were the more convinced that there must be danger, the more evidence accumulated to prove the contrary. Arago thus concludes his series of facts and arguments tending to show the needlessness of alarm.

"The foregoing facts do not differ from those which Olbers published in a note, the meaning of which has been so strangely mistaken by the public, and by several journalists. Shall I be more successful in my endeavors to explain myself? I hope so; but I cannot be very confident, so long as there are persons who, believing that the earth will not come in contact with the comet or receive any direct injury from it, yet think that the comet cannot cross the earth's orbit without altering its form, as if this orbit were a material substance; as if the parabolic line described by a bomb through the air, when discharged from a mortar, could be affected in its course by other bombs having formerly been projected through the same space."

On comparing the intervals between the successive perihelion passages of Encke's comet, after allowing in the most careful and exact manner for all the disturbances due to the actions of the planets, a very singular fact has come to light, viz. that the periods are continually diminishing, or, in other words, the mean distance from the sun, or the major axis of the ellipse, dwindling by slow but regular degrees. This is evidently the effect which would be produced by a resistance experienced by the comet from a very rare ethereal medium pervading the regions in which it moves; for such resistance, by diminishing its actual velocity, would diminish also its centrifugal force, and thus give the sun more power to draw it nearer. Accordingly, no other mode of accounting for the phenomenon in question appearing, this is the solution proposed by Encke, and generally received. It will, therefore, probably fall ultimately into the sun, should it not first be dissipated altogether—a thing no way improbable, when the lightness of its materials is considered, and which seems authorized by the observed fact of its having been less and less conspicuous at each appearance.

A new element, then, must in future be taken into consideration, namely, the resistance which is offered to all bodies by a very thin, gaseous substance, that fills all space, and is called by common consent *ether*.

This resistance does not produce any perceptible effect upon the planets, on account of their great density; but comets, being for the most part only a collection of light vapor, may be greatly retarded by it in their motion. To feel the truth of what we have just stated with regard to the different effect of resistance upon light and heavy bodies, we need only compare the very unequal distances to which three balls of the same size could be thrown in the air, if one were made of lead, another of cork, and a third of eider down, supposing they were all projected by equal explosions of powder, and received, at starting, equal impulses.

The effect of the resistance of the ether upon the whole duration of the revolution of Encke's comet round the sun, amounted to about two days,

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* Biela's comet, during its appearance in 1832, was never within about *fifty millions of miles* of the earth.

according to the calculations of Encke himself. If this influence upon Biela's comet were of the same nature, it could not materially affect the results we have obtained respecting the least distance of the comet from the earth in 1832.

Do comets affect the temperature of the seasons?

This question brings to the recollection the beautiful comet of 1811, the high temperature of that year, the abundant harvest which it produced, and, above all, the superior quality of the *comet wines.* We are well aware how much prejudice one may have to encounter, in maintaining that neither the comet of 1811, nor any other comet yet known, has been the occasion of the slightest change in the seasons on our globe. This opinion is founded on all the circumstances of the case; whilst the opposite belief, however general it may be, is the result of vague conjectures, and destitute of any solid basis. We shall first state the facts, and then consider the theory founded upon them.

It is said that comets heat our globe by their presence. If it be so, nothing is easier than to prove it. Are not the thermometers in all observatories consulted several times a day? Are there not kept in the same places exact accounts of every comet that appears? Let us see then whether the *average temperature* of Paris, for instance, during the years in which there have been the greatest number of comets, exceeds the average temperature of those periods in which none of these bodies have approached us. The year 1805, with its two comets, was one in which the temperature was lowest; the year 1808 must be considered a cold year, though there have rarely been seen so many comets in so few days; 1829 was a very cold year, notwithstanding the appearance of a comet; 1831, during which no such body was seen, was much warmer than 1819, when there were three comets, one of which was very bright. Now, with these facts before us, how is it possible to believe that comets raise the temperature of the earth? One thing more should be here noticed, and that is, the circumstance of cold years being generally cloudy, and that, when the heavens are overcast, the most brilliant comets may pass without being perceived.

Let us now put aside these results of observation, for they are still too few for the consequences deduced from them to be beyond the reach of objection, and look at the problem in another point of view. A comet can act from a distance upon the earth in three several ways only: by means of attraction, by the rays of light and heat which it radiates or reflects in all directions, and by the gaseous matter that composes its envelope or its tail, which, in certain positions, may mix with the atmosphere of the earth. The comet of 1811 had a very brilliant tail, the extent of which was variable. Its greatest length was found by calculation to be one hundred millions of miles. Without taking the trouble to examine whether this tail was ever directed toward the earth, we may safely assert that it never touched it, for on the 15th of October, when it was nearest, it was at least one hundred and fourteen millions of miles from us.

At the time of its greatest brilliancy, the comet of 1811 did not certainly afford a light equal to a tenth part of that of the full moon; and the light of the full moon, even when concentrated by the focus of the largest mirror and lenses, and acting upon the blackened bulb of an air thermometer, has never produced any sensible effect, although, from the manner in which this experiment has been conducted, a hundredth part of a degree [centigrade] would have been readily appreciated. We must reject the use of reason, if, with such a result before us, we could entertain the idea that a comet, even ten times more brilliant than that of 1811, could, by its light, produce upon the earth such variations of temperature as would affect the quantity or quality of its crops, or even such minute changes as are capable of affecting our most delicate meteorological instruments. It must then be in the comet's power of attraction that we are to look for the efficient cause of its meteorological influence. Here the moon will serve as a standard of comparison.

This planet causes the tides of the ocean. Mathematically speaking, the comet of 1811 ought to have produced similar tides; but none such were perceived, and therefore it must be admitted that they were inappreciable.

The height of the tide varies in proportion to the intensity of the attractive force. We have just found that the lunar tide is very great, and the cometary tide imperceptible: therefore the action of the comet upon the earth is but a very small part of that of the moon. This important result is deduced still more clearly from an examination of the disturbance which takes place among the planets in their elliptical orbits, and which are known by the name of *perturbations.* We shall confine ourselves to the aërial tides.

The attractive force of the moon cannot fail to produce an atmospherical tide, the variations of which would be indicated by the barometer. But in this case, amid so many accidental causes of disturbance, the only way of ascertaining the effects of the constant action of the moon is to bring together several thousand observations. This laborious and minute calculation has been made, with the greatest care, upon observations collected from various places; and the effect of the moon upon the atmosphere has scarcely been sufficient to produce a perceptible variation in the barometer. We need hardly add, after this, that it has never entered any body's head to try the effect of a comet upon this aërial tide.

We repeat, that the direct action of the tail and the nebulous head of the great comet of 1811 on the earth's atmosphere was insensible, on account of the immense distance at which this comet has always been from the earth. As to its power of heating or attracting our globe, the most delicate instruments cannot detect its existence.

Many comets have no perceptible tail; some have been seen in which no nucleus could be discovered; but none have ever been visible, since they have been attentively examined with the telescope, which had not that sort of foggy appearance or nebulous atmosphere called by astronomers the *envelope* or *chevelure.*

Among the comets that have no apparent nucleus, and which seem to be only globular masses of vapor, slightly condensed towards the centre, we shall notice those of 1795, 1797, and 1798, observed by Olbers, and the little comet of 1804, the envelope of which was forty-eight hundred miles in diameter.

Seneca remarks, that stars may be seen through comets. This assertion cannot be called in question, so far as comets without any proper nucleus are concerned. It may even be added, that the nebulous matter which forms the envelope is so thin and transparent that the light of very small stars may pass through it to a great distance without ceasing to be visible.

For instance, Herschel saw a star of the sixth magnitude in the very middle of the comet without a nucleus of 1795; also, on the 28th of November, 1828, Struve plainly distinguished a star of the eleventh magnitude through the central part of Encke's comet. Many more such examples might be given.

When there is a nucleus in the centre of a comet, it seldom happens that the nebulous envelope extends to it with a progressively increased intensity; on the contrary, that part of the envelope nearest the nucleus is faintly illuminated, and appears to be extremely rare and transparent. At some distance from the centre the envelope becomes suddenly brighter, so that it looks like a luminous ring, more or less extended, surrounding the nucleus, and maintaining itself at a nearly equal distance from it on all sides. Sometimes there have been seen two and even three of these concentric rings, separated by spaces more feebly illuminated. It will be easily conceived, that what appears to the eye to be a ring is really a spherical envelope; and we shall have a good idea of this complicated structure of comets, if we imagine, at different heights in our atmosphere, three strata of clouds completely encircling the globe. To make the similitude more exact, we must suppose these three strata to be transparent, and yet possessed of optical properties different from the intervening portions of pure air.

In the comet of 1811, the envelope could not be less than twenty-four thousand miles thick, and its interior surface must have been twenty-nine thousand miles from the centre of the nucleus. The envelopes of the comets of 1807 and 1799, were respectively twenty-nine thousand and nineteen thousand miles thick.

It is, in all probability, to the feeble coercion of the elastic power of their gaseous parts, by the gravitation of so small a central mass, that we must attribute this extraordinary development of the atmospheres of comets. If the earth, retaining its present size, were reduced, by any internal change, (as by hollowing out its central parts,) to one thousandth part of its actual mass, its coercive power over the atmosphere would be diminished in the same proportion, and in consequence the latter would expand to a thousand times its actual bulk, and indeed much more, owing to the still farther diminution of gravity, by the recess of the upper parts from the centre.

The nucleus of a comet generally resembles a planet in form and brilliancy. It is commonly very small, but sometimes it approaches the dimensions of the lesser planets.

Some astronomers maintain that the nucleus of a comet, even when from its brilliant light it most resembles a planet, is always transparent; that comets are, in short, nothing but masses of vapor. The observations on which this opinion is founded are specious enough; but they do not warrant such conclusions as have been drawn from them. The question is an important one. Its solution must decide, in a great measure, the degree of influence to be attributed to comets in the physical revolutions of the world.

All comets pass successively in their proper motions through different constellations; but the regions in which these movements take place, are vastly nearer to us than to the stars. Now it would seem evident that if the nucleus of a comet is interposed between the observer and a star, we can judge better of its intimate constitution than in any other position.

Unfortunately these conjunctions are extremely rare, and for the very simple reason, that the part of the firmament which is the most crowded with stars contains incomparably more void than occupied space. Instances, however, are not wanting of such conjunctions.

On the 23d of October, 1774, Montaigne saw, at Limages, a star of the sixth magnitude through the nucleus of a little comet.

This observation would undoubtedly prove that the comet of 1774 had no solid or opaque part, if the star had been seen through the middle of it; but Montaigne does not mention this last circumstance, and indeed the feeble powers of his telescope would scarcely admit of his being thus explicit.

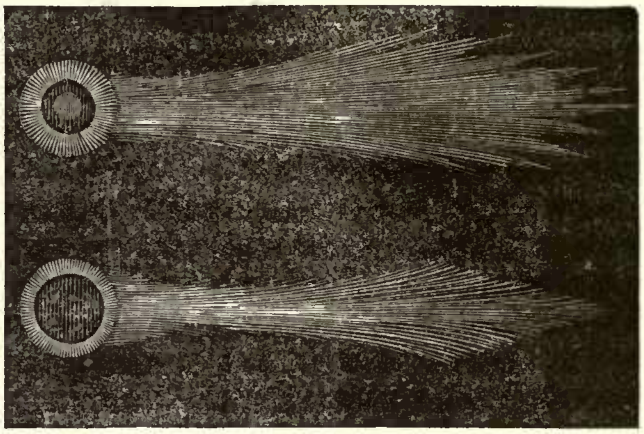
On the first of April, 1796, Olbers saw a star of the sixth or seventh magnitude; and, though covered by a comet, its light was not sensibly diminished. But this celebrated astronomer protests against the conclusion which some drew from his observation as to the transparency of the nucleus. According to his conjectures, the star was situated a little to the north of the centre of the envelope, and if the nucleus disappeared for a time, it might be only in consequence of the neighborhood of the greater light of the fixed star.

The same doubts may be entertained with regard to the passage, without a real occultation, of a star of the seventh magnitude, behind the nucleus of the comet observed at Nismes, in 1825, by Valz; also with regard to former observations of the same kind.

If we wished to maintain the opinion that there is a solid and opaque centre to the luminous nucleus of comets, the annals of astronomy would furnish us with sufficiently plausible arguments. When Messier perceived, for the first time, the little comet of 1774, there was, very near its nucleus, one telescopic star only, and some hours after a second star was seen near the first. This second star was not less brilliant than the first, and there is but one way of explaining why Messier did not see it before: we must admit with him that it was concealed behind the opaque part of the comet. On the 28th of November, 1828, at half past ten at night, Encke's comet, which returns to its perihelion every three years and a third, was observed by Wartmann, at Geneva, to pass over a star of the eighth magnitude, which was entirely eclipsed. Now a positive fact, like this real disappearance, may always be opposed with advantage to a negative fact, to a non-disappearance, because the latter may be always explained without difficulty by a supposition fairly admissible, that the small *nucleus, which is solid and opaque,* did not pass exactly over the star, however it might have appeared to do so, whilst a total eclipse cannot be subject to any such uncertainty.

To be sure, Wartmann used too small a telescope, and a magnifier not sufficiently powerful. And Messier's observation would be much more convincing, if he had seen the star before it was eclipsed: if the astronomer, aware of its existence, had looked for it, we might not then suppose that it had escaped him through inattention. Whatever may be deduced from these remarks as to the constitution of the nucleus of *very small* comets, which we have spoken of as passing over stars, no general consequences can be inferred from them. There are *comets* that have no apparent nucleus, and are equally bright throughout their whole extent, and which are, beyond all doubt, simple collections of gaseous matter. An increased degree of concentration in these vapors may form a nucleus in the centre of the head, remarkable for the intensity of its light; but this, being still liquid, may be very transparent. At a later period, this liquid may cool down till it becomes surrounded by a solid crust, and then all transparency of the nucleus will have ceased. If, after this, it should pass between an observer and a star, it would cause an eclipse as real and as entire as that which is produced by the moon and planets. Now nothing is known which goes to prove that there may not be comets of this third class with a solid nucleus. The great variety in appearance and in brightness which these bodies exhibit, will justify any supposition of the kind. Those who, since the observations of the last forty years, can believe that all comets are formed on one model, need only examine the archives of science to perceive how little such an idea is founded on fact.

Among the representations of comets given by Hevelius, there are two of the comet of 1661, presenting quite a curious phenomenon. One figure shows the nucleus as a single round body, which it appeared to be at one observation. The other view represents the same comet when its nucleus seemed to have separated into several small bodies.



In the year 43 before Christ, we are told that a *hairy star* appeared which could be seen *by daylight with the naked eye.* This comet was considered by the Romans as the metamorphosis of the soul of Cæsar, who was assassinated a short time before.

In the year 1402 after Christ, we hear of two very remarkable comets. The first was so bright that the light of the sun, towards the end of March, did not prevent its nucleus, or even its tail, from being seen at noon. The second was visible in the month of June, and could be seen long before sunset.

Cardan relates, that, in 1532, the curiosity of the inhabitants of Milan was greatly excited by a star which could be seen at mid-day. At the time, Venus was not in a position in which it could be seen by daylight: the star of Cardan must therefore have been a comet. This is the fourth visible by daylight recorded by historians.

The beautiful comet of 1577, was *discovered* the 13th of November, by Tycho Brahe, from his observatory in the island of Hwen, in the Sound, before sunset.

On the 1st of February, the comet of 1744 was more conspicuous than the brightest star in the heavens, that is, than Sirius; on the 8th, it equalled Jupiter; some days afterwards, it was only surpassed by Venus; at the beginning of the next month, it was visible by daylight. On the 1st of March, several persons, conveniently situated, perceived this comet, without the aid of glasses, an hour after noon.

What ground, then, is there for comparing, as to physical structure, bodies of such brilliancy as those just mentioned, and the comets observed during the last fifty years, which are rendered almost entirely invisible by the feeble light which is brought into the field of the astronomical telescope, in order to show the cross-threads necessary to determine its position ?

We may now conclude that there are,

Comets without a nucleus ;

Comets of which the nucleus *may be* transparent;

Comets more brilliant than the planets, the nucleus of which is *probably* solid and opaque.

Peter Apian says, after attentively observing the comet of 1531, that the tail, whatever may be the situation or motions of the comet, is always in the prolongation of the line which joins the sun and the nucleus.

This statement is not strictly correct. It is true that the tail is generally behind the comet as viewed from the sun; but the line which joins the two bodies, hardly ever coincides exactly with the axis of the tail. Sometimes the difference in the two lines is considerable: cases might be mentioned, indeed, in which they form a right angle. It is found, moreover, that *the tail constantly inclines towards the region which the comet is leaving*, as if, in its motion through a gaseous medium, the matter of which the tail is composed experienced more resistance than the nucleus. This is sometimes so great as to produce a very perceptible curvature. The tail of the comet of 1744, for instance, formed nearly a quarter of a circle in an extent of only a small number of degrees.

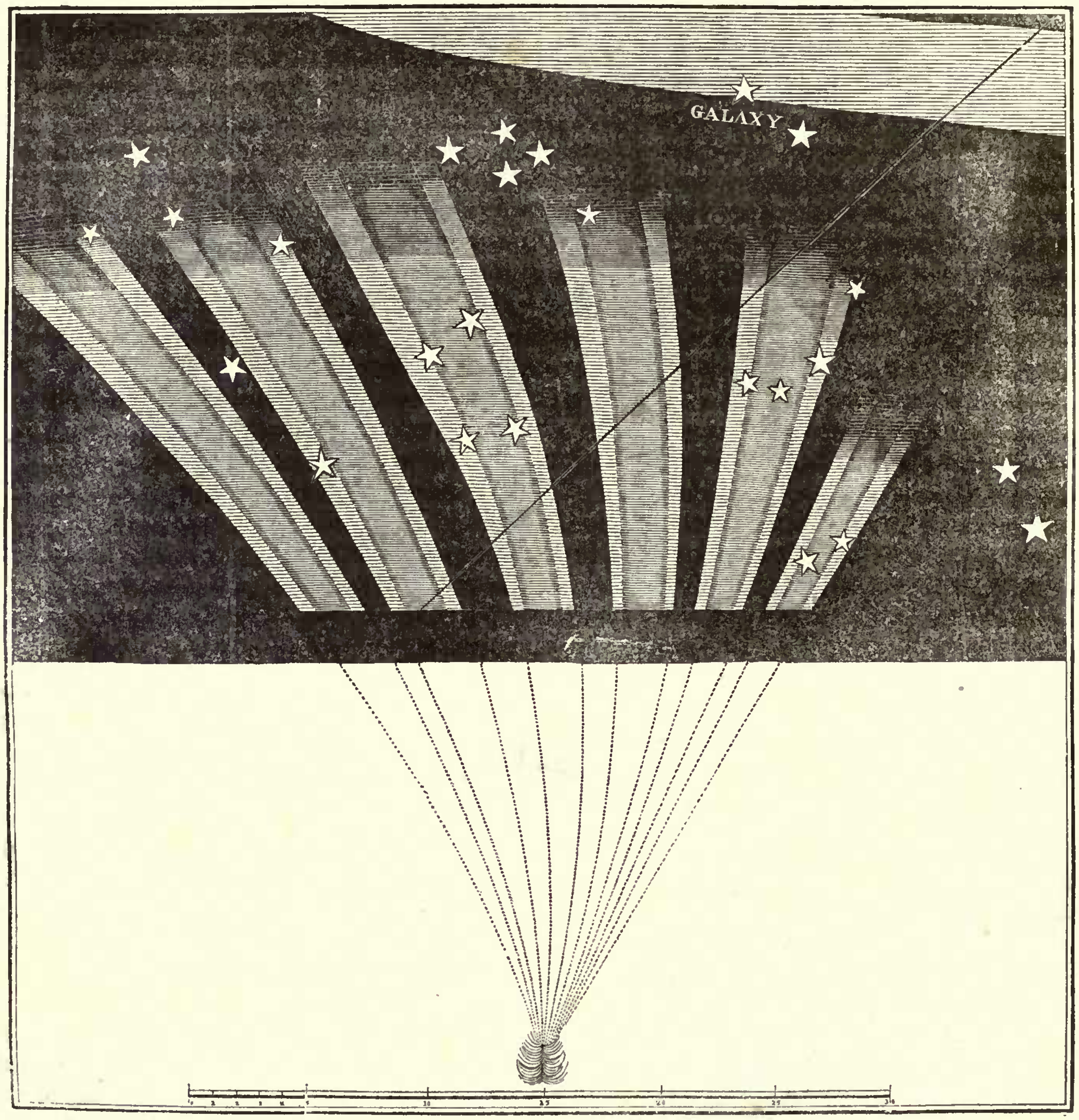
If this be the real cause of the curvature of the tail, it follows, as a necessary consequence, that the convexity must always be turned towards that region to which the comet is tending. One or two exceptions to this rule may perhaps be found.

According to the hypothesis under consideration, the nebulous matter of the tail must be more concentrated, more dense, and consequently more luminous, and the outline must be better defined, on the convex side than the other. All known observations tend to confirm the truth of this position.

The tail of a comet becomes larger the further it is from the head. The middle often presents a dark space, which divides it longitudinally into two distinct and often nearly equal parts. Former observers considered this dark space as the shadow of the body of the comet. This explanation, however, is not applicable to tails that are not in a line with the nucleus and the sun. It is more accordant with all the particulars of this phenomenon, to consider the tail as a hollow cone, the sides of which have a certain degree of thickness. For the line of sight, in passing through the edges of the cone, will strike a great many more nebulous particles, than a line through the middle: now, whether these particles shine of themselves, or only reflect the rays of the sun, it is their whole number which must, in every direction, determine the intensity of the light. Thus the hypothesis of the hollow cone does away all the difficulty respecting the edges of the tail being the brightest, and respecting its division into two luminous portions, by a comparatively dark space.

The tail of the great comet of 1680, immediately after its perihelion passage, was found by Newton to have been no less that *twenty millions* of leagues in length, and to have occupied only two days in its emission from the comet's body: a decisive proof this of its being darted forth by some active force, the origin of which, to judge from the direction of the tail, must be sought in the sun itself. Its greatest length amounted to *forty-one million* leagues, a length much exceeding the whole interval between the sun and earth. The tail of the comet of 1769, extended *sixteen million* leagues, and that of the great comet of 1811, *thirty-six million.* The portion of the head of this last comprised within the transparent atmospheric envelope which separated it from the tail, was one hundred and eighty thousand leagues in diameter. It is hardly conceivable that matter once projected to such enormous distances should ever be collected again by the feeble attraction of such a body as a comet —a consideration which accounts for the rapid progressive diminution of the tails of such as have been frequently observed.

It is not uncommon for comets to have several separate tails. That of 1744, on the 7th and 8th of March, had no less than six, each about four degrees broad, and from thirty degrees to forty-four degrees long. Their edges were well defined, and bright: the middle portions emitted a very faint light. The space between these separate tails was as dark as the rest of the heavens. At the moment when the drawing was made, the head of the comet was below the horizon. The dotted lines indicate the invisible part of the six branches.



Do comets shine by their own light, or do they, like the planets, only reflect the rays of the sun? It will be allowed that this is a most important question. It has, however, never been settled. We might state, on the faith of certain observations of Cassini, that the comet of 1744 exhibited such a phase; but to this it might be replied, that the words of that astronomer prove that the nucleus was very irregular, not that it had a proper phase. Heinsius and Chézeaux, say positively that no phase existed at the very time; and the observations of the English geometrician Dunn were contradicted by the contemporary observations of Messier. Yet the absence of phases in a nucleus surrounded, as that of a comet is, with a thick atmosphere, capable of disseminating the light on every side, cannot lead to any certain conclusion. The recent labors of philosophers have given rise to a new mode of investigating this subject, which promises more valuable results. They have discovered, that when light is reflected under certain angles, it is distinguished by some peculiar properties from light that comes to us directly. Now some traces of these peculiar properties have been perceived, at the observatory in Paris, in the light from the tail of the comet of 1819, but not so distinctly as to warrant a *positive conclusion* that these bodies shine only by a borrowed light, for bodies that become self-luminous do not lose the power of reflecting light received from other sources.

The nebulous envelopes of comets, when closely studied, present inexplicable difficulties. It is very natural, to be sure, to suppose them masses of permanent gas, or collections of vapor disengaged from the nucleus, upon which the solar rays are constantly acting; but what becomes, upon this supposition, of the luminous, concentric envelopes of which we have spoken? Why should the nucleus be eccentric, generally towards the sun, but sometimes on the opposite side?

Wholly occupied with the motions of comets, and carried away perhaps by favorite theories, modern astronomers have neglected one observation, worthy of note, as to the manner in which the envelopes of comets vary in size. Hevelius, who was bound to no system, stated distinctly that the real diameter of the envelope increased according as the comet became more distant from the sun. Pingré observed this, also, but hardly dared to avow it; for in his work, this important fact is thrown out, as if by chance, in a paragraph upon the variations of the tail.

Thanks to Encke's comet, we may now place the observation of Hevelius among the best established facts of science.

On the 28th of October, this comet was nearly three times as far from the sun as on the 24th of December; nevertheless, at the former of these two periods, the real diameter of the nebulous matter was about twenty-five times as great as at the latter! Or we may put the same thing into other words, by saying that, in the interim between the 28th of October and the 24th of December, the size or volume of the comet was reduced to a *sixteen thousandth* part of its former size: the least bulk thus corresponds to the least distance of the comet from the sun.

Valz supposes that the ethereal matter forms a true atmosphere about the sun, in which the lower strata are so much the more compressed, and so much the more dense, according as there are a greater number of strata above them. He imagines, therefore, that the comet, in traversing these strata, must undergo a pressure proportional to their density! There would be no objection to this, if it were proved that the exterior envelope of nebulous matter was not permeable to the ether. It is indeed well known, that a bladder, filled with air at the base of a mountain, expands as it is raised to higher positions, and that it finally bursts when carried to a sufficient height. But have we discovered about the nebulous matter any case or pellicle, which will allow us to make the comparison, which would prevent the ether from penetrating it in every direction? This difficulty appears at present insurmountable, and we cannot but regret it; for the ingenious hypothesis of Valz gives the law of variation for the magnitude of the nebulous matter, both for Encke's comet, and for that of 1618, with an exactness truly surprising.

It is very possible, however, that the change may consist in no real expansion or condensation of volume, (further than is due to the convergence or divergence of the different parabolas described by each of its molecules to or from a common vertex,) but may rather indicate the alternate conversion of evaporable materials in the upper regions of a transparent atmosphere, into the states of visible cloud and invisible gas, by the mere effects of heat and cold.

It would require a volume to give even a faint idea of the great variety of theories by which astronomers and philosophers have endeavored to explain the tails of comets. The least objectionable of these theories is that which supposes the lightest particles of the nebulous matter to be detached and carried off by the force of the sun's rays. Accordingly the tail would always be directly opposite to the sun, as Apian would have it. But this rule does not apply universally, for the tail is sometimes perpendicular to the line drawn from the sun to the nucleus. It is also occasionally very much curved. There are sometimes six tails at once. These multiplied tails appear and disappear in a few days, and their direction is so various that, in certain positions of the earth, the comet of 1823 appeared for several days to have *one tail extended toward the sun, and another in the opposite direction.* There are indications in these multiplied tails of a very rapid rotary motion, which must soon occasion their entire dispersion in space. There are comets, too, the nebulous matter of which seems very light, and which nevertheless have no tails at all. The resistance of the ether, which has hitherto been overlooked, may explain some of these difficulties; but it is to be feared that the complete solution of so intricate a problem will long be wished for in vain.

Those who take an interest in comets only with a view to satisfying themselves whether, in striking the earth, they will produce great disasters, must find, in the telescopic observations of which we have given some account, strong reasons for feeling secure. We may also add, that these observations are not the only means of ascertaining the ordinary smallness of the mass of these bodies; the same result is arrived at by studying attentively the motions of planets, near which comets have passed.

The comet of 1770 came very near the earth's orbit.* La Place discovered that the action of the earth upon it increased the length of its revolution by more than two days. Mathematically speaking, the reaction of this comet upon the earth ought to have increased the length of the earth's revolution round the sun. If we suppose the mass of the comet to be equal to that of the earth, the time thus added to the year would be, by strict calculation, two hours and fifty-three minutes. Now it is well known that in 1770 the length of the year did not vary one second. We have taken, then, for the ground of our calculations a very exaggerated statement, in supposing the mass of this comet to be equal to that of the earth; and we may fairly infer from the above fact, that the mass or quantity of matter in the comet is not one five-thousandth part of that of the earth. This result explains how it was possible for the comet of 1770 to traverse twice the system of Jupiter's satellites without producing the slightest disturbance.

We shall conclude this section by a table containing the smallest distances *from the earth's orbit* of the comets which have approached the nearest to it. It will be easily seen that the same numbers would also express the least distances from the earth, to which these bodies have ever been able to approach.

	Least distance from the Earth's orbit.	
Comet of 1680,	112	semi-diameters of the earth.
Comet of 1684,	215	"
Comet of 1805,	260	"
Comet of 1742,	330	"
Comet of 1779,	346	"

Let us remember now, that Biela's comet passed within about four terrestrial semi-diameters or two diameters of the earth's path; and we shall perceive that such a circumstance, if it justified none of the fears which were excited, deserved at least to be noted.

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* The shortest distance of the comet of 1770 from the earth, was 368 semi-diameters of the earth, or 1,456,840 miles; the mean distance of the moon is 60 semi-diameters of the earth, or 237,160 miles. Thus, at the nearest approach of the comet of 1770, it was still six times as far from us as the moon.

SECTION II.

Chances against a comet's striking the earth—Do they finally fall into the sun?—Or into the stars?—Can the earth draw off the tail of a comet?—The effects—Were the fogs of 1783 and 1831 caused by a comet?—Was the cholera caused by a comet?—The deluge not caused by a comet—Has the climate of Siberia suddenly changed?—Is the severe climate of North America owing to a comet?—Is the depression in the centre of Asia owing to a comet?—Was the moon ever a comet?

In virtue of first causes, the nature of which is unknown to us, and which have given rise to various theories more or less plausible, the planets of our system make their revolutions round the sun all in the same direction, and in orbits nearly circular. Comets, on the contrary, travel in very elongated ellipses, and move in all possible directions. In coming from their aphelions, they continually traverse our solar system, passing within the orbits of the planets, sometimes even between Mercury and the sun. *It is not, therefore, impossible for a comet to encounter the earth.*

The probability of such an event is extremely small. This will be evident at first sight, if we compare the immense space in which our globe and the comets move, with the very small size of these bodies. Mathematical calculation carries us much further. It gives us, in numbers, the chances for or against the event in question, founded on the relative magnitude of the comet and the earth.

Suppose, now, a comet of which we know nothing but that, at its perihelion, it will be nearer the sun than we are, and that its diameter is equal to a quarter of that of the earth; the doctrine of chances shows that, out of two hundred and eighty-one millions of cases, there is but one against us—but one in which the two bodies could meet.

Here the chances of a collision between the earth and the comet are given, *without any thing being known of the form or position of the comet's orbit.* There is for the nucleus, properly so called, one chance of its striking the earth, one unhappy chance, to two hundred and eighty-one million chances of its escaping us; and for the nebulous head, according to its ordinary dimensions, about ten or twenty chances in favor of a contact to the same number of two hundred and eighty-one millions against it.

At the time of passing its perihelion, the comet of 1680 was separated from the sun by a space not greater than a sixth part of the diameter of that luminary. In a region thus near to that immense orb, the atmosphere by which it is surrounded may have an appreciable density, producing upon a body that passes through it such effects as ought to be taken into consideration, particularly in regard to comets, the swiftness of whose motion at their perihelion is very great, and whose density is generally very small. The inevitable effect of this atmospheric resistance upon the comet of 1680, must have been to diminish its tangential velocity. But when a heavenly body slackens its pace, whatever may be the cause, the centrifugal force lessens also; the centripetal force, which it counterbalanced, preponderates immediately, and that body quits the curve it was describing to approach nearer to the centre of attraction. Thus the comet of which we have been speaking must have passed nearer the sun's surface in 1680 than at its former appearance. This diminution in the dimensions of its orbit must occur at each return to the perihelion; *the comet of* 1680 *must, therefore, in the end, fall into the sun.*

This reasoning is founded on incontestable mechanical principles; therefore the consequence deduced is not less certain. We must only bear in mind that our ignorance of the density of the several successive strata of the solar atmosphere, of that also of the comet of 1680, and of the length of its revolution, renders it impossible to *calculate* how many ages must elapse before this strange event is to take place. The annals of astronomy furnish us no reason for supposing that such a thing has ever happened within the period of authentic history.

Pliny mentions a star, which appeared suddenly in the heavens, in the time of Hipparchus (that is, two thousand years ago,) and suggested to this great astronomer the idea of that catalogue of stars for which science is so much indebted to him, and which was preserved by Ptolemy.

Similar phenomena occurred in the years 1572, and 1604.

The *new star* of 1572 appeared on the 8th of November, in the north, in the constellation Cassiopeia. It was more conspicuous than the brightest star in the heavens, that is, than Sirius; it gave almost as much light as the planet Venus, and was visible for nearly a year and a half. That of 1604, when seen by the disciples of Kepler, on the 30th of September, at noon, in the constellation Serpentarius, surpassed Jupiter in splendor, though the night before it appeared very small. At the end of sixteen months there was no trace of it to be seen.

Fixed stars are real suns, around which, in all probability, planets and comets revolve. The facts just stated prove that there are, besides the common stars, exhausted or extinguished stars, that are ordinarily invisible. Newton believed that this kind of stars again become conspicuous, and suddenly recover their former brilliancy, when comets, by falling into them, furnish them with fresh combustible matter.

If this explanation were adopted, it would follow, that within the period of authentic history, comets had, in three instances, fallen, if not into the still brilliant sun of our system, at least into the extinct suns of other systems.

By comparing the fires of the heavenly bodies with those of our own kindling, and considering comets like the billets of wood, which must be constantly renewed upon our hearths, we carry the laws of analogy much too far. It is now generally known, that, under certain specific conditions, and particularly in certain electrical states, all bodies may become luminous, without any thing combining with their substance, and without any thing being disengaged from them. This is the case with two pieces of charcoal, *placed in a vacuum*, one of which touches a wire connected with one end of a powerful galvanic battery, whilst the other communicates with the opposite end. As soon as the surfaces of the two coals are brought near each other, they become more resplendent than any other known terrestrial fire, so much so, that it is agreed to distinguish the light thus produced by the name of *solar light.*

Newton thought that the matter, the *exhalation*, of which the tails of comets are composed, might fall by its gravity into the atmosphere of any planet, but more especially into that of the earth, be condensed there, and give rise to all sorts of chemical reactions, and a thousand new combinations.

Comets appear to be, for the most part, mere collections of vapor. Now since it is an incontestable principle that attraction is in proportion to the mass or quantity of matter, each particle of the tail of a comet must be feebly attracted towards the body. The attraction lessens as the distance increases, not merely in a simple ratio, but according to the squares of the distance. Thus at the distances 2, 3, 4,—10, the attraction, exerted by any body, is 4, 9, 16,—100 times less than at the distance 1.

We have seen that a comet, in consequence of the small quantity of matter it contains, exerts upon what is near it but a feeble attraction; and upon particles far removed from its head the attraction must be hardly perceptible. Now have we not seen comets with very long tails? In the comet of 1680, the extreme visible particles were, in a right line, about one hundred millions of miles from the nucleus.

It will now be seen that a planet like the earth, the mass of which, for the most part, is much greater than that of a comet, must have the power of attracting and of drawing in and appropriating to itself the extreme particles in the tail of a comet, even when in its annual course it may be very distant from it.

The introduction of some new gaseous element into the terrestrial atmosphere might, as it was more or less abundant, occasion the death of all animals, or produce epidemics. Such, indeed, has been, according to various authors, the origin of most of those scourges which are mentioned in history.

In a work on astronomy, published at Oxford, in 1702, Gregory says, that among all nations, and in all ages, *it has been observed* that the appearance of a comet has always been followed by great calamities; and he adds, "it does not become philosophers lightly to set down these things as fables."

Gregory has not confined himself within the strict limits of truth, when he gives as *observations* worthy of confidence the careless remarks of historians concerning a pretended influence of these bodies over the events of the world at the time of their appearance.

An English physician, Mr. T. Forster, has lately treated particularly of this subject. According to him, "*It is certain*, that, ever since the Christian era, the most unhealthy periods are precisely those in which some great comet has appeared; that the approach of these bodies to our earth has always been accompanied by earthquakes, eruptions of volcanoes, and atmospheric commotions; whereas no comet has ever been seen during the salubrious periods."

The whole number of comets mentioned by historians, reckoning from the beginning of the Christian era to the present time, is about five hundred. At the present time, when the heavens are examined attentively and skilfully, when comets that can be seen only by the aid of the telescope are no longer overlooked, the average number of these bodies is more than two for each year. If we agree with Forster that their influence begins before they are visible, and continues some time after, we shall never be without a comet to account for every phenomenon, misfortune, or epidemic, that can occur.

Hot or cold seasons, tempests, hurricanes, earthquakes, volcanic eruptions, violent hail-storms, great falls of snow, heavy rains, overflowings of rivers, droughts, famines, thick fogs, flies, grasshoppers, plague, dysentery, contagious diseases among animals, &c., are all registered by Forster as consequences of the appearance of some comet, whatever may be the continent, the kingdom, the town, or the village, so visited. By thus making out for each year a complete catalogue of all the miseries of this lower world, any one might foresee that a comet would never approach the earth without finding a part of its inhabitants suffering under some calamity or other.

By a strange accident, well worthy of remark, the year 1680, the year of the most brilliant of modern comets, the year of its passage so near the earth, is that which has furnished our author with the fewest phenomena. "*A cold winter, followed by a hot and dry summer; meteors in Germany.*" As to maladies, we find no record whatever! How then, with such a fact as this, can we attach any importance to the accidental coincidences noted in other parts of the table? How are we to regard this celebrated comet of 1680, which, blowing now hot and now cold, increased the frosts of winter, and the heat of summer?

In 1665, the city of London was ravaged by the plague. If, with Forster, we attribute this to the remarkable comet which appeared the same year, in the month of April, how are we to explain why the same pestilence did not extend to America, to France, to Holland, or even to any of the other towns in England? Until such a difficulty as this is done away, we shall expose ourselves to ridicule, and with good reason, if we attempt to make comets the messengers of evil.

Let us now see which are the comets whose tails might have mingled with the earth's atmosphere, and then seek to discover whether, at the same time, there were manifested, *in all parts of the earth at once*, unusual phenomena; though the extreme rarity of the matter which composes the tail would lead one to expect nothing but negative results. But when an author appends to the date of a comet, as to that of 1668, the remark that *all the cats in Westphalia were sick;* and to the date of a another, that a *meteoric stone* fell in *Scotland* into a high tower, and broke the wheels of a clock; that, during the winter, *wild pigeons appeared in large flocks in America*, or that Ætna or Vesuvius threw out torrents of lava, "the gentle nymphs will smile." If, in thus registering contemporary events, he thinks he has established some new relations between them, he is as much mistaken as the woman, who, never having put her head out of her window without seeing coaches in the street, imagined herself to be the cause of their passing.

When, in 1456, the splendid comet appeared which returned in November, 1835, Pope Calixtus was so terrified at it that he ordered public prayers to be offered up in all the churches; and, in the middle of each day, the comet and the Turks were excommunicated. That no one need fail in this duty, he established the practice, which has been continued to this day, of ringing the church bells at noon.

The fog of 1783 began nearly on the same day (the 18th of June) in places very distant from each other, as Paris, Avignon, Turin, Padua ;

It extended from the northern coast of Africa to Sweden ; it was also observed in a great part of North America ;

It lasted more than a month ;

The air, at least that of the lower regions, did not appear to be its vehicle, because in some places it came on with a north wind, and in others with a south or east wind ;

Travellers found it on the highest summits of the Alps ;

The abundant rains that fell in June and July, and the highest winds, did not disperse it ;

In Languedoc, its density was occasionally so great that the sun did not become visible in the morning, till it was twelve degrees above the horizon ; it was very red the rest of the day, and might be looked at with the naked eye.

This fog or smoke, as some meteorologists have called it, had a disagreeable odor.

The property by which it was particularly distinguished from common fogs, was its being, by all accounts, very dry, whereas most fogs are moist. At Geneva, Sénebier found that the hair hygrometer of Saussure, which in real fogs stands at 100°, ranged in the midst of this as low as 68°, 67°, 65°, and even 57°.

Besides all this, there was one very remarkable quality in the fog or smoke of 1783 ; it appeared to possess a phosphoric property, a light of its own. We find, at least in the accounts of some observers, that it afforded, even at midnight, a light which they compare to that of the full moon, and which was sufficient to enable one to see objects distinctly at a distance of two hundred yards. To remove all doubts as to the source of this light, it is recorded that at the time there was a new moon.

Such is the state of the facts. Let us now see whether, in order to explain them, it will be necessary to admit that in 1783 the earth was immersed in the tail of a comet.

The fog of 1783 was neither so constant nor so thick as to prevent the stars being seen every night in all the places where it occurred. Admitting therefore that the earth was in the tail of a comet, there is but one way of explaining why the head of that comet was never seen, and that is, by supposing that it rose and set almost at the same time with the sun ; that the superior light of that luminary rendered it invisible ; and that this conjunction of the sun and comet lasted more than a month.

At a time when the proper motions of comets appeared subject to no rule, when every one disposed of them as he pleased, considering them as mere meteors, the supposition we have just made might be admitted ; but now that comets are known to all astronomers to be heavenly bodies, as obedient as the planets to the laws of Kepler—now that the mutual dependence of distance and velocity is known—now that observation and theory combine to prove that all these bodies *necessarily* move in their orbits with a rapidity that increases as they approach the sun—it would be contrary to all established principles to admit that a comet, interposed between the sun and earth, could revolve about the sun in such a manner as to appear constantly near it for more than a month to a spectator on the earth ! It is in vain to attempt to explain the difficulty attending an exact conjunction by supposing the tail very large. If it were as large as that of 1744, the objection would remain in all its force. The dry fog of 1783, then, whatever may have been said of it, was not the tail of a comet.

The remarkable fog of 1831, which excited the public mind in all quarters of the globe, resembled so much that of 1783 as to dispense with the necessity of proving that this also could not be attributed to the tail of a comet.

But to what cause shall we attribute the fog of 1783? We might suppose, with Franklin, that it was simply the result of the general diffusion of the thick columns of smoke emitted all summer by Mount Hecla, and carried about by the winds; or we might avail ourselves of another suggestion of the illustrious American philosopher, for there is no reason against believing it, viz. that an immense fire-ball, in penetrating our atmosphere, was there but partially inflamed or ignited, and that torrents of smoke, occasioned by this imperfect combustion, were deposited in the higher regions of the air, and were afterwards carried into all the atmospheric strata by the action of common winds, and by the currents ascending and descending vertically, which exert so important an influence in meteorological phenomena. The passing of the earth through the tail of a comet, is an event that must happen several times in a century. If it did not occur in 1819, and in 1823, it could only be on account of a purely accidental circumstance, that of the tail not being long enough to reach the earth; for in each case it was for several hours directed exactly towards us. It is therefore important to prove that there is really no danger to be apprehended on this score, and that we even pass through these immense trains without being in the least aware of it. Now this may be considered as a fact clearly proved, if it be granted that the tail of a comet does not serve to explain all the circumstances attendant on the dry fogs of 1783 and 1831.

Many authors have chosen to see some connection between the extraordinary fog of 1831, and the entrance of the *cholera morbus* into Europe. This opinion reminds one of what an old English traveller says of the effects of a periodical wind on the west coast of the continent of Africa, which is called the *Harmattan*.

A *fog*, of a particular kind, and thick enough to impede at noon all but the red rays of the sun, always presents itself where the Harmattan blows. The particles of which this fog is formed are deposited on the grass, on the leaves of trees, and on the skin of the negroes, in such profusion as to produce a white appearance. Of the nature of these particles we are ignorant. We only know that the wind carries them but a short distance from the shore. A league out at sea the fog is much lighter, and, at the distance of three leagues, it disappears entirely, although the Harmattan is still felt in all its force.

The *extreme dryness* of the Harmattan is one of its most striking characteristics. When it lasts some time, the branches of orange and citron trees die; the covers of books (even when these are shut up in tight trunks, and have an additional covering of linen) warp as if they had been before a glowing coal fire; pannels of doors and furniture crack, and often break. The effects of this wind upon the human body are not less remarkable: the eyes, lips, and palate become dry and painful; if the Harmattan lasts four or five days in succession, the skin of the hands and face come off.

After what has been stated of the fatal effects of the Harmattan on vegetables, it may be thought that this wind *must be very unhealthy*, whereas quite the contrary is observed. Intermittent fevers are completely cured by the first breath of the Harmattan. Patients reduced by the excessive bleeding practised in that country, recover their strength; remittent and epidemic fevers also disappear, as if by enchantment. Such is the salutary influence of this wind, that, while it lasts, *infection cannot be communicated even artificially.*

Whiston not only proposed to show in what manner a comet might have occasioned the deluge mentioned in the Scriptures, but he wished moreover to adapt his explanation to all the minute details of this great catastrophe as given in the book of Genesis.

This flood took place in the year 2349 before the Christian era, according to the modern Hebrew text, or in the year 2926, according to the Samaritan text, the Septuagint, and Josephus. Is there any reason to suppose that at either of these epochs there was a large comet present?

Among all the comets observed by modern

astronomers, we may, without hesitation, consider that which appeared in 1680 as the first in point of brilliancy.

Many historians mention a comet of *great size, resembling the sun in brightness, and having an immense tail*, which appeared in 1106. Going still further back, we find, in the year 531, a comet mentioned as *very large and very alarming*, called by the Byzantine writers *lampadias*, because it resembled a burning lamp. Every one has heard of the comet that appeared in the year of Cæsar's death, during the games that Augustus was giving to the Romans. This must have been a very brilliant comet, since its light began to be visible about five o'clock in the evening, or *before sunset.* The date of this is the year 43 before our era.

We have no exact observations of these bodies either in —43, or in 531, or in 1106; we cannot calculate their parabolic orbits; we are without the only criterion that would enable us to pronounce with certainty on the identity of two comets; but let us observe that these, as well as the comet of 1680, were peculiarly brilliant, and let us compare their dates.

From 1106 to 1680 is a period of 574 years.
" 531 " 1106 " 575 "
" —43 " 531 " 575 "

As we have taken no note of months, or parts of years, these periods may be considered as equal among themselves, and it hence becomes *probable* that the comet which appeared at the time of Cæsar's death, that of 531, of 1106, and of 1680, are periodical returns of the same body, which, after completing its revolution in about 575 years, becomes again visible from the earth. Now if we multiply this period of 575 years by four, we have 2300, which, added to 43, the date of Cæsar's comet, carries us back within six years of the time of the deluge, according to the modern Hebrew text. If we multiply by five, we have the date of it according to the Septuagint within eight years.

If we consider the remarkable variations which the comet of 1759 exhibited in the duration of its revolution round the sun, we must allow that Whiston was justified in believing that the great comet of 1680, or Cæsar's comet, was near the earth at the time of Noah's deluge, and had some effect in producing this great phenomenon.

We shall not stop to examine particularly the series of transformations by which Whiston supposes the earth to have been changed from a comet to the globe we inhabit. It will suffice to say, that he believed the nucleus of the earth to be a hard and compact substance, and that it is the old nucleus of a comet; that various kinds of matter, which, mixed together, formed the envelope, settled with more or less rapidity, according to their specific gravity; that thus the solid nucleus was at first encompassed by a thick and heavy fluid; that the earthy matter was then precipitated, forming upon the fluid a dense covering, a kind of crust, which may be compared to the shell of an egg; that water came afterwards to cover this solid crust, filtering through the fissures and extending over the thick fluid; that finally the gaseous matter remained suspended, being gradually purified, and constituting at last our atmosphere.

Thus, in this system, the *great deep* of the Bible is composed of a solid nucleus and two concentric orbs. The orb nearest the centre is formed of the heavy fluid which was first precipitated: the second is water. It is upon this latter fluid, then, that the exterior and solid crust of the earth rests.

We must now examine how, according to this construction of the globe, against which modern geology offers many objections, Whiston has explained the two principal events of the deluge as described by Moses.

"In the sixth hundredth year of Noah's life, in the second month, and the seventeenth day of the month, the same day *were all the fountains of the great deep broken up, and the flood-gates of heaven were opened.*"—Gen. vii. 11.

At the time of the deluge, the comet of 1680, according to Whiston, was only seven or eight thousand miles from the earth. It must therefore have attracted the fluids of the great deep, as the moon attracts the waters of the ocean. Its action at this small distance must have produced an immense tide in the fluid beneath the earth. The terrestrial crust, incapable of withstanding the impetuous flood, must have broken in many places. The waters were thus let loose, and allowed to spread themselves over the continents. Here the reader finds *the breaking up of the fountains of the great deep.*

The ordinary rains of our globe, even if continued forty days, would have produced but a small effect. Taking for a day's rain all that falls in a year, the quantity that would fall in six weeks, far from covering the tops of the highest mountains, would hardly form a layer twenty-eight yards deep. We must therefore look further for the *windows* or *flood-gates of heaven that were opened.* Whiston has found them in the atmosphere, and in the tail of the comet.

According to him, this atmosphere reached the earth towards the Gordæan mountains, (Ararat,) which mountains are supposed to have entirely intercepted the tail. The terrestrial atmosphere being thus charged with an immense quantity of aqueous particles, the consequence might be a rain of forty days, falling in such torrents as the ordinary state of the earth can give us no idea of.

Whiston, having occasion for an immense tide, in order to explain the phenomena of the *great deep* of the Bible, is not contented with making his comet pass very near the earth at the time of the deluge; he has moreover given to it a mass six times as great as that of the moon.

Such a supposition is wholly gratuitous; and yet that is its least defect, for it does not, after all, explain the phenomena. The reason why the moon produces such a great effect upon the waters of the ocean is, because its daily angular motion is comparatively small; in the course of a few hours its distance from the earth scarcely varies at all; for some considerable time it continues vertical over the same points of our globe; the waters attracted by it have always time enough to yield to its influence before the moon removes to another region where its force would be differently directed. But this was not true of the comet of 1680. When near the earth, its angular motion, apparently through the constellations, must have been extremely rapid. In a few minutes it must have corresponded to a numerous series of points situated on meridians of the earth very distant from each other. As to its rectilinear distance from the earth, that might certainly have been very small, but only for a few short moments. These circumstances taken together are, it must be allowed, very unfavorable to the production of a great tide.

In order to lessen these difficulties we have only to enlarge the comet, to make its mass not merely six times, but thirty or forty times, that of the moon. We cannot, however, be allowed this latitude with respect to the comet of 1680. In that year, on the 21st of November, it passed near the earth. It is proved that at the time of the deluge its distance was not less. Now, as in 1680 it produced neither floods from above, nor tides from below, nor any breaking up of the *great deep*—as, moreover, neither its tail nor its envelope inundated us—we may affirm with confidence that Whiston's theory is a mere romance, unless, giving up the comet of 1680, the same effects are ascribed to another body, of the same kind, but *much larger.*

A few words, before quitting this subject, upon the consequences of a comet's striking the earth, so far as its rotary motion is concerned.

The earth turns upon its axis in twenty-four hours from west to east. The circumference of the equator is a little more than twenty-four thousand miles.

Twenty-four thousand miles, therefore, is the distance travelled by the equatorial regions, solid and fluid, every twenty-four hours, in consequence of the rotary motion of the globe. An observer who should be placed in space, and far enough removed from the earth and its atmosphere not to be carried round with it, would see every part of the equator pass before his eyes at the rate of about one thousand miles an hour, or seventeen in a minute. At the very poles, there is no motion. In the latitude of Brest, in France, the earth moves only at the rate of about ten miles in a minute.

The waters of the ocean, though they participate in this rapid movement, do not overflow the land that surrounds them; but this is because in every country the land has exactly the same velocity as the water. In all latitudes, the continents, and the seas that border on them, are, with regard to each other, in a state of *relative rest.* If this state of things were changed, if the water, in a given part of the globe, continued to move at its usual rate, whilst the land near it suddenly lost a part of its velocity, the ocean must overflow its boundaries.

In order to have a clear idea of this subject, let us imagine, that, by an oblique stroke from a comet, all the *solid parts* of the earth were suddenly made to turn round the diameter, for instance, that passes through Brest. This town having become a pole, the whole peninsula of Brittany would be in a state of nearly absolute rest; but the case would be very different with the ocean that washes it on the west, because, as we said just now in speaking of the progressive motion, the water is only *laid* upon the solid bed which contains it. The water would then be thrown in great masses on the shore, which would no longer flee before it with the former velocity of the parallel of Brest, namely, with a velocity of about ten miles a minute.

Thus, through the agency of a comet, vast portions of a continent might be inundated, and high regions covered with water. But is it really in this way that the marine deposits, discovered on the tops of mountains, have been formed? By no means. These beds are frequently horizontal, very extensive, deep, and regular. The shells are of various kinds, and it often happens that there are among them very small ones, in which the most delicate points and most fragile parts remain unbroken. All this is against their being carried there by violence. Every thing shows that the deposit was formed upon the spot. In what way, then, can we account for these marine beds, without supposing them to be formed by an irruption of the ocean? We must consider the mountains, and the more or less elevated lands which serve as their base, to have been gently heaved up from below, to have risen through the bosom of the waters, *as mushrooms rise out of the earth.* In 1694, Halley gave this hypothesis as a *possible* explanation of the presence of marine productions on the tops and sides of mountains. This explanation was the *true* one; and it is now almost universally admitted to be such. A comet which should perceptibly change either the progressive or rotary motion of this globe, would, no doubt, occasion frightful convulsions in the crust of the earth; but these physical revolutions would differ, in a thousand ways, from those which are now the objects of study to geologists.

All the regions of Europe contain, either in the bowels of their mountains, in caverns, or at moderate depths in certain kinds of earth, the bones of animals, such as the rhinoceros, elephant, &c., which are not now the inhabitants of such cold climates. We must then suppose, either that Europe, in the course of many ages, has become colder, or else that, during one of the violent deluges which this planet has experienced, currents, running from the south to the north, have carried with them the remains of numerous species of animals that were actually destroyed.

Two very remarkable events have occurred to contradict the latter explanation, and to show its insufficiency. One is, the discovery, made in Siberia, in the year 1771, on the sandy shores of the Wilhoui, some feet below the surface, of a rhinoceros so perfectly preserved that it was covered with flesh and skin; and the other is the later and still more curious discovery, made, in 1799, on the shores of the Frozen Ocean, near the mouth of the Lena, of an enormous elephant, enclosed in a block of ice, the flesh of which was so unchanged, that the *Yakoutes* of the neighborhood cut it up for their dogs to eat. In such a case as this, there could be no action of a current—no long transportation from the south to the north; for if such large animals as these had not been frozen as soon as killed, their flesh would have become putrid. Are we therefore led to suppose that Siberia was once a warm country, since elephants and rhinoceroses lived in it? and also to conclude that the same catastrophe which killed those animals, suddenly rendered that part of the globe the cold region we now find it?

In the present state of our knowledge, we can think of but one way in which the thermometrical character of a country could be materially and suddenly changed, and that is, by suddenly changing its latitude. Any other circumstances would make but a very slight difference.

If deep snows cover Spitsbergen during half the year, it is only because it is situated very near one of the poles of rotation. Change the place of the pole ninety degrees—this archipelago would be at the equator, and its desert valleys, fertilized by the solar heat, would be clothed in the richest verdure. Imagine the earth's axis to be somewhere in Peru or Brazil, without the inclination of the equator to the ecliptic being changed, and there would soon be icebergs floating in the ports of Callao and Rio Janeiro. The thousand beautiful plants which now enrich and embellish those countries, would perish under deep snows, and be replaced by lichens. We need not hesitate to say, that if any other tropical region became *suddenly* the pole of the earth, it would freeze there in less than twenty-four hours.

The problem to which the elephant of Siberia has given rise, leads, then, at last, to this question: Has the earth's axis of rotation ever suddenly changed its direction?

Such a change, particularly if very sudden, could not be produced by the forces usually acting upon our globe; but if the earth should be violently struck by a foreign body, a change of place in the axis round which it turns would be the *almost* necessary consequence. *Almost*, because there are directions in which a blow, however hard, would not alter the original position of the axis.

Comets are evidently the only foreign bodies in our system that could possibly strike the earth. The Lena elephant, and the Wilhoui rhinoceros seem then to prove, however strange such a catastrophe may seem, that in the lapse of ages a rencontre of that nature has taken place. This proof would even be indubitable, if it were well ascertained that elephants have never been able to live in such a climate as that of Siberia. Now some doubts are entertained on this subject, of which the reader may judge from the following facts.

In form and dimensions the elephant of the Frozen Ocean bore a great resemblance to those that inhabit Africa and Asia. His tusks were ten feet long; his head weighed four hundred and fifty pounds; but his skin exhibited a very marked peculiarity, and one well worthy of notice—it was covered with long black hair, and a reddish, woolly coat. The white bears, in devouring the flesh, had trampled into the wet soil more than thirty pounds of this hairy coat, which were taken up by Mr. Adams. The neck was also furnished with a long mane.

This double coat of the polar elephants, and the stiff hair, three or four inches long, which covered the skin of the Wilhoui rhinoceros, were too well adapted to the severity of a Siberian climate for us to entertain a doubt as to these animals being able to live in very cold climates, though, without such warm covering, those of their race now living could not endure them. Moreover, Humboldt became acquainted, in his travels, with an important fact, very much to our purpose, and likely to throw new light upon the subject. He ascertained that the royal tiger of India, which we are accustomed to call a tropical animal, lives in Asia in very high latitudes, and that in summer it makes excursions to the western side of the Altaï mountains, near Barnoul, where several have been killed of an enormous size. It appears, then, that elephants with thick coats must have been formerly able to travel, during summer, as far as Siberia. Once there, any common accident, a mere slide of earth, would be sufficient to account for their bodies being found in frozen beds, capable of preserving them from decomposition. The observations of Humboldt prove, that, in the steppes beyond the sixty-second degree of latitude, the earth, at a depth of fourteen or fifteen feet, is always frozen.

While it is thus shown that we can satisfactorily account for fossil elephants being found in Siberia, without admitting that there has been *a sudden change of climate*, we may here also assert that nothing has yet been brought forward to prove that a comet has ever had any agency in the great physical revolutions on our globe, of which traces are everywhere to be seen.

As soon as the northern regions of America were discovered, navigators remarked that they were much colder than the same parallels in Europe. This fact, for which the *astronomical theory* of climates does not satisfactorily account, has exercised the ingenuity of many philosophers, and, among the rest, of Halley. According to that learned and celebrated man, a comet formerly struck the earth obliquely, and changed the position of its axis of rotation, in consequence of which the north pole, which was once very near Hudson's Bay, was carried further eastward. The country which it left had been so long and so deeply frozen, that the effects of this once polar cold are still experienced, and a long series of years must elapse before the northern parts of the new world can receive, by the action of the sun's rays, that climate which its geographical position indicates.

This might have appeared to be a plausible hypothesis in the time of Halley. But now that the meteorological fact which it was meant to explain is understood in all its details, it is found to be insufficient and useless, and even opposed to the results of observation.

It is true that, in the same latitudes, it is much colder in the United States than in Europe; but this difference disappears almost entirely when the points of comparison in America are taken from the western side of that continent, that is, on the shores of the Pacific Ocean. Thus, according to Halley's hypothesis, the old north pole has modified only the temperature on the eastern side of the continent: this pole must then have been situated originally in that part, or on the meridians near it. But then what is to be said as to the cause of the excessive cold on the coast of Asia, which, in similar latitudes, is not less severe than it is on the Atlantic coast of North America? It cannot be denied that Halley was acquainted with but a small part of the interesting phenomena that belong to the subject of climate. He was not aware, that, in the old world, as well as in the new, the eastern coast is remarkable for its low temperature; that the lines of equal temperature, called now *isothermal* lines by Humboldt, differ greatly from terrestrial parallels; that they incline towards the equator according as, leaving the western coast, we approach the interior of continents. Halley's hypothesis is wholly unsatisfactory, and there are no meteorological phenomena to prove that the axis of the earth has ever undergone any change by the shock of a comet.

Russia and Persia present us with a geographical phenomenon truly extraordinary. There is in these countries a vast region, covered with populous towns, great commercial establishments, and fertile lands, which is nevertheless *much below the level of the ocean.* According to Humboldt, the extent of this low region cannot be less than one hundred thousand square miles. That no one may imagine the depression to be slight, or that it is overestimated on account of errors liable to be committed in ascertaining the level of very large tracts, we will observe that the level of the Caspian Sea, and consequently that of the city of Astracan, is more than three hundred feet below the level of the Black Sea, or of the ocean. Even in the heart of Russia, the course of the Wolga, and the countries through which it flows, are depressed one hundred and fifty feet.

This enormous sinking of a whole country, a phenomenon of which the globe does not offer another example, being very difficult to explain by the operation of known causes, has led persons, in despair of all other agency, to attribute it to the action of a comet.

In *ricochet* firing, it is evident that the spot struck by the ball is somewhat depressed. Thus, according to some, the Caspian Sea and the surrounding country has been indented by the stroke of an immense ball, that is, of a comet.

In the present state of geological science, this idea of Halley's cannot be favorably received. No one doubts now that isolated peaks, as well as the longest and highest ranges of mountains, have been gradually heaved up from the bosom of the earth. Now the very idea of a rise necessarily implies a void in some neighboring part, and the possibility of an ulterior depression.

In looking at a map of Asia, it will be easily seen that no other part of the world contains so much high land. Around the Caspian Sea are the large elevated regions of Iran and of central Asia, those of Himalaya, of Kuen-Lun, of Thian-Chan, the mountains of Armenia, those of Erzerum, and the range of Caucasus. Now, without calling in the aid of a comet, may we not suppose, as Humboldt does, in his "Asiatic Fragments," that the uplifting of so many enormous masses must be attended with a perceptible depression in the intermediate places? This solution of one of the most curious problems in physical geography is less liable to objection on account of the actual state of the ground in the region to which it belongs, which has not yet become stable. The bottom of the Caspian Sea, for instance, is occasionally raised and depressed.

The Arcadians thought themselves of older date than the moon. They maintained that their ancestors had inhabited this planet before it had any satellite. Struck with this singular opinion, some philosophers have imagined that the moon was formerly a comet, which, in performing its elliptical course round the sun, came into the neighborhood of the earth, and was drawn in to revolve around it.

Such a change of orbit is possible; but it evidently could not have taken place if the comet's perihelion distance had been great. The comet must, therefore, have passed very near the sun, and have experienced an intense heat, capable of dissipating every trace of humidity. The almost entire absence of an atmosphere round the moon, the scorched appearance of its vast mountains and deep valleys, and the few plains that are seen, have been cited as proofs that this luminary was once a comet.

This reasoning is founded upon the strangest confusion of language. The moon has, indeed, a scorched appearance, if by that is meant that all parts of its surface show traces of former volcanic eruptions; but nothing in its aspect indicates, or can indicate at the present day, what temperature the moon has heretofore been subjected to by the action of the solar rays. These two phenomena have no connection with each other. The volcanoes of Iceland, of Mayen's Island, and of Kamtschatka, show every year that the frosts at the surface of polar regions have no effect upon the subterraneous matter, the chemical action of which produces eruptions.

In all the multitude of bodies, of various forms and degrees of brightness, which the firmament displays, comets are the only ones which are evidently and sensibly surrounded with a gaseous envelope, a real atmosphere. We do not deny that this atmosphere has been formed by the evaporation of matter which originally existed in the nucleus; but it is always found to accompany a comet, and there would be no reason for its being separated from it, whatever derangement the comet might experience in the form and original position of its orbit from an accidental attraction. Thus the small extent of atmosphere around the moon, is rather against than for the opinion that it was once a comet.

CHAPTER VII.

Reflections on the system—Proofs from analogy that the planets are inhabited—Their magnitude—Their rotation—Their revolution round the sun—They have moons—Mountains and valleys—Clouds and snow—Our globe a small part of the universe—No limits to future discoveries—Rapid motion of the planets—Infinite power requisite to give them this motion—Immense spaces around the heavenly bodies—Their mutual influences—Astronomy an aid to religion.

Such is a general outline of the leading facts connected with that system of which we form a part. Though the energies of Divine Power had never been exerted beyond the limits of this system, it would remain an eternal monument of the wisdom and omnipotence of its Author. Independent of the sun, which is like a vast universe in itself, and of the numerous comets which are continually traversing its distant regions, it contains a mass of material existence, arranged in the most beautiful order, two thousand five hundred times larger than our globe.

Such a glorious system must have been brought into existence to subserve purposes worthy of the infinite wisdom and benevolence of the Creator. To suppose that the distant globes of which it is composed, with their magnificent apparatus of rings and moons, were created merely for the purpose of affording a few astronomers, in these latter times, a peep at them through their glasses, would be inconsistent with every principle of reason, and would be charging Him who is the source of wisdom with conduct which we would pronounce to be folly in the sons of men.

What a magnificent idea of the Creator and his works is presented to the imagination even by the bodies themselves! The sun, a stupendous luminous globe, is placed at the centre of the system, around whose orb the planets, satellites, and comets perform their revolutions with an order and regularity that must fill our minds with the most exalted conceptions of their divine original. Who can contemplate the magnitudes and distances of these vast bodies, and not be struck with the grandeur of the scene, and the power of omnipotence? What wonder, then, that the ancients should imagine that these spheres made a divine melody as they rolled on in their orbits, or even that some should be found enthusiastic enough to fancy that they sometimes heard this "music of the spheres?"

Shall we conclude that all these glorious orbs are desolate and forsaken? Shall we suppose them monuments of omnipotence only, and not of infinite goodness also?

Let us look around us, and reflect upon the evidence afforded by nature and analogy on this subject, and, other guides failing, let us follow these to whatever conclusions they may lead.

The world in which we live is a round ball, of a determined magnitude, and occupies its own place in the firmament. But when we explore the unlimited tracts of that space which is everywhere around us, we meet with other balls of equal or superior magnitude, and from which our earth would either be invisible, or appear as small as any of those twinkling stars which are seen on the canopy of heaven. Why then suppose that this little spot—little at least in the immensity which surrounds it—should be the exclusive abode of life and intelligence? What reason to think that those mightier globes which roll in other parts of creation, and which we have discovered to be worlds in magnitude, are not also worlds in use and in dignity? Why should we think that the great Architect of nature, supreme in wisdom as he is in power, would call these stately mansions into existence, and leave them unoccupied? When we cast our eye over the broad sea, and look at the country on the other side, we see nothing but the blue land stretching obscurely over the distant horizon. We are too far away to perceive the richness of its scenery, or to hear the sound of its population. Why not extend this principle to the still more distant parts of the universe? What though, from this remote point of observation, we can see nothing but the naked roundness of yon planetary orbs? Are we therefore to say that they are so many vast and unpeopled solitudes; that desolation reigns in every part of the universe but ours; that the whole energy of the divine attributes is expended on one insignificant corner of these mighty works; and that to this earth alone belongs the bloom of vegetation, or the blessedness of life, or the dignity of rational and immortal existence?

But this is not all. We have something more than the mere magnitude of the planets to allege in favor of the idea that they are inhabited. We know that this earth turns round upon itself; and we observe that all those celestial bodies which are accessible to such an observation have the same movement. We know that the earth performs a yearly revolution round the sun; and we can detect in all the planets which compose our system a revolution of the same kind, and under the same circumstances. They have the same succession of day and night. They have the same agreeable vicissitude of the seasons. To them, light and darkness succeed each other; and the gaiety of summer is followed by the dreariness of winter. To each of them the heavens present as varied and magnificent a spectacle; and this earth, the encompassing of which would require the labor of years from one of its inhabitants, is but one of the lesser lights which sparkle in their firmament. To them, as well as to us, has God divided the light from the darkness.

In all the greater arrangements of divine wisdom, we can see that God has done the same things for the accommodation of the planets that he has done for the earth which we inhabit. And shall we say that the resemblance stops here, because we are not in a situation to observe it? Shall we say that this scene of magnificence has been called into being merely for the amusement of a few astronomers? Shall we measure the counsels of heaven by the narrow impotence of the human faculties? or conceive that silence and solitude reign throughout the mighty empire of nature; that the greater part of creation is an empty parade; and that not a worshipper of the Divinity is to be found through the wide extent of yon vast and immeasurable regions?

It lends a delightful confirmation to the argument, when, from the growing perfection of our instruments, we can discover a new point of resemblance between our earth and the other bodies of the planetary system. It is now ascertained, not merely that all of them have their day and night, and that all of them have their vicissitudes of seasons, and that some of them have their moons to rule their night and alleviate the darkness of it. We can see of one, that its surface rises into inequalities, that it swells into mountains and stretches into valleys; of another, that it is surrounded by an atmosphere which may support the respiration of animals; of a third, that clouds are formed and suspended over it, which may minister to it all the bloom and luxuriance of vegetation; and of a fourth, that a white color spreads over its northern regions, as its winter advances, and that on the approach of summer this whiteness is dissipated—giving room to suppose that the element of water abounds in it, that it rises by evaporation into its atmosphere, that it freezes upon the application of cold, that it is precipitated in the form of snow, that it covers the ground with a fleecy mantle which melts away from the heat of a more vertical sun; and that other worlds bear a resemblance to our own in the same yearly round of beneficent and interesting changes.

Who shall assign a limit to the discoveries of future ages? Who can prescribe to science her boundaries, or restrain the active and insatiable curiosity of man within the circle of his present acquirements? We may guess with plausibility what we cannot anticipate with confidence. The day may yet be coming when our instruments of observation shall be inconceivably more powerful. They may ascertain still more decisive points of resemblance. They may resolve the same question by the evidence of sense which is now so abundantly convincing by the evidence of analogy. They may lay open to us the unquestionable vestiges of art, and industry, and intelligence. We may see summer throwing its green mantle over those mighty tracts, and we may see them left naked and colorless after the flush of vegetation has disappeared. In the progress of years, or of centuries, we may trace the hand of cultivation spreading a new aspect over some portion of a planetary surface. Perhaps some large city, the metropolis of a mighty empire, may expand into a visible spot by the powers of some future telescope.

The discoveries of science widen the empire of creation far beyond the limits which were formerly assigned to it. They give us to see that the sun, throned in the centre of his planetary system, gives light, and warmth, and the vicissitude of seasons, to an extent of surface several hundreds of times greater than that of the earth which we inhabit. They lay open to us a number of worlds, rolling in their respective circles around this vast luminary, and prove that the ball which we tread upon, with all its mighty burden of oceans and continents, instead of being distinguished from the others, is among the least of them, and, from some of the more distant planets, would not occupy a visible point in the concave of their firmament. They let us know, that, though this mighty earth, with all its myriads of people, were to sink into annihilation, there are some worlds where an event so awful to us would be unnoticed and unknown, and others where it would be nothing more than the disappearance of a little star which had ceased from its twinkling. We should learn not to look on our earth as the universe of God, but as a small portion of it; as only one of the many mansions which the Supreme Being has created for the accommodation of his worshippers; only one of the many worlds rolling in that flood of light which the sun pours around him to the outer limits of the planetary system.

Since it appears, so far as our observation extends, that matter exists solely for the sake of sensitive and intelligent beings, and that the Creator made nothing in vain, it is a conclusion, to which we are necessarily led, that the planetary globes are inhabited by various orders of intellectual beings, who participate in the bounty, and celebrate the glory, of their Creator.

Here, then, with reverence, let us pause and wonder! Over all this vast assemblage of material existence God presides. Amidst the diversified objects and intelligences it contains, he is eternally and essentially present. By his unerring wisdom all its complicated movements are directed. By his almighty fiat it emerged from nothing into existence, and is continually supported from age to age. "HE SPAKE AND IT WAS DONE; HE COMMANDED AND IT STOOD FAST." "By the word of the Lord were the heavens made, and all the host of them by the spirit of his mouth." What an astonishing display of divine power is here exhibited to our view! How far transcending all finite comprehension must be the energies of Him who only "spake, and it was done;" who only gave the command, and this mighty system of the universe, with all its magnificence, started into being! The infinite ease with which this vast fabric was reared, leads us irresistibly to conclude that there are powers and energies in the divine mind which have never yet been exerted, and which may unfold themselves to intelligent beings, in the production of still more astonishing and magnificent effects, during an endless succession of existence.

We can acquire accurate ideas of the relative velocities of moving bodies only by comparing the motions with which we are familiar, with one another, and with those which lie beyond the general range of our minute inspection. We can acquire a pretty accurate conception of the velocity of a ship impelled by the wind—of a steam-car—of a race horse—of a bird darting through the air—of an arrow flying from a bow—and of the clouds when impelled by a stormy wind. The velocity of a ship is from eight to twelve miles an hour—of a race horse, from twenty to thirty miles—of a bird, say from fifty to sixty miles—and of the clouds, in a violent hurricane, from eighty to one hundred miles an hour. The motion of a ball from a loaded cannon is incomparably swifter than any of the motions now stated; but of the velocity of such a body we have a less accurate idea, because, its rapidity being so great, we cannot trace it distinctly by the eye, through its whole range, from the mouth of the cannon to the object against which it is impelled. By experiments, it has been found that its rate of motion is from four hundred and eighty to eight hundred miles in an hour; but it is retarded every moment by the resistance of the air and the attraction of the earth. This velocity, however, great as it is, bears no sensible proportion to the rate of motion which is found among the celestial orbs. That such enormous masses of matter should move at all is wonderful; but when we consider the amazing velocity with which they are impelled, we are lost in astonishment. The planet Jupiter, in describing its circuit round the sun, moves at the rate of twenty-nine thousand miles an hour. The planet Venus, one of the nearest and most brilliant of the celestial bodies, and about the same size as the earth, is found to move through the spaces of the firmament at the rate of seventy-six thousand miles an hour; and the planet Mercury with a velocity no less than one hundred and fifty thousand miles an hour, or one thousand seven hundred and fifty miles in a minute—a motion two hundred times swifter than that of a cannon ball.

These velocities will appear still more astonishing, if we consider the magnitude of the bodies which are thus impelled, and the immense forces which are requisite to carry them along in their courses. However rapidly a ball flies from the mouth of a cannon, it is the flight of a body only a *few inches* in diameter; but one of the bodies, whose motion has been just now stated, is *eighty-six thousand miles* in diameter, and would comprehend within its vast circumference more than a thousand globes as large as the earth. Could we contemplate such motions, from a fixed point, at the distance of only a few hundreds of miles from the bodies thus impelled, it would raise our admiration to its highest pitch, it would overwhelm all our faculties, and, in our present state, would produce an impression of awe, and even of terror, beyond the power of language to express. The earth contains a mass of matter equal in weight to at least 2,200,000,000,000,000,000,000 tons, supposing its mean density to be only about two and a half times greater than water. To move this ponderous mass a single inch beyond its position, were it fixed in a quiescent state, would require a mechanical force almost beyond the power of numbers to express. The physical force of all the myriads of intelligences within the bounds of the planetary system, though their powers were far superior to those of man, would be altogether inadequate to the production of such a motion. How much more must be the force requisite to impel it with a velocity one hundred and forty times swifter than a cannon ball, or sixty-eight thousand miles an hour, the actual rate of its motion in its course round the sun! But whatever degree of mechanical power would be requisite to produce such a stupendous effect, it would require a force one hundred and fifty times greater to impel the planet Jupiter in its actual course through the heavens! Even the planet Saturn, one of the slowest-moving bodies of our system, a globe ten hundred times larger than the earth, is impelled through the regions of space at the rate of twenty-two thousand miles an hour, carrying along with it two rings, and seven moons larger than ours, through its whole course round the central luminary. Were we placed within a thousand miles of this stupendous globe, where its hemisphere, encompassed by its magnificent rings, would fill the whole extent of our vision, the view of such a glorious object, flying with such amazing velocity before us, would infinitely exceed every idea of grandeur we can derive from terrestrial scenes, and overwhelm our powers with astonishment and awe. The ideas of *strength* and *power* implied in the impulsion of such enormous masses of matter through the illimitable tracts of space, are forced upon the mind with irresistible energy, far surpassing what any abstract propositions or reasonings can convey.

If we consider the *immense number* of bodies thus impelled through the vast spaces of the universe—the rapidity with which the *comets*, when near the sun, are carried through the regions they traverse; if we consider the high probability, if not absolute certainty, that the sun, with all his attendant planets and comets, is impelled with a still greater degree of velocity towards some distant region of space, or around some wide circumference—that all the thousands of systems of that nebulæ to which the sun belongs are moving in a similar manner—that all the nebulæ in the heavens are moving around some magnificent central body—in short, that all the suns and worlds in the universe are in rapid and perpetual motion, as constituent portions of one grand and boundless empire, of which Jehovah is the sovereign; and if we consider, still farther, that all these mighty movements have been going on, without intermission, during the course of many centuries, and some of them, perhaps, for myriads of ages before the foundations of our world were laid;—it is impossible for the human mind to form any adequate idea of the stupendous forces which are in incessant operation throughout the unlimited empire of the Almighty. To estimate such mechanical force, even in a single instance, completely baffles the mathematician's skill, and sets the power of numbers at defiance. "Language," and figures, and comparisons, are "lost in wonders so sublime," and the mind, overpowered with such reflections, is irresistibly led upwards to search for the cause in that OMNIPOTENT BEING who upholds the pillars of the universe, the thunder of whose power none can comprehend. While contemplating such august objects, how emphatic and impressive appears the language of the sacred oracles: "Canst thou by searching find out God? Canst thou find out the Almighty to perfection?"

Again, the *immense spaces* which surround the heavenly bodies, and in which they perform their revolutions, tend to expand our conceptions on this subject, and to illustrate the magnificence of the divine operations. In whatever point of view we contemplate the scenery of the heavens, an idea of grandeur irresistibly bursts upon the mind; and, if empty space can, in any sense, be considered as an object of sublimity, nothing can fill the mind with a grander idea of magnitude and extension than the amplitude of the scale on which planetary systems are constructed. Around the body of the sun there is allotted a cubical space three thousand and eight hundred millions of miles in diameter, in which eleven planetary globes revolve, every one being separated from another by intervals of many millions of miles. The space which surrounds the utmost limits of our system, extending in every direction to the nearest fixed stars, is, at least, 40,000,000,000,000 miles in diameter; and it is highly probable that every star is surrounded by a space of equal, or even of greater, extent. A body impelled with the greatest velocity which art can produce, (a cannon ball, for instance,) would require twenty years to pass through the space that intervenes between the earth and the sun, and four millions seven hundred thousand years ere it could reach the nearest star. Though the stars seem to be crowded together in clusters, and some of them almost to touch one another, yet the distance between any two stars which seem to make the nearest approach, is such as neither words can express, nor imagination fathom. These immense spaces are as unfathomable on the one hand, as the magnitude of the bodies which move in them, and their prodigious velocities, are incomprehensible on the other; and they form a part of those magnificent proportions according to which the fabric of universal nature was arranged, all corresponding to the majesty of that infinite and incomprehensible Being "who measures the ocean in the hollow of his hand, and meteth out the heavens with a span." How wonderful that bodies at such prodigious distances should exert a mutual influence on one another! that the sun, at the distance of ninety-five millions of miles, should raise the vapors, move the ocean, direct the course of the winds, fructify the earth, and distribute light and heat and color through every region of the globe; yea, that his attractive influence and fructifying energy should extend even to the planet Herschel, at the distance of nineteen hundred millions of miles! So that, in every point of view in which the universe is contemplated, we perceive the same *grand scale* of operation by which the Almighty has arranged the provinces of his universal kingdom.

We would now ask, in the name of all that is sacred, whether such magnificent manifestations of Deity ought to be considered as irrelevant to religion? If religion consists in the intellectual apprehension of the perfections of God, and in the moral effects produced by such an apprehension—if all the rays of glory emitted by the luminaries of heaven are only so many reflections of the grandeur of Him who dwells in light unapproachable—if they have a tendency to assist the mind in forming its conceptions of that ineffable Being whose uncreated glory cannot be directly contemplated—and if they are calculated to produce a sublime and awful impression on all created intelligences,—shall we rest contented with a less glorious idea of God than his works are calculated to afford? Shall we disregard the works of the Lord, and contemn "the operations of his hands?" If, at the command of God, we lift up our eyes to the "firmament of his power," surely we ought to do it, not with a brute "unconscious gaze," not with the vacant stare of a savage, not as if we were still enveloped with the mists and prejudices of the dark ages, but as surrounded by that blaze of light which modern science has thrown upon the scenery of the sky, in order that we may contemplate with fixed attention all that enlightened reason, aided by the nicest observations, has ascertained respecting the magnificence of the celestial orbs. To overlook the sublime discoveries of modern times, to despise them, or to call in question their reality, because they bring to our ears such astonishing reports of the "eternal power" and majesty of Jehovah, is to act as if we were afraid lest the Deity should be represented as more grand and magnificent than he really is, and as if we would be better pleased to pay him a less share of homage and adoration than is due to his name.

Any person of common understanding may be made to comprehend the leading ideas of extended space, magnitude, and motion, which have been stated above, provided the descriptions be sufficiently simple, clear, and well-defined; and should they be at a loss to comprehend the principles on which the conclusions rest, or the mode by which the magnificence of the works of God has been ascertained, an occasional reference to such topics would excite them to inquiry and investigation, and to the exercise of their powers of observation and reasoning on such subjects, which are too frequently directed to far less important objects. The following illustration, however, stands clear of every objection of this kind, and is level to the comprehension of every man of common sense. Either the earth moves round its axis once in twenty-four hours, or the sun, moon, planets, comets, stars, and the whole frame of the universe, move around the earth in the same time. There is no alternative, or third opinion, that can be formed on this point. If the earth revolve on its axis every twenty-four hours to produce the alternate succession of day and night, the portions of its surface about the equator must move at the rate of more than a thousand miles an hour, since the earth is more than twenty-four thousand miles in circumference. This view of the fact, when attentively considered, furnishes a most sublime and astonishing idea. That a globe of such vast dimensions, with all its load of mountains, continents, and oceans, comprising within its circumference a mass of two hundred and sixty-four thousand millions of cubical miles, should whirl round with so amazing a velocity, gives us a most august and impressive conception of the greatness of that Power which first set it in motion, and continues the rapid whirl from age to age! Though the huge masses of the Andes were in a moment detached from their foundations, carried aloft through the regions of the air, and tossed into the Pacific, it would convey no idea of a force equal to that which is every moment exerted if the earth revolve on its axis. But should the motion of our earth be called in question, or denied, the idea of force, or power, will be indefinitely increased. For, in this case, it must necessarily be admitted that the heavens, with all the innumerable host of stars, have a diurnal motion around the globe, which motion must be inconceivably more rapid than that of the earth, on the supposition of its motion. For, in proportion as the celestial bodies are distant from the earth, in the same proportion would be the rapidity of their movements. The sun, on this supposition, would move at the rate of four hundred and fourteen thousand miles in a minute; the nearest stars, at the rate of fourteen hundred millions of miles in a *second;* and the most distant luminaries, with a degree of swiftness which no numbers could express. Such velocities, too, would be the rate of motion, not merely of a single globe like the earth, but of all the ten thousand times ten thousand spacious globes that exist within the boundaries of creation. This view conveys an idea of power still more august and overwhelming than any of the views already stated, and we dare not presume to assert that such a degree of physical force is beyond the limits of infinite perfection. But on the supposition it existed, it would confound all our ideas of the wisdom and intelligence of the Divine mind, and would appear altogether inconsistent with the character which the scripture gives us of the Deity as "the only wise God;" for, it would exhibit a stupendous system of means altogether disproportioned to the end intended—namely, to produce the alternate succession of day and night to the inhabitants of our globe, which is more beautifully and harmoniously effected by a simple rotation on its axis, as is the case with the other globes which compose the planetary system. Such considerations, however, show us, that, on whatever hypothesis, whether on the vulgar or the scientific, or in whatever other point of view, the frame of nature may be contemplated, the mind is irresistibly impressed with ideas of power, grandeur, and magnificence. And, therefore, when an inquiring mind is directed to contemplate the works of God, on any hypothesis it may choose, it has a tendency to arouse reflection, and to stimulate the exercise of the moral and intellectual faculties, upon objects that are worthy of the dignity of immortal minds.

CHAPTER VIII.

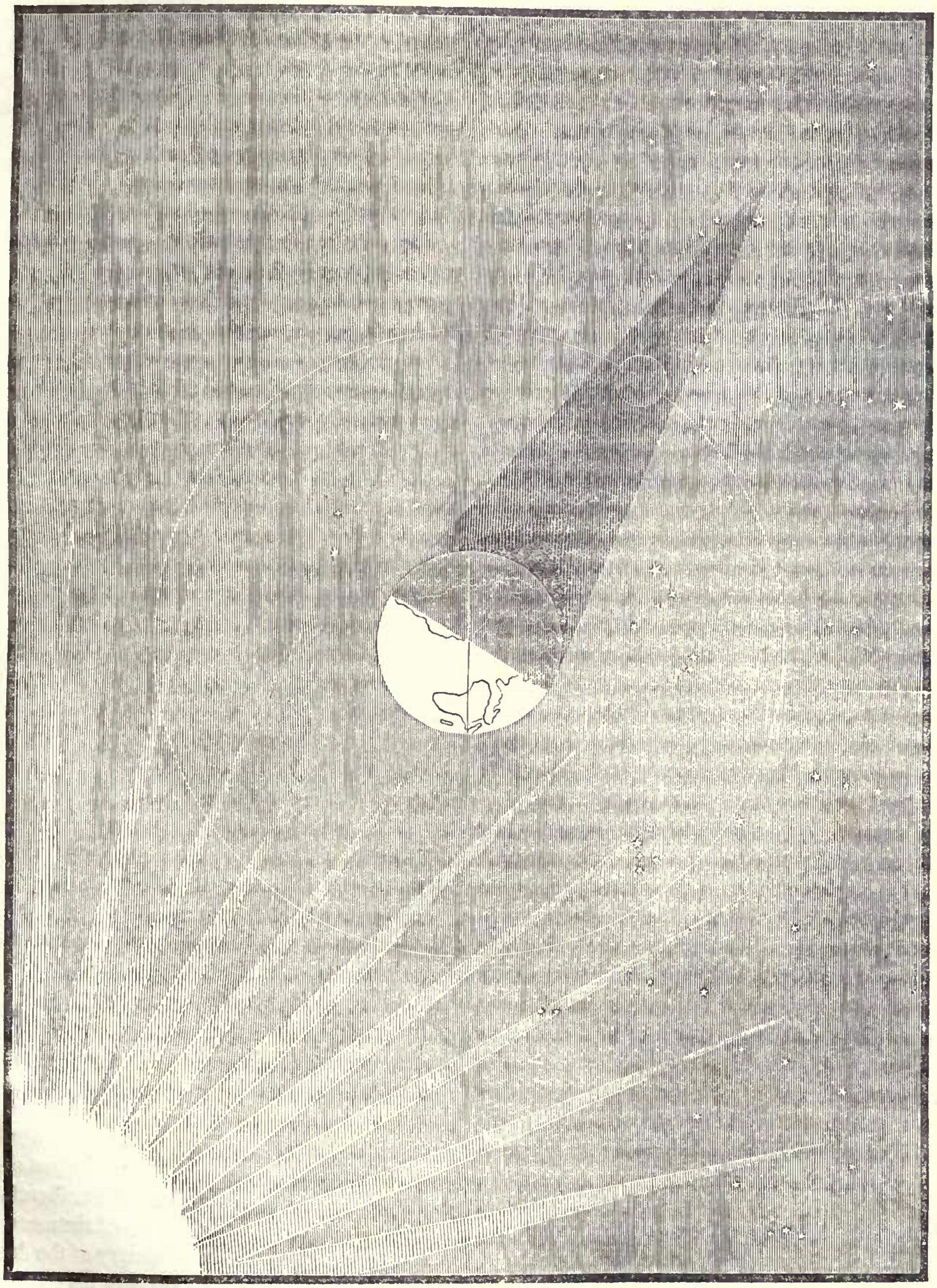
SECTION I.

Eclipses—All opaque bodies cast shadows—The moon visible during total eclipses—Explanation of this phenomenon—Lunar eclipses universal—The shadow conical—The penumbra, or partial shadow—Eclipses of the sun not universal—Breadth of the lunar shadow on the earth—Primaries never eclipse each other—Duration of total eclipses—Solar and lunar ecliptic limits—Detail of several eclipses—Eclipse of 585 B. C.—of 434 B. C.—of 383 B. C.—of 201 B. C.—Two mentioned by Dionysius—Chinese customs respecting eclipses—Eclipse of 1560—of May, 1706—of April, 1715—of June, 1406—Annular eclipse of 1836—Number of eclipses in a year—Particular explanation of eclipses—How affected by the position of the earth's axis—Use of eclipses in astronomy, geography, and chronology—Darkness at the crucifixion—Occultations.

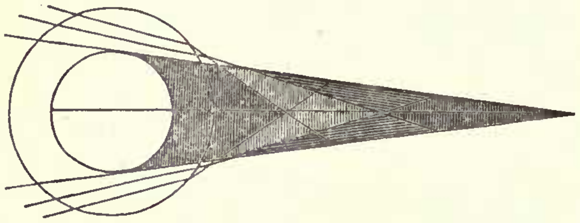
Of all the phenomena of the heavens, there are none that have more engaged the attention of mankind than eclipses of the sun and moon; and to those unacquainted with astronomical principles, nothing appears more extraordinary than the accuracy with which they can be predicted. In the early ages, ere religion and science had enlightened the world, appearances of this kind were generally regarded as alarming deviations from the established laws of nature, and but few, even among philosophers themselves, were able to account for them. At length, when men began to apply themselves to observations, and the celestial motions were better understood, these phenomena were found to depend upon a regular cause, and to admit of a natural and easy solution.

To enter into a popular explanation of all parts of this doctrine would be impracticable. We shall therefore only attempt to give a general idea of the subject, and to show, without the embarrassment of calculations, the foundation upon which it depends. In the first place, all opaque or dark bodies, when they are exposed to the light of the sun, cast a shadow in the opposite direction; and, as the earth is a body of this kind, whose shadow extends over a large space, and to a great distance, it is plain that if the moon in its orbit passes into this shadow it must be deprived of light, and suffer an eclipse.

The plate represents, in the simplest and most intelligible manner, a total eclipse of the moon: the earth represented as stationary, with a conical shadow, whose base rests on the globe, and whose vertex is beyond the lunar orbit—the moon still remaining visible, though its light is dimmed. Nor is this last appearance merely pictorial, for there is generally some light discernible on the whole face of the moon, even during a total eclipse. Its surface is feebly illuminated with a reddish light resembling that of the clouds after sunset. This light proceeds from the solar rays refracted by the earth's atmosphere, and bent to such a degree as to pass into the shadow, those rays which are not sufficiently refracted to reach the surface of the earth, where they would be absorbed, continuing on their course. After they have traversed the atmosphere, they are bent behind the earth, and



tend, as it were, to the focus of a lens; and some of them reach the moon, even when the earth is directly interposed between it and the sun so as to prevent its reception of any light independently of this inflection of rays. If the light thus tending to a point behind the earth were not in a great degree absorbed by the atmosphere, its effect would be very considerable; for, if we consider one of the luminous points of the sun's disc, this point could only send directly a single ray to each point of space, but the effect of the earth's atmosphere is to cause a cone of luminous rays to fall behind the earth. The consequence is, that in most eclipses the obscured part of the moon is more or less faintly visible. The degree in which this takes place depends much on the general state of the earth's atmosphere at the time. The red rays, having the greatest momentum, are those which principally find their way to the moon. Thus, in the eclipse of September 2d, 1830, the moon appeared, at some places, of a deep blood-red color, even during the period of the greatest obscuration.

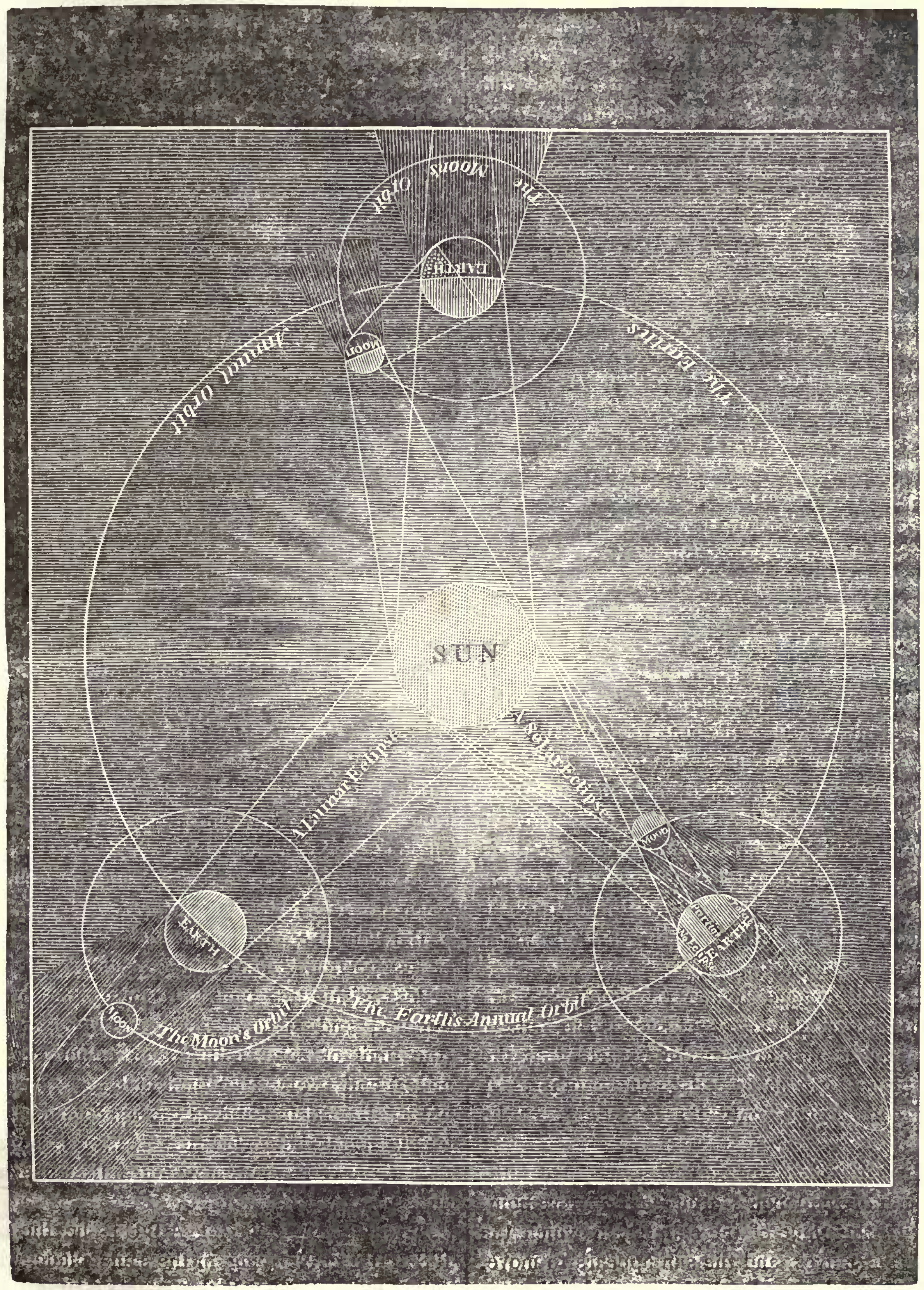


A lunar eclipse being occasioned by the interposition of the earth between the sun and moon, is an actual deprivation of light to the moon. It therefore is for the time really dimmed, not merely in appearance to a spectator at some particular place, but absolutely and universally. We have no occasion, therefore, to refer to any particular point on the surface of the earth, or to embarrass ourselves with any considerations of difference between observations made at different places. We have only to ascertain when the light transmitted to the moon from the sun actually fails.

The farther the earth is from the sun, the more slowly do the lines joining them, or the boundaries of the shadow, approach each other, and the larger, therefore, is the shadow at the moon's distance; and, besides this, the nearer the moon is to the earth, the larger, all other things continuing the same, is the part of the shadow through which it passes. On both accounts, the duration of an eclipse is greatest when the moon is at the least, and the sun at the greatest, distance from the earth.

We have thus far spoken of the shadow as conical; and it is true that the portion of space in which the earth will entirely conceal the sun from the moon is so. But it is clear that there will be another portion in which part of the sun will be concealed, or there will be a partial shadow beyond the outline of the darker conical shadow. This partial shadow, called technically the penumbra, will be a portion of a cone. This appearance is represented in the subjoined plate by the lighter shading on each side of the shadow proper. It exists both in the earth and the moon. In this plate, the earth is represented in three different points of its orbit. In the first, the moon is represented as advancing in her orbit after an eclipse of the sun. In the second, an eclipse of the sun is actually in progress; and to that part of the earth where the dark conical shadow rests, the solar eclipse is total; to that represented as covered by the fainter shadow, the eclipse is partial; as respects the rest of the earth, there is no eclipse. In the third position of the earth, the moon is undergoing a total eclipse; and it disappears or becomes dim to all those parts of the earth that are turned towards it. The reader is to bear in mind that both bodies move in their orbits from west to east, that is, as far as respects the plate, from left to right.

We do not consider a lunar eclipse to take place when the moon is enveloped in this partial shadow merely, nor until some part of that luminary is entirely darkened. The lunar ecliptic limits, therefore, are not affected by them. But it is of importance to observe that the penumbra does exist, and that in proportion as the moon is nearer the absolute shadow, the proportion of the sun obscured to her is increased. The penumbra, therefore, increases in depth, or the brilliancy of the moon diminishes, as we approach the boundary of the dark part of the moon; and this appearance may actually be


The Moons Orbit
EARTH
Moon
Annual Orbit
The Earths
SUN
A Lunar Eclipse
A Solar Eclipse
Moon
EARTH
Moon
The Moon's Orbit
The Earth's Annual Orbit
EARTH
Moon

observed during a lunar eclipse, the brilliancy of the moon decreasing near the part that has disappeared.

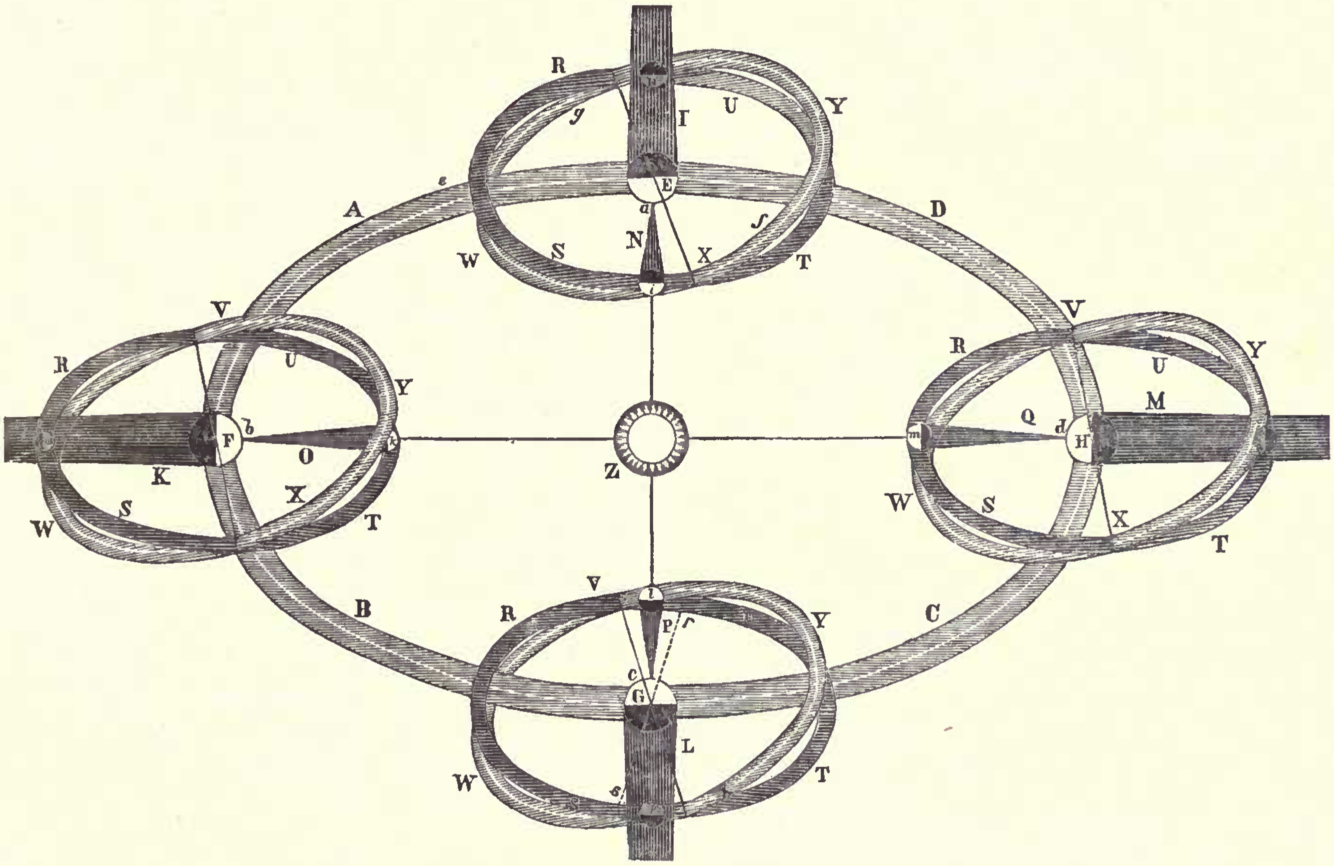
If the earth and sun were equally large, the earth's shadow would be infinitely extended, and all the way of the same size; and the planet Mars, in either of its nodes and opposite to the sun, would be eclipsed in the earth's shadow. Were the earth larger than the sun, its shadow would increase in size the farther it extended, and would eclipse the planets Jupiter and Saturn, with all their moons, when they were opposite to the sun. But as Mars in opposition never falls into the earth's shadow, although it is not then above fifty-one millions of miles from the earth, it is plain that the earth is much less than the sun; for otherwise its shadow could not end in a point at so small a distance. If the sun and moon were equally large, the moon's shadow would reach the earth with an equal breadth, and cover a portion of the earth's surface more than two thousand miles broad, even if it fell directly against the earth's centre, as seen from the moon, and much more if it fell obliquely on the earth. But the moon's shadow is seldom one hundred and fifty miles broad at the earth, unless when it falls very obliquely on the earth, in total eclipses of the sun. In annular eclipses, the moon's real shadow ends in a point at some distance from the earth. The moon's small distance from the earth, and the shortness of its shadow, prove it to be less than the sun. And, as the earth's shadow would be large enough to cover the moon, even if the moon's diameter was three times as large as it is, it is plain that the earth is much larger than the moon.

Though all opaque bodies on which the sun shines have their shadows, yet such is the bulk of the sun, and the distances of the planets, that the primary planets can never eclipse one another. A primary can eclipse only its secondary, or be eclipsed by it.

For the sake of greater clearness, we have hitherto spoken of the moon's orbit as if it were coincident with the plane of the ecliptic, in which the earth always moves, and the sun appears to move. In this case, the moon's shadow would fall upon the earth at every change, and eclipse the sun to some parts of the earth. In like manner, the moon would go through the middle of the earth's shadow, and be eclipsed, at every full; but with this difference, that the moon would be totally darkened for above an hour and a half, whereas the sun never was more than eight minutes totally eclipsed by the interposition of the moon. But one half of the moon's orbit is elevated five and one seventh degrees above the ecliptic, and the other half as much depressed below it; consequently, the moon's orbit intersects the ecliptic in two opposite points, called the moon's nodes, as has been already noticed. When these points are in a right line with the centre of the sun at new or full moon, the sun, moon, and earth are all in a right line; and if the moon be then new, its shadow falls upon the earth —if full, the earth's shadow falls upon the moon. When the sun and moon are more than seventeen degrees from either of the nodes at the time of conjunction, the moon is then generally too high or too low in its orbit to cast any part of its shadow on the earth; and when the sun is more than twelve degrees from either of the nodes at the time of full moon, the moon is generally too high or too low in its orbit to go through any part of the earth's shadow; and in both these cases there will be no eclipse. But when the moon is less than seventeen degrees from either node at the time of conjunction, its shadow or penumbra falls more or less upon the earth as it is more or less within this limit; and when it is less than twelve degrees from either node at the time of opposition, it goes through a greater or less portion of the earth's shadow as it is more or less within this limit. Its orbit contains three hundred and sixty degrees, of which seventeen (the limit of solar eclipses on either side of the nodes) and twelve (the limit of lunar eclipses) are but small portions; and as the sun commonly passes by the nodes but twice in a year, it is no wonder that we have so many new and full moons without eclipses.

To illustrate this, let A B C D be the *ecliptic*, R S T U a circle lying in the same plane with the ecliptic, and V W X Y the *moon's orbit*, all thrown into an oblique view, which gives them an elliptical shape to the eye. One half of the moon's orbit, at V W X, is always below the ecliptic, and the other half X Y V above it. The points V and X, where the moon's orbit intersects the circle R S T U, which lies even with the ecliptic, are the *moon's nodes;* and a right line, as X E V, drawn from one to the other through the earth's centre, is the *line of the nodes*, which is carried almost parallel to itself round the sun in a year.

If the moon moved round the earth in the orbit R S T U, which is coincident with the plane of the ecliptic, its shadow would fall upon the earth every time it is in conjunction with the sun, and at every opposition it would go through the earth's shadow. Were this the case, the sun would be eclipsed at every change, and the moon at every full, as already mentioned.

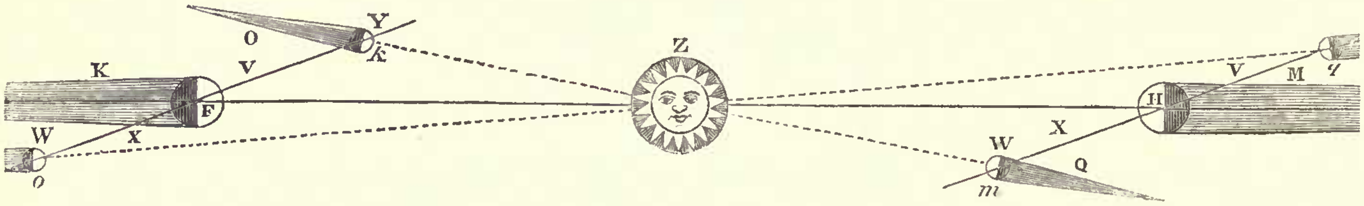


But although the moon's shadow N must fall upon the earth at *a* when the earth is at E and the moon in conjunction with the sun at *i*, because it is then very near one of the nodes, and at opposition *n* must go through the earth's shadow I, because it is then near the other node, yet, in the time that it goes round the earth to the next change according to the order of the letters X Y V W, the earth advances from E to *e* according to the order of the letters E F G H, and the line of the nodes V E X, being carried nearly parallel to itself, brings the point *f* of the moon's orbit in conjunction with the sun at that next change, and then the moon, being at *f*, is too high above the ecliptic to cast a shadow on the earth; and as the earth is still moving forward, the moon at the next opposition will be at *g*, too far below the ecliptic to go through any part of the earth's shadow, for by that time the point *g* will be at a considerable distance from the earth as seen from the sun.

When the earth comes to F, the moon in conjunction with the sun Z is not at *k*, in a plane coincident with the ecliptic, but above it at Y in the highest part of the orbit, and then the point *b* of the shadow O goes far above the earth. The moon at the next opposition is not at *o* but at W, where the earth's shadow goes far above her. In both these cases the line of the nodes V F X is about ninety degrees from the sun, and both luminaries are as far as possible from the limits of eclipses.

When the earth has gone half round the ecliptic from E to G, the line of the nodes V G X is nearly, if not exactly, directed towards the sun at Z; and then the new moon *l* casts its shadow P on the earth G, and the full moon *p* goes through the earth's shadow L, which brings on an eclipse again, as when the earth was at E.

When the earth comes to H, the new moon does not happen at *m* in a plane coincident with the ecliptic C D, but at W below it, and then the shadow Q goes far below the earth. At the next full, the moon is not at *q* but at Y, five and one seventh degrees above *q*, and at its greatest height above the ecliptic C D, being then as far as possible, at any opposition, from the earth's shadow M.*



If the line of the nodes, like the earth's axis, was carried parallel to itself round the sun, there would be just half a year between the conjunctions of the sun and nodes. But the nodes shift backward, or contrary to the earth's annual motion, nineteen and one third degrees every year, and, therefore, the same node comes round to the sun nineteen days sooner every year than on the year before. Consequently, from the time that the ascending node passes by the sun as seen from the earth, it is only one hundred and seventy-three days (not half a year) till the descending node passes by him. Therefore, in whatever time of the year we have eclipses of the luminaries about either node, we may be sure that in one hundred and seventy-three days afterward we shall have eclipses about the other node.

It is particularly to be noted that eclipses which have happened many centuries ago, will not be found by our present tables to agree exactly with ancient observations, by reason of the great anomalies in the lunar motions.

We are credibly informed, from the testimony of the ancients, that there was a total eclipse of the sun predicted by Thales to happen, in the fourth year of the 48th Olympiad, either at Sardis or Miletus, in Asia, where Thales then resided. That year corresponds to the 585th year before Christ; when, accordingly, there happened a very signal eclipse of the sun, on the 28th of May, answering to the present 10th of that month, central through North America, the south parts of France, Italy, &c., as far as Athens, or the isles in the Ægean sea, which is the farthest that even the Caroline Tables carry it, and consequently make it invisible to any part of Asia in the total character, though we have good reason to believe that it extended to Babylon, and went down central over that city. We are not, however, to imagine that it was set before it past Sardis and the Asiatic towns, where the predictor lived, because an invisible eclipse could have been of no service to demonstrate his ability in astronomical sciences to his countrymen, as it could give no proof of its reality.

Thucydides relates that a solar eclipse happened on a summer's day, in the afternoon, in the first year of the Peloponnesian war, so great that the

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* In some parts of the explanation the two preceding plates are referred to in connection, the latter being an edge view of the former.

stars appeared. Rhodius was victor in the Olympic games the fourth year of the said war, being also the fourth of the 87th Olympiad; so that the eclipse must have happened in the 431st year before Christ. And by computation it appears that on the 3d of August there was a signal eclipse which would have past over Athens, central about six in the evening, but which our present tables bring no farther than the ancient Syrtes, on the African coast, above four hundred miles from Athens, which, suffering in that case but nine digits, could by no means exhibit the remarkable darkness recited by this historian. The centre, therefore, seems to have past Athens about six in the evening, and probably might go down about Jerusalem, or near it, contrary to the construction of the present tables.

There are two ancient eclipses of the moon recorded by Ptolemy from Hipparchus. The first of these was observed at Babylon, December 22d, in the year before Christ 383, when the moon began to be eclipsed about half an hour before the sun rose, and the eclipse was not over before the moon set; but by most of our astronomical tables the moon was set at Babylon half an hour before the eclipse began, in which case there could have been no possibility of observing it. The second eclipse was observed at Alexandria, September 22d, the year before Christ 201, where the moon rose so much eclipsed that the eclipse must have begun about half an hour before she rose; whereas, by most of our tables, the beginning of this eclipse was not till about ten minutes after the moon rose at Alexandria. Had these eclipses begun and ended while the sun was below the horizon, we might have imagined, that, as the ancients had no certain way of measuring time, they might have been so far mistaken in the hours that we could not have laid any stress on the accounts given by them. But as in the first eclipse the moon was set, and consequently the sun risen, before it was over—and in the second eclipse the sun was set, and the moon not risen, till some time after it began,—these are such circumstances as the observers could not possibly be mistaken in.

Many other remarkable eclipses are spoken of by the ancients, and if their relations could be depended on they would be of great use in chronology. Dionysius, of Halicarnassus, mentions two total eclipses of the sun, that happened, one at the birth of Romulus, and the other at his death; in each of which the obscurity was as great as in the darkest night. But this account, like that of the prodigies which were seen at the time of Cæsar's death, deserves very little credit. In ancient times, every great event was said to have been accompanied by comets or other portentous appearances; and eclipses of the sun, in particular, were always regarded as calamitous omens, presaging the death of kings or some illustrious character. This superstition is frequently alluded to by the poets. Milton says that the sun

> "From behind the moon,
> In dim eclipse, disastrous twilight sheds
> On half the nations, and with fear of change
> Perplexes monarchs."

In China, where astronomy is made subservient to the interest of the state, they have particular ceremonies appropriated to those days on which eclipses are to take place, and both the prince and the people are scrupulously exact in their observance. The chief of the "tribunal of mathematics" is there a grand but a dangerous appointment, for under the reign of one of their monarchs the two principal astronomers were condemned to death on account of their negligence in omitting to announce the precise time of an eclipse.

A total eclipse of the sun is an extraordinary spectacle. Clavius, who observed that which happened at Coimbra, in Portugal, on the 21st of August, 1560, informs us that the obscurity was greater, or at least more striking and sensible, than that of the night. "It was so dark, for a short time, that he could scarcely see his hand," some of the stars made their appearance for two or three minutes, and the birds were so terrified that they fell to the ground. On May 12th, 1706, a total eclipse of the sun was observed at Geneva. Though the sky was somewhat overcast, the heat of the sun was already felt when the eclipse began. But quite a sensible coldness took place, and the light evidently decreased as the moon gradually covered a greater and greater part of the sun. When that body was nearly covered, the bright crescent was visible until it became very narrow, when it disappeared instantaneously, and, in a twinkling, the eclipse was total. The darkness, which was already considerable, became much greater. The clouds suddenly changed color, first becoming red and then a pale violet. During the whole time of the total immersion, a whiteness was seen, which seemed to break out from behind the moon, and to encompass it equally on all sides, in breadth less than a twelfth part of the moon's diameter. This secondary appeared very black, and its disc very well defined within the whiteness. Venus was visible in a north-easterly direction from the sun. Saturn and Mercury were also seen, by many persons, eastward of the sun. If the sky had been clear, Jupiter and Mars, and many more of the heavenly bodies, would have been visible. And, indeed, some one in the country counted more than sixteen stars. To those who were on high land, the sky, where it was not overcast, seemed in all respects like the nocturnal sphere during full moon. The total immersion began about three quarters after nine. The duration of total darkness was three minutes, when the first ray shot forth with much splendor. A little after the sun began to appear, the whiteness mentioned above entirely vanished. Just before the total obscuration, the country to the west of the observer already appeared overcast with darkness; and, after the total obscuration was past, he perceived the country to the east in like manner darkened. An observer of the same eclipse at Berne, stated that the sun was totally darkened for four and a half minutes, and that its immersion was preceded by a blood-red streak of light from its left limb, which continued about seven seconds, and then, all of a sudden, a part of the sun's disc appeared brighter than Venus was ever seen in the night, and in that very instant gave a light and a shadow to objects as strong as ever moonlight does.

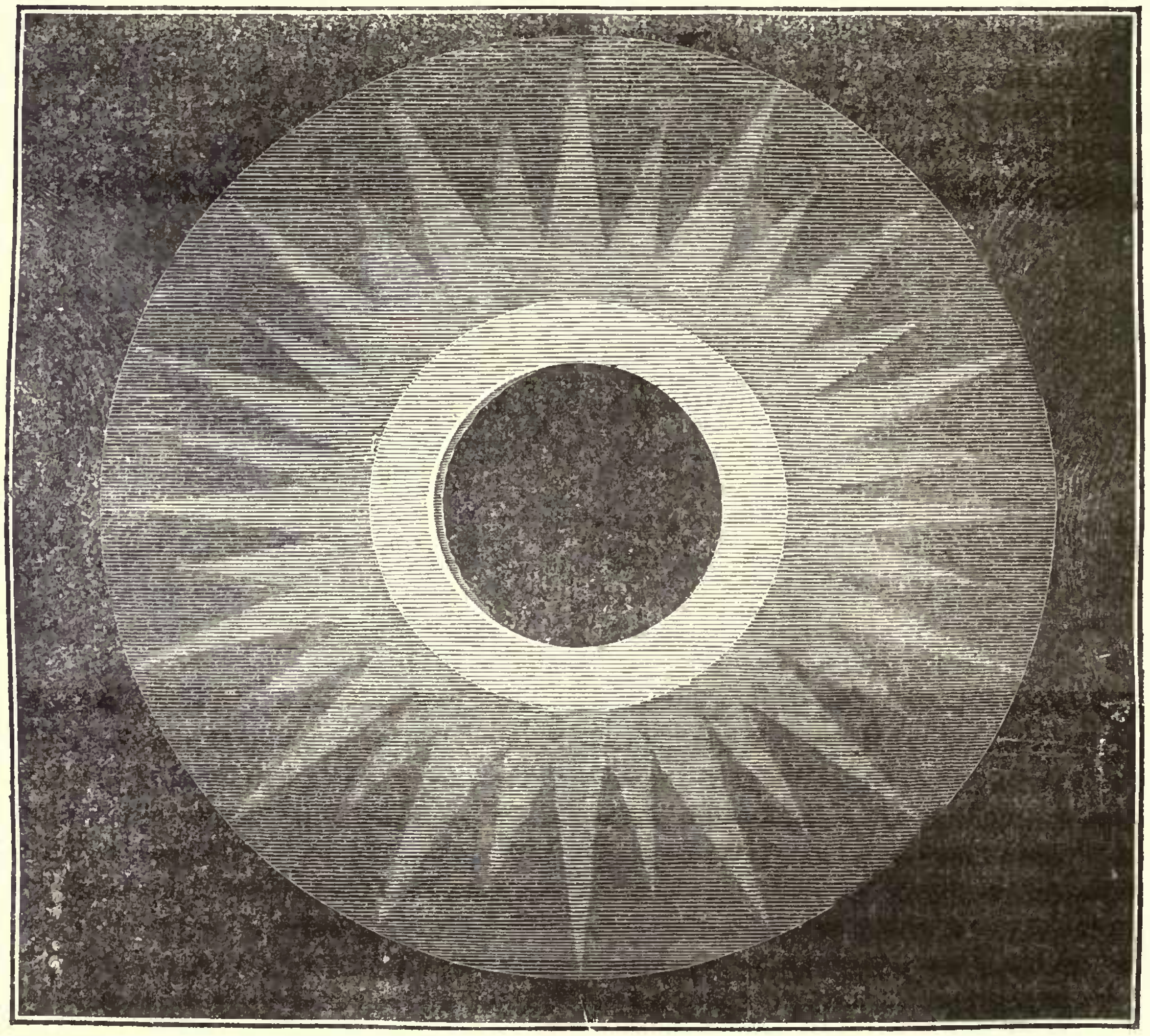
In 1715, April 22d, Halley, having found, by comparing what had been before observed of solar eclipses, that the whole shadow would fall upon England, thought it a good opportunity to have the dimensions of the shadow ascertained from observation. He therefore caused maps containing the calculated limits of the eclipse to be distributed in the different towns, with a request that the phenomena attending it might be observed.

His own observations were made at London. The eclipse there began at six minutes after eight. From that moment, the eclipse advancing was about ten digits at nine o'clock, when the face and color of the sky gradually changed from a perfectly serene azure to a dusky livid color, with a slight tinge of purple intermixed, and grew darker and darker till the total immersion, which happened at nine minutes after nine o'clock. It was universally observed that when the last part of the sun (the east side) remained alone visible, it grew very dim, and was easily supportable by the unshaded eye, even through the telescope, for more than a minute preceding the total darkness. But the eye could not endure the splendor of the emerging beams from the first moment in the telescope. To this, perhaps, two causes concurred. One, that the pupil of the eye had dilated during the darkness; the other, that the eastern part of the moon, having been heated by the long-continued action of the sun, would have an atmosphere replete with vapors, while the western limb had endured as long a night, during which all the vapors would have fallen in dews, and its atmosphere would be pure and transparent. A few seconds after the sun was totally covered, there was visible round the moon a luminous ring, in breadth about a tenth part of the moon's diameter. It was of a pale white or rather pearl color, seeming a little tinged with the colors of the iris, and concentric with the moon. Whatever was its cause, this ring appeared much brighter and whiter near the body of the moon than at a distance from it, and its external circumference, which was ill defined, seemed terminated only by the extreme rarity of the matter of which it was composed, and in all respects resembled in appearance an enlightened atmosphere viewed from a distance. About two or three seconds before the emersion, on the western side of the moon, where the sun was about to appear, Halley observed a long and very narrow streak of a dusky, but strong red light, seeming to color the dark edge of the moon. But this instantly vanished, as well as the white ring, on the first appearance of the sun.

The degree of darkness was not very great. It was such, however, that Venus, Jupiter, and Mercury became visible, and, among the fixed stars, Aldebaran and Capella. The darkness was more perfect in those places that were near the centre of the shadow, in some of which more than twenty stars became visible. At London, the lower parts of the hemisphere, particularly in the southeast, under the sun, had a crepuscular brightness, and all around so much of the atmosphere as was above the horizon and without the cone of the moon's shadow was more or less enlightened by the sun's beams, and its reflection gave a diffused light, which made the air seem hazy, and prevented the appearance of the stars.

Total eclipses, however, happen but seldom at any particular place, and annular eclipses are equally uncommon. There was a remarkable annular eclipse visible in Europe, in April, 1764. Total eclipses are so rare, that Halley, in his account of the above eclipse, observes "that although twenty-eight eclipses of the sun happen in eighteen years, and of these eight pass over the parallel of London, yet from 1140 to 1715 no total eclipse of the sun had been seen in that metropolis." It may be added that in annular eclipses, as well as in all those that are not total, the degree of darkness that takes place is not so considerable as persons are apt to imagine. Maclaurin, in his account of the annular eclipse which happened at Edinburg in 1737, states that during the appearance of the ring daylight was not greatly obscured, appearing only as much dimmer than usual as it does during a gentle mist in an April morning. And Le Monnier, who went from France to England on purpose to observe the annular eclipse which happened in 1748, says, that, during the middle of the eclipse, he could perceive nothing on the sun, when he looked at it with his naked eyes, but saw it full, though faint in its light.

June 16th 1806, a total eclipse of the sun was observed in various parts of this country. The following is by an observer stationed at Kinderhook, state of New York. First interior contact, or total obscurity, took place at ten hours fifty-five minutes and fifty-eight seconds, at the distance of fifty degrees from the right superior vertex. Four or five seconds before the total obscurity, the remainder of the sun's disc was reduced to a very short line, interrupted in many places. The darkened glass with which this phenomenon was observed, was sufficiently clear to distinguish terrestrial objects. After this observation, the colored glass was laid aside in order to observe the end of total darkness. The moon was closely observed during two minutes without the appearance of a single luminous point in its disc. But the disc had round it a ring or illuminated atmosphere, which was of a pearl color, and projected six minutes from the limb. The diameter of this ring was estimated at forty-five minutes. The darkness was not so great as had been expected, the light being probably greater than that of the full moon. From the extremity of the ring, many luminous rays were projected to more than three degrees' distance. The lunar disc was ill-defined, and very dark, forming a contrast with the luminous ring. With a telescope, some appearances like very slender columns of smoke were distinguished issuing from the western part of the moon. During the whole eclipse the sky was very clear, not a single cloud being visible, and there was scarcely any wind. The sun was without a spot. A little dew fell during the darkness. Five or six principal stars and planets were visible. The plate accompanying represents the total eclipse. The luminous ring round the moon is exactly as it appeared in the middle of the eclipse. The illumination which is seen in the lunar disc preceded the appearance of the first rays of the sun by about seven seconds. Two minutes before the emersion the observer fixed his eye on the point whence it was to proceed, and, as the field of his telescope did not embrace more than a third part of the disc, he could not observe whether the circumference of the ring was diminished on the opposite side. In the part where the emersion took place, the ring was illuminated by degrees, and the atmosphere was more dense and brilliant near the edge of the moon. A little before the illumination of the lunar disc, a zone was observed to issue, concentric with the sun, and similar in appearance to a cloud illuminated by the sun's rays. It is represented in the plate. But in order to have a proper conception of what is intended to be represented, we must transfer our ideas to the heavens, and imagine, at the departure of the last ray of the sun in its retreat behind the moon, an awful gloom immediately diffused over the face of nature, and round a dark circle near the zenith an immense radiated *glory*, like a new creation, in a moment bursting on the sight, and for several minutes fixing the gaze of man in silent amazement.



An English paper gives the following description of the appearance of the sun and moon during the annular eclipse of those luminaries, on May 15, 1836 :—

A singularly beautiful appearance was exhibited by the telescopes at the instant of the completion of the ring. The two horns or points of the uneclipsed part of the sun had been gradually approaching each other till their distance had become small. Instead, however, of continuing to make this gradual approach, there seemed to issue from each great numbers of beads of light, resembling drops of quick-silver, or a line of electric sparks, and in an instant the ring was completed. This seems obviously to establish, what appears on other considerations to be very likely, that the limbs of the sun and moon are not the fine and perfectly regular curves that they appear to be, but that they are full of numerous minute inequalities. The appearance of the ring was peculiarly striking and beautiful. The sun's whole central parts were blotted out, and all that remained of his magnificent orb was a small but brilliant rim of light.

Murray, a well-known scientific lecturer, furnishes some further interesting particulars connected with this phenomenon:—

During the period of the eclipse, insect life was still and motionless. The birds of the air flew near the ground, and there was a peculiar solemnity in the silence that reigned around, unbroken save by the song of the lark which rose at intervals. Even the "attic warbler," was still, however, during the greatest obscuration. At the close of the eclipse, numerous insects appeared, and the lark soared higher with its welcome note. The atmosphere had been almost free from clouds; but floating cumuli collected and condensed, and toward the close of the eclipse had rallied, as if in sympathy, round the standard of the sun. The diminution of light was by no means so great as many had expected. No stars were visible. Venus, perhaps, might have been seen, save that clouds intercepted her path. The light during the greatest obscuration of the sun was quite peculiar. Nature assumed a lurid aspect, and the sea, too, had a livery different from its usual tone of color. It was not a twilight hue: it was "itself alone"—such as I have seen in looking through a Claude-Lorraine glass. The prophet's language describes it: "The light was neither clear nor dark." "It was not day nor night." During the solar eclipse of 1820, I was among the serpentine rocks near Portsoy, Scotland; and the diminution of light on that occasion seemed greater than in the present instance.

In any year, the number of eclipses of both luminaries cannot be less than two, nor more than seven. The most usual number is four, and it is very rare to have more than six. For the sun passes by both the nodes but once a year, unless he passes by one of them in the beginning of the year; and if he does, he will pass by the same node again a little before the year be finished; because, as these points move nineteen and one third degrees backward every year, the sun will come to either of them one hundred and seventy days after the other; and when either node is within seventeen degrees of the sun at the time of new moon, the sun will be eclipsed. At the subsequent opposition, the moon will be eclipsed in the other node, and come round to the next conjunction again ere the former node be seventeen degrees past the sun, and will therefore eclipse him again. When three eclipses fall about either node, the like number generally fall about the opposite, as the sun comes to it in one hundred and seventy-three days afterward; and six lunations contain but four days more. Thus there may be two eclipses of the sun, and one of the moon, about each of her nodes. But when the moon changes in either of the nodes, she cannot be near enough to the other node at the next full to be eclipsed; and in six lunar months afterward she will change near the other node. In these cases there can be but two eclipses in a year, and they are both of the sun.

A longer period for comparing and examining eclipses which happen at intervals of time, is five hundred and fifty-seven years twenty-one days eighteen hours thirty minutes eleven seconds, in which time there are six thousand eight hundred and ninety mean lunations, and the sun and node meet again so nearly as to be but eleven seconds distant; but then it is not the same eclipse that returns, as in the shorter period above mentioned.

Before the cause of eclipses was explained to the world at large, and shown to be a natural and necessary phenomenon, astrologers and crafty men took advantage of the terror they inspired to keep the multitude in slavish subjection to their will. Treatises were written to show against what regions the malevolent effects of any particular eclipse was aimed; and the writers affirmed that the effects of an eclipse of the sun continued as many years as the eclipse lasted hours, and that of the moon as many months.

Such idle notions were once of no small advantage to Christopher Columbus, who, in the year 1493, was driven on the Island of Jamaica, where he was in the greatest distress for want of provisions, and was moreover refused any assistance from the inhabitants; on which he threatened them with a plague, and told them, that, in token of it, there should be an eclipse, which accordingly happened on the day he had foretold, and so terrified the barbarians that they strove who should be first in bringing him all sorts of provisions, throwing them at his feet, and imploring his forgiveness.

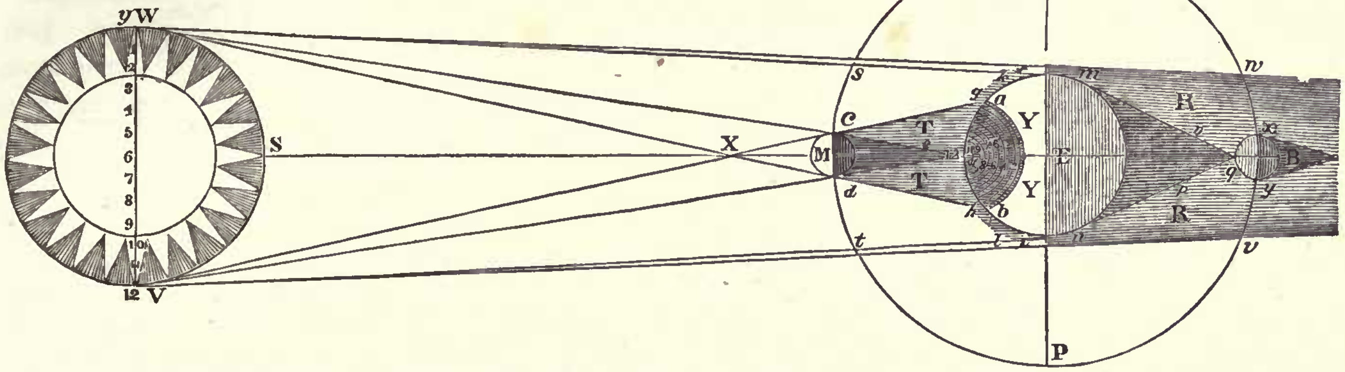
Eclipses of the sun are more frequent than those of the moon, because the sun's ecliptic limits are greater than the moon's; yet we have more visible eclipses of the moon than of the sun, because eclipses of the moon are seen from all parts of that hemisphere of the earth which is next her, and are equally great to each of those parts; but the sun's eclipses are visible only to that small portion of the hemisphere next him whereon the moon's shadow falls.

The moon's orbit being elliptical, and the earth in one of its foci, it is once at its least distance from the earth, and once at its greatest, in every lunation. When the moon changes at its least distance from the earth, and so near the node that its dark shadow falls upon the earth, it appears large enough to cover the whole disc of the sun from that part on which her shadow falls, and the sun appears totally eclipsed there for some minutes. But when the moon changes at its greatest distance from the earth, and so near the node that the dark shadow is directed towards the earth, its diameter subtends a less angle than the sun's, and therefore it cannot hide the whole disc from any part of the earth, nor does the shadow reach it at that time; and to the place over which the point of the shadow hangs the eclipse is annular, the sun's edge appearing like a luminous ring all around the body of the moon. When the change happens within seventeen degrees of the node, and the moon at her mean distance from the earth, the point of the shadow just touches the earth, and eclipses the sun totally to that small spot whereon the shadow falls; but the darkness is not of a moment's continuance.

The moon's apparent diameter when largest exceeds the sun's when least only one minute and thirty-eight seconds of a degree; and in the greatest eclipse of the sun that can happen at any time and place, the total darkness continues no longer than whilst the moon is going one minute and thirty-eight seconds from the sun in her orbit, which is about three minutes and thirteen seconds.

The moon's dark shadow covers only a spot on the earth's surface about one hundred and eighty miles broad when the moon's diameter appears largest and the sun's least, and the total darkness can extend no farther than the dark shadow covers. Yet the moon's partial shadow or penumbra may then cover a circular space four thousand and nine hundred miles in diameter, within all which the sun is more or less eclipsed as the places are less or more distant from the centre of the penumbra. When the moon changes exactly in the node, the penumbra is circular on the earth at the middle of the general eclipse, because at that time it falls perpendicularly on the earth's surface; but at every other moment it falls obliquely, and will therefore be elliptical, and the more so as the time is longer before or after the middle of the general eclipse, and then much greater portions of the earth's surface are involved in the penumbra.

When the penumbra first touches the earth, the general eclipse begins: when it leaves the earth, the general eclipse ends: from the beginning to the end the sun appears eclipsed to some portion of the earth. When the penumbra touches any place, the eclipse begins at that place, and ends when the penumbra leaves it. When the moon changes in the node, the penumbra goes over the centre of the earth's disc, as seen from the moon, and consequently, by describing the longest line possible on the earth, continues the longest upon it, namely, (at a mean rate,) five hours and fifty minutes—more, if the moon be at her greatest distance from the earth, because she then moves slowest; less, if she be at her least distance, because of her quicker motion.



To make these and several other phenomena plainer, let S be the sun, E the earth, M the moon, and A M P the moon's orbit. Draw the right line W *c* 12 from the western side of the sun at W, touching the western side of the moon at *c*, and the earth at 12. Draw also the right line V *d* 12 from the eastern side of the sun at V, touching the eastern side of the moon at *d*, and the earth at 12. The dark space *c e* 12 *d* included between those lines is the moon's shadow ending in a point at 12, where it touches the earth, because in this case the moon is supposed to change at M, in the middle between A the apogee, or farthest point of her orbit from the earth, and P the perigee, or nearest point to it. For had the point P been at M, the moon had been nearer the earth, and her dark shadow at *e* would have covered a space upon it about one hundred and eighty miles broad, and the sun would have been totally darkened for some time; but had the point A been at M, the moon would have been farther from the earth, and her shadow would have ended in a point about *e*, and, therefore, the sun would have appeared like a luminous ring all around the moon. Draw the right lines W X *d b* and V X *c g*, touching the contrary sides of the sun and moon, and ending on the earth at *a* and *b;* draw also the right line S X M 12 from the centre of the sun's disc, through the moon's centre, to the earth at 12; and suppose the two former lines W X *d b* and V X *c g* to revolve on the line S X M 12 as an axis, and their points *a* and *b* will describe the limits of the penumbra T T on the earth's surface, including the large space *a o b* 12 *a*, within which the sun appears more or less eclipsed as the places are more or less distant from the verge of the penumbra *a o b*.

Draw the right line *y* 12 across the sun's disc perpendicular to S X M, the axis of the penumbra; then divide the line *y* 12 into twelve equal parts, as in the figure, for the twelve digits * of the sun's diameter, and, at equal distances from the centre of the penumbra at 12 (on the earth's surface Y Y) to its edge *a o b*, draw twelve concentric circles, as marked with the numeral figures 1 2 3 4, &c., and remember that the moon's motion in her orbit A M P is from west to east, as from *s* to *t*. Then, to an observer on the earth at *b*, the eastern limb of the moon at *d* seems to touch the western limb of the sun at W when the moon is at M, and the sun's eclipse begins at *b*, appearing as at A, (next figure ;) but, at the same moment of absolute time to an observer at *a*, in the previous figure, the western edge of the moon at *c* leaves the eastern edge of the sun at V, and the eclipse ends, as at the right hand C of the next figure. At the very same instant, to all those who live on the circle marked 1 on the earth E in the last figure, the moon M cuts off or darkens a twelfth part of the sun S, and eclipses him one digit, as at 1 in the next figure; to those who live on the circle marked 2 in the last figure, the moon cuts off two twelfth parts of the

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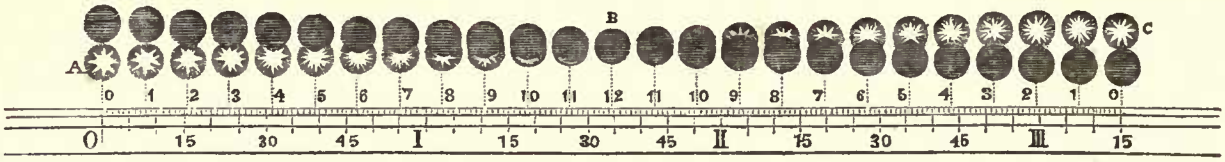
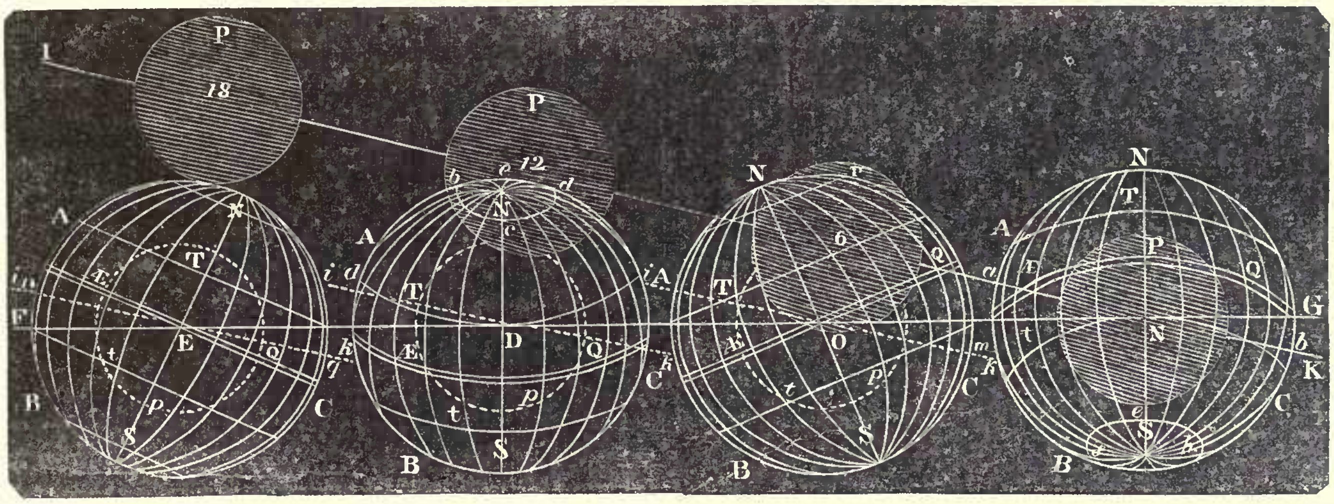
* A digit is a twelfth part of the diameter of the sun or moon.

sun, as at 2 in the next figure; to those on the circle 3, three parts; and so on to the centre at 12, where the sun is centrally eclipsed, as at B in the middle of the next figure, under which there is a scale of hours and minutes to show, at a mean state, how long it is from the beginning to the end of a central eclipse of the sun, and how many digits are eclipsed at any particular time from the beginning at A to the middle at B, or the end at C. Thus, in sixteen minutes from the beginning, the sun is two digits eclipsed; in an hour and five minutes, eight digits; and in an hour and thirty-seven minutes, twelve digits.



By the last figure but one, it is plain that the sun is totally or centrally eclipsed but to a small part of the earth at any time, because the dark conical shadow *e* of the moon M falls but on a small part of the earth, and that the partial eclipse is confined at that time to the space included by the circle *a o b*, of which only one half can be projected in the figure, the other half being supposed to be hid by the convexity of the earth E; and, likewise, that no part of the sun is eclipsed to the large space Y Y of the earth, because the moon is not between the sun and any of that part of the earth, and therefore to all that part the eclipse is invisible. The earth turns eastward on its axis, as from *g* to *b*, which is the same way that the moon's shadow moves; but the moon's motion is much swifter in her orbit from *s* to *t*, and, therefore, although eclipses of the sun are of longer duration on account of the earth's motion on its axis than they would be if that motion ceased, yet, in four minutes of time at most the moon's swifter motion carries her dark shadow quite over any place that its centre touches at the time of greatest obscuration. The motion of the shadow on the earth's disc is equal to the moon's motion from the sun, which is about thirty and a half minutes of a degree every hour, at a mean rate; but so much of the moon's orbit is equal to thirty and a half degrees of a great circle on the earth, and therefore the moon's shadow goes thirty and a half degrees, or eighteen hundred and thirty geographical miles, on the earth in an hour, or thirty and a half miles in a minute, which is nearly four times as swift as the motion of a cannon-ball.

As seen from the sun or moon, the earth's axis appears differently inclined every day of the year, on account of keeping its parallelism throughout its annual course. Let E, D, O, N (next figure) be the earth at the two equinoxes and the two solstices, N S its axis, N the north pole, S the south pole, Æ Q the equator, T the tropic of cancer, *t* the tropic of capricorn, and A B C the circumference of the earth's enlightened disc as seen from the sun or new moon at these times. The earth's axis has the position N E S at the vernal equinox, lying towards the right hand, as seen from the sun or new moon, its poles N and S being then in the circumference of the disc, and the equator and all its parallels seem to be straight lines, because their planes pass through the eye of an observer looking down on the earth from the sun or moon directly over E, where the ecliptic F G intersects the equator Æ. At the summer solstice, the earth's axis has the position N D S, and that part of the ecliptic F G, in which the moon is then new, touches the tropic of cancer T at D. The north pole N, at that time inclining twenty-three and a half degrees towards the sun, falls so many degrees within the earth's enlightened disc, because the sun is then vertical to D twenty-three and a half degrees north of the equator Æ Q; and the equator and all its parallels seem elliptic curves bending downward, or towards the south pole, as seen from the sun, which pole, together with twenty-three and a half degrees all around it is behind the disc in the dark hemisphere of the earth. At the autumnal equinox, the earth's axis has the position N O S, lying to the left hand, as seen from the sun or new moon, which are then vertical to O, where the ecliptic cuts the equator, Æ Q. Both poles now lie in the circumference of the disc, the north pole just going to disappear behind it, and the south pole just entering into it, and the equator and all its parallels seem to be straight lines, because their planes pass through the observer's eye, as seen from the sun, and very nearly so as seen from the moon. At the winter solstice, the earth's axis has the position N N S, when its south pole S, inclining twenty-three and a half degrees toward the sun, falls twenty-three and a half degrees within the enlightened disc, as seen from the sun or new moon, which are then vertical to the tropic of capricorn *t* twenty-three and a half degrees south of the equator Æ Q, and the equator and all its parallels seem elliptic curves bending upward, the north pole being as far behind the disc in the dark hemisphere, as the south pole has advanced into the light. The nearer any time of the year is to the equinoxes or solstices, the more does it partake of the phenomena relating to them.



Thus it appears that from the vernal equinox to the autumnal, the north pole is enlightened, and the equator and all its parallels appear elliptical, as seen from the sun, more or less curved as the time is nearer to or farther from the summer solstice, and bending downwards or towards the South pole. The reverse of this happens from the autumnal equinox to the vernal. A little consideration will be sufficient to convince the reader that the earth's axis inclines towards the sun at the summer solstice, from the sun at the winter solstice, and sidewise to the sun at the equinoxes—towards the right hand, as seen from the sun, at the vernal equinox, and towards the left hand at the autumnal. From the winter to the summer solstice, the earth's axis inclines more or less to the right hand, as seen from the sun, and the contrary from the summer to the winter solstice.

The different positions of the earth's axis, as seen from the sun at different times of the year, affect solar eclipses greatly with regard to particular places—so far that they would make central eclipses which fall at one time of the year invisible if they fell at another, even though the moon should always change in the nodes, and at the same hour of the day, of which various affections we shall only give examples for the times of the equinoxes and solstices.

In the above figure let F G be part of the ecliptic, and I K, *i k*, *i k*, *i k*, parts of the moon's orbit, (all seen edgewise, and therefore projected into right lines;) let the intersections N, O, D, E be one and the same node at the above times, when the earth has the above-mentioned different positions; and let the spaces included by the circles, P, *p*, *p*, *p*, be the penumbra at these times, as its centre is passing over the centre of the earth's disc. At the winter solstice, when the earth's axis has the position N N S, the centre of the penumbra P touches the tropic of capricorn *t* in N at the middle of the general eclipse; but no part of the penumbra touches the tropic of cancer T. At the summer solstice, when the earth's axis has the position N D S, (*i* D *k* being then part of the moon's orbit, whose node is at D,) the penumbra *p* has its centre at D, on the tropic of cancer T, at the middle of the general eclipse, and then no part of it touches the tropic of capricorn *t*. At the autumnal equinox, the earth's axis has the position N O S, (*i* O *k* being then part of the moon's orbit,) and the penumbra equally includes parts of both tropics T and *t* at the middle of the general eclipse. At the vernal equinox it does the same, because the earth's axis has the position N E S. But, in the former of these two last cases, the penumbra enters the earth at A, north of the tropic of cancer T, and leaves it at *m*, south of the tropic of capricorn *t*, having gone over the earth obliquely southward, as its centre described the line A O *m;* whereas, in the latter case, the penumbra touches the earth at *n*, south of the equator Æ Q, and, describing the line *n* E *q*, (similar to the former line A O *m* in open space,) goes obliquely northward over the earth, and leaves it at *q*, north of the equator.

In all these circumstances, the moon has been supposed to change at noon in her descending node. Had she changed in her ascending node, the phenomena would have been as various the contrary way, with respect to the penumbra's going northward or southward over the earth. But because the moon changes at all hours, as often in one node as in the other, and at all distances from them both at different times, the variety of the phases of eclipses are almost innumerable, even at the same places. We mnst consider, also, how variously the same places are situated on the enlightened disc of the earth, with respect to the penumbra's motion, at the different hours when eclipses happen.

When the moon changes seventeen degrees short of her descending node, the penumbra P 18 just touches the northern part of the earth's disc, near the north pole N, and, as seen from that place, the moon appears to touch the sun, but hides no part of him from sight. Had the change been as far short of the ascending node, the penumbra would have touched the southern part of the disc near the south pole S. When the moon changes twelve degrees short of the descending node, more than a third part of the penumbra P 12 falls on the northern parts of the earth at the middle of the general eclipse. Had she changed as far past the same node, as much of the other side of the penumbra about P would have fallen on the southern part of the earth, and all the rest in open space. When the moon changes six degrees from the node, almost the whole penumbra P 6 falls on the earth at the middle of the general eclipse. And, lastly, when the moon changes in the node at N, the penumbra P N takes the longest course possible on the earth's disc, its centre falling on the middle thereof at the middle of the general eclipse. The farther the moon changes from either node, (within seventeen degrees of it,) the shorter is the penumbra's continuance on the earth, because it goes over a less portion of the disc, as is evident by the figure.

The nearer the penumbra's centre is to the equator at the middle of the general eclipse, the longer is the duration of the eclipse at all those places where it is central, because, the nearer any place is to the equator the greater is the circle it describes by the earth's motion on its axis, and thus the place, moving quicker, keeps longer in the penumbra, whose motion is the same way with that of the place, though faster, as has been already mentioned. Thus (see the earth at D, and the penumbra at 12,) whilst the point *b* in the polar circle *a b c d* is carried from *b* to *c* by the earth's diurnal motion, the point *d* on the tropic of cancer T is carried a much greater length from *d* to D; and, therefore, if the penumbra's centre goes one time over *c* and another time over D, the penumbra will be longer in passing over the moving place *d* than it was in passing over the moving place *b*. Consequently, central eclipses about the poles are of the shortest duration, and about the equator of the longest.

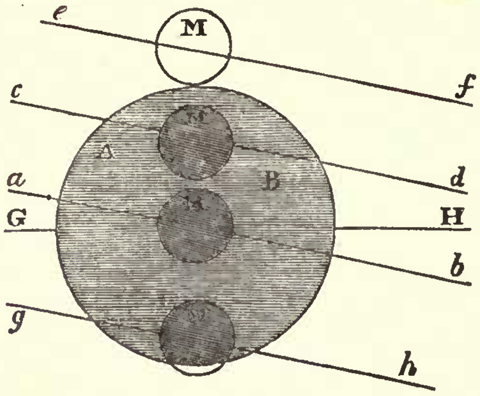
In the middle of summer, the whole frigid zone included by the polar circle *a b c d* is enlightened, and if it then happens that the penumbra's centre goes over the north pole, the sun will be eclipsed nearly the same number of digits at *a* as at *c;* but whilst the penumbra moves eastward over *c*, it moves westward over *a*, (because, with respect to the penumbra, the motions of *a* and *c* are contrary, for *c* moves the same way with the penumbra towards *d*, but *a* moves the contrary way towards *b*,) and, therefore, the eclipse will be of longer duration at *c* than at *a*. At *a* the eclipse begins on the sun's eastern limb, but at *c* on his western. At all places lying without the polar circles, the sun's eclipses begin on his western limb, or near it, and end on or near his eastern. At those places where the penumbra touches the earth, the eclipse begins with the rising sun, on the top of his western or uppermost edge; and at those places where the penumbra leaves the earth, the eclipse ends with the setting sun, on the top of his eastern edge, which is then the uppermost, just at its disappearing in the horizon.

That the moon can never be eclipsed but at the time of its being full, and the reason why it is not eclipsed at every full, has been shown already. In the figure on page 237 let S be the sun, E the earth, R R the earth's shadow, and B the moon in opposition to the sun. In this situation the earth intercepts the sun's light in its way to the moon, and when the moon touches the earth's shadow at *v*, it begins to be eclipsed on the eastern limb *x*, and continues eclipsed until the western limb *y* leaves the shadow at *w*. At B it is in the middle of the shadow, and consequently in the middle of the eclipse.

The moon when totally eclipsed is not invisible if it be above the horizon, and the sky be clear; but it appears generally of a dusky color, like tarnished copper, which some have thought to be the moon's native light. But the cause of its being visible is the scattered beams of the sun, bent into the earth's shadow by going through the atmosphere, which, being more dense near the earth than at considerable heights above it, refracts or bends the sun's rays the more inward the nearer they pass to the earth's surface, than those rays which go through higher parts of the atmosphere, where it is less dense according to its height, until it becomes so thin or rare as to lose its refractive power. Let the circle *f g h i*, concentric to the earth, include the atmosphere whose refractive power vanishes at the heights *f* and *i*, so that the rays W *f w* and V *i v* go on straight without suffering the least refraction. But all those rays which enter the atmosphere between *f* and *k*, and between *i* and *l*, on opposite sides of the earth, are gradually more bent inward as they go through a greater portion of the atmosphere, until the rays W *k* and V *l* touching the earth at *m* and *n* are bent so much as to meet at *q*, a little short of the moon, and therefore the dark shadow of the earth is contained in the space *m o q p n*, where none of the sun's rays can enter. All the rest R R, being entered by the scattered rays which are refracted as above, is in some measure enlightened by these rays, and some of them falling on the moon, give it the color of tarnished copper, or of iron almost red hot. So that if the earth had no atmosphere the moon would be as invisible in total eclipses as it is when new. If the moon were so near the earth as to go into its dark shadow, suppose about *p o*, it would be invisible during its stay in it, but visible before and after in the fainter shadow R R.

When the moon goes through the centre of the earth's shadow, it is directly opposite to the sun; yet the moon has been often seen totally eclipsed in the horizon when the sun was also visible in the opposite part of it, for, the horizontal refraction being almost thirty-four minutes of a degree, and the diameter of the sun and moon being each at a mean state but thirty-two minutes, the refraction causes both luminaries to appear above the horizon when they are really below it.

When the moon is full at twelve degrees from either of its nodes, it just touches the earth's shadow, but does not enter it. Let G H be the ecliptic, *e f* the moon's orbit where it is twelve degrees from the node at its full, *c d* its orbit where it is six degrees from the node, *a b* its orbit where it is full in the node, A B the earth's shadow, and M the moon. When the moon describes the line *e f*, it just touches the shadow, but does not enter into it; when it describes the line *c d*, it is totally, though not centrally, immersed in the shadow; and when it describes the line *a b*, it passes by the node at M in the centre of the shadow, and takes the longest line possible, which is a diameter, through it, and such an eclipse being both total and central is of the longest duration, namely, three hours fifty-seven minutes six seconds from the beginning to the end if the moon be at its greatest distance from the earth, and three hours thirty-seven minutes twenty-six seconds if it be at its least distance. The reason of this difference is, that when the moon is farthest from the earth it moves slowest, and quickest when nearest to it.



The moon's diameter, as well as the sun's, is supposed to be divided into twelve equal parts, called *digits;* and as many of these parts as are darkened by the earth's shadow, so many digits is the moon eclipsed. All the moon is said to be eclipsed above twelve digits, show how far the shadow of the earth is beyond the body of the moon on that edge to which she is nearest at the middle of the eclipse.

It is difficult to observe exactly either the beginning or end of a lunar eclipse, even with a good telescope, because the earth's shadow is so faint, and ill defined about the edges, that, when the moon is either just touching or leaving it, the obscuration of her limb is scarcely sensible, and, therefore, the nicest observers can hardly be certain to four or five seconds of time. But both the beginning and end of solar eclipses are visibly instantaneous, for the moment that the edge of the moon's disc touches the sun's his roundness seems a little broken on that part, and the moment the moon leaves the sun he appears perfectly round again.

In astronomy, eclipses of the moon are of great use for ascertaining the periods of its motions, especially such eclipses as are observed to be alike in all circumstances, and have long intervals of time between them. The longitudes of places are found by eclipses; but for this purpose eclipses of the moon are more useful than those of the sun, because they are more frequently visible, and the same lunar eclipse is of equal extent and duration at all places where it is seen. Both solar and lunar eclipses serve to determine the time of any past event, for there are so many particulars observable in every eclipse, with respect to its quantity, the places where it is visible, (if of the sun,) and the time of the day or night, that it is impossible there can be two solar eclipses in the course of many ages which are alike in all circumstances.

From the above explanation of the doctrine of eclipses, it is evident that the darkness at our Savior's crucifixion was supernatural ; for he suffered on the day on which the passover was eaten by the Jews, on which day it was impossible that the moon's shadow could fall on the earth, as the Jews kept the passover at the time of full moon; nor does the darkness in total eclipses of the sun last above four minutes in any place, whereas the darkness at the crucifixion lasted three hours, and overspread at least all the land of Judea.

Occultations. The moon, in moving through its orbit, will appear to pass over such of the stars as lie in or near its apparent path.

This phenomenon is called an *occultation* of the stars because they are entirely concealed from our view. Now the moon's apparent path through the heavens is constantly changing, owing to the inclination of its orbit to the ecliptic, and the continual motion of the line of the lunar nodes, so that all the stars situated within a certain zone, extending each side of the ecliptic, and of a breadth equal to double the greatest geocentric latitude of the moon, may suffer an occultation. The breadth of this zone on each side of the ecliptic is about thirteen degrees and twelve minutes, and those stars whose latitudes are less than six degrees and thirty-six minutes may suffer an occultation to some portion of the earth.

To find the time when any of the stars situated in the above-mentioned zone will be occulted or eclipsed by the moon, we must find at what time the moon and star will be in conjunction, that is, at what time they will have the same longitude.

If this conjunction happen at a time of the night when the star is visible, or within two hours of it, the occultation (other circumstances agreeing to render it one) will be visible. In order to find if the moon will pass above or below the star, or over it so as to produce an occultation, we must compute the moon's parallax in latitude, which, subtracted from its true latitude, if it be north, and added to it, if it be south, will give the apparent latitude of the moon as seen from the earth at the given place. If the difference between the moon's apparent latitude, and the latitude of the star, does not exceed the semidiameter of the moon, the last will pass over the star and produce an occultation. When this difference exceeds the moon's semidiameter, the latitude of the star being less than that of the moon, and the latitude of the moon being north, it will pass above the star—being south, it will pass below the star. When the star's latitude is greater than that of the moon, and the moon's latitude is north, it will pass below the star—if south, it will pass above the star.

But the calculation of the moon's parallax in latitude is a tedious operation, and we may find, without the aid of this parallax, in some cases, if a conjunction will be attended with an occultation by the following rule:—If the difference between the latitude of the moon and that of the star exceeds one degree and thirty-seven minutes, no occultation can take place; and if the difference be less than fifty-one minutes, there must be an occultation to some part of the earth. When the difference is between these limits, we must have recourse to the moon's parallax in latitude to ascertain if an occultation will happen.

If it appears that an occultation will take place, we may find the longitude and latitude of the moon and of the star at the time of conjunction, the hourly motion of the moon in longitude and in latitude at the same time, its horizontal parallax and semidiameter, and the time when the star passes the meridian of the given place. With these elements we can proceed to project the occultations.

In calculating an occultation of a planet, the same method will answer, with this difference only—Instead of the hourly motion of the moon in latitude and longitude, we must take the difference of the hourly motions of the moon and planet, if they are moving in the same direction, or their sum if they are moving in opposite directions, for the relative hourly motion. With this relative motion we may find the inclination of the relative orbit in the same manner as we should proceed in finding the angle of the moon's visible path with the ecliptic.

SECTION II.

Universal gravitation—Dr. Hooke's suggestions and experiments—Newton's successful investigation—All bodies tend toward each other—Pressure and weight the effects of gravity—Heavy and light, relative terms—Weight varies at different parts of the earth—How discovered—Gravity diminishes as we recede from the centre—There would be no weight if but one body existed—Gravity retains the moon in its orbit—Explanation—The planets affected by the same force—Nature of this force inexplicable—Attraction of mountains.

The motions of the heavenly bodies have been variously accounted for. We have already adverted to the rude mechanism of deferent and epicyclic spheres, by which some of the ancient philosophers attempted to explain the celestial motions, as also to a more sensible attempt made by Cleanthes, another philosopher of Greece, who, from observing that bodies are easily carried round by whirlpools or vortices of water, imagined that the celestial spaces are filled with an ethereal fluid, which is in continual motion round the earth, and that it carried the sun and planets round with it. Though this hypothesis affords no real explanation of the phenomena, it was revived in modern times, and maintained by two of the most eminent mathematicians and philosophers in Europe, namely, by Des Cartes and Leibnitz, and for a long time met with general acquiescence. But a much nearer approximation to right conceptions on this subject was made by many philosophers of modern times, who supposed that the planets were deflected from uniform rectilineal motions by forces similar to what we observe in the motions of magnetical and electrical bodies, or in the motion of common heavy bodies, where one body seems to influence the motion of another at a distance from it without any intervening impulsion. Fermat was the first who suggested that the weight of a body is the sum of the tendencies of each particle of matter in the body to every particle of the earth. Kepler made another approximation to the truth, when he said that if there were two bodies placed out of the reach of all external forces, and at perfect liberty to move, they would approach each other with velocities inversely proportional to their quantities of matter; when he asserted that the earth and the moon mutually attract each other, and are prevented from meeting by their revolution round their common centre of attraction; and when he attributed the tides to the attractive influence of the moon in heaping up the waters immediately under it.

But Dr. Hooke formed the most precise theory on this subject. At a meeting of the Royal Society, May 3d, 1668, he expressed himself in the following manner:—"I will explain a system of the world very different from any yet received, which is founded on the three following propositions:—

"That all the heavenly bodies have not only a gravitation of their parts to their own centres, but they mutually attract each other.

"That all bodies having a simple motion will continue to move in straight lines, unless continually deflected from them by some extraneous force.

"And that this attraction is greater in proportion to the proximity of the bodies."

The philosophical views stated in the above propositions relative to the celestial motions, were illustrated by an experiment which Dr. Hooke exhibited to the society. A ball, suspended by a long thread from the ceiling, was made to swing round another ball laid on a table immediately below the point of suspension. When the impulse given to the pendulum was nicely adjusted to its deviation from the perpendicular, it described a perfect circle round the ball on the table; but when the impulse was very great or very little, it described an ellipse having the other ball in its centre. The force under the influence of which this circular or elliptic motion was produced, Hooke showed to be a deflecting force, proportional to the distance from the other ball. But he added that though this illustrated the planetary motions in some degree, yet it was not wholly suitable to their case, for the planets describe ellipses, having the sun not in their centre, but in their focus, so that they are not retained in their orbits by a force proportional to the distance from the sun.

Thus we see that certain points of resemblance between the motions of the planets and the motions of magnets and heavy bodies had attracted the attention of many philosophers; but these observers failed to deduce any satisfactory conclusions from the principles they thus dimly discerned.

At length the powerful genius of Newton was directed to the subject, and, by his penetrating sagacity, the law of universal gravitation was brought fully into view, and successfully applied to explain the celestial phenomena.

About the year 1666, the twenty-fourth year of his age, Newton, having retired into the country, in order to avoid the plague, which raged at that time with great violence, was there led, by the leisure such a situation afforded him, to meditate on the probable cause of the planetary motions, and upon the nature of the central force by which they are retained in their orbits. In this inquiry the phenomena of falling bodies first engaged his attention, and, pursuing the ideas which a careful consideration of the subject presented to his mind, he carried his researches from the earth to the heavens, and began to investigate the nature of motion in general. Because there is motion, he observed, there must be a force which produces it: but what is this force? That a body, when left to itself, will fall to the ground, is known to the most ignorant; but if you ask them the reason of its doing so, they will consider you a fool or a madman. The circumstance is too common to excite their surprise, although philosophers are so much embarrassed with it that they find it almost inexplicable.

Let us follow Newton, and examine this question a little farther. Does the cause of weight or gravity exist in the bodies themselves, or out of them? It seems natural to conclude that the propensity which all suspended bodies have of falling to the earth, exists in the bodies themselves. When we take a stone and let it drop from the hand it falls immediately to the ground, and it would fall farther if there were a hole in the earth, and nothing impeded its progress.

The same happens to all other bodies with which we are acquainted. There is no material substance, either great or small, which will not fall toward the earth the moment it is disengaged and free from all outward impediments.

In like manner it may be observed that when a stone, or any other body, is placed upon a table, it presses the table with the same force by which it would, if left to itself, fall to the ground; and if a body be suspended at the end of a string, the force that pushes it downwards stretches the string, and, if it is not sufficiently strong, will break it. From these circumstances it appears plain that all bodies press with a certain force against the obstacles which support and hinder them from falling, and that the degree of force, in either case, is precisely the same as that, which, in free space, would bring them to the ground.

The cause of this propensity in all bodies to fall to the earth, be it what it may, is called gravitation or attraction; and when a substance is said to be very heavy, nothing more is meant than the great tendency it has to fall to the ground, or the great force with which it presses upon any other body that supports it. The weight and gravity of a body may therefore be considered as the same thing. Each of them expresses the force by which the body is impelled toward the earth, whether this force exist in the body itself, or out of it.

With this property of bodies, obvious as it is, the ancients were very imperfectly acquainted. They believed that there were substances, such as vapors and smoke, that, by their nature, were light, and would, for that reason, ascend. This notion, however, as well as that of absolute levity in general, is now known to be erroneous, for, in a receiver perfectly exhausted, or a space void of air, all bodies whatever, smoke or stone, gold or feathers, would fall in the same time. The distinction, therefore, between light and heavy bodies is merely relative, as they are of the same nature, and have all a like propensity to fall toward the earth.

Neither can there be the least doubt that gravity acts as a force, for whatever is capable of putting a body in motion is properly so called. But in all forces there are two things to be considered—the direction in which they act, and their intensity or power. With respect to the direction of gravity, we are sufficiently assured, both by reason and experience, that a body in falling moves towards a point which is in, or near, the centre of the earth, or rather in a straight line that is perpendicular to its surface. The intensity or power of gravity is proportional to the weight of the body under consideration, those that are the heaviest, or that weigh the most, being always observed to descend with the greatest force, and those that weigh the least, with the least force; so that the weight of every body may always be considered as the just measure of its gravity, or of the force by which it is made to fall toward the earth.

The weight of a body, as we have before stated, is less at the equator than at either pole; and in every other situation it varies in a certain proportion according to the latitude of the place, which is occasioned by the oblate spheroidal figure of the earth. This difference, however, is not discoverable by means of a balance, or the scales which are usually employed upon these occasions, because the weight against which the body is opposed is subject to the same variation. The method by which it has been determined is by observations made on the vibrations of pendulums of equal length, which have been found to move swifter as they are more distant from the equator.

It may be farther observed, that, since the earth is a globe, or nearly, and gravity acts perpetually in straight lines that are perpendicular to its surface, if a hole should be bored from one side to the other entirely through it, and a body were placed at the centre, it would remain there forever unsupported, and be wholly without weight, because, in this situation, being equally acted upon on all sides by the same attractive force, it could have no tendency to move either way, and consequently would continue at rest. For the same reason, if a body were dropped into this orifice from the earth's surface, the velocity acquired at the centre by the repeated impulses of gravity during the time of its fall would carry it on to the opposite extremity of the opening, from which it would again return, and, provided the medium had no resisting power, would perpetually continue to move backward and forward.

If we extend our researches, we shall find as we recede from the earth's surface a diminution of the force of gravity, the cause of which is not obvious. All that can be said, indeed, on this head is, that the fact has been ascertained from constant observations, but the cause of it is as little understood as that of gravity itself. The truth of facts, however, is not weakened from the causes being unknown; and Newton proved, in a satisfactory manner, that the gravity of bodies above the earth's surface continually diminishes as the squares of their distances from the centre increase, or, which is the same, that the forces are as four to one when the distances from the centre are as one to two, as nine to one when the distances are as one to three, and so on.

From this account, it will be perceived that gravity is a force which acts upon all bodies, whether at rest or in motion, and gives them a tendency to fall toward the centre of the earth, and that this force, whatever it may be, acts most strongly upon bodies nearest the earth's surface. Does it appear, then, that gravity or weight is an inherent and necessary property of body? It increases or diminishes perpetually, according to a certain proportion of the distance from the centre; but what is permanent does not admit of such mutations. If there were but one body in the universe, we could by no reasonable supposition consider it as possessing weight.

Newton perceived that the force of gravity was not confined to the surface of our globe, being found to act in the same manner at the greatest heights to which we can ascend; and he therefore conceived that it might extend, under some modifications, as far as the moon, and be the means of retaining it in its orbit, by causing a constant deflection from a rectilinear path.

The conjecture was as ingenious as it was simple; but before it could be submitted to the test of calculation, it was necessary to assume some hypothesis relative to the strength or energy of this force with respect to the distance. In this case, the supposition made was, that the power of gravity, as above mentioned, decreases as the square of the distance increases,—to which idea he was probably led by knowing that light, heat, and other emanations thrown off from certain bodies, become weaker in this proportion as they proceed.

But when Newton first attempted to verify this conjecture, the requisite data with regard to the distance of the moon in radii of the earth, and the measure of the earth's radius, were but imperfectly known, and the result he obtained, though near the truth, was not so exact as could be wished.

He therefore, at first, abandoned his hypothesis, which may be regarded as a remarkable proof of the cool and dispassionate frame of mind that this great man preserved, even at the time when he had flattered himself with having discovered one of the most important secrets of nature.

A few years afterwards, he was induced to return to his calculations in consequence of more correct data having been obtained in the interval by the measure of an arc of the meridian. In this second attempt Newton was completely successful. It is related, that, toward the conclusion of his computation, he became so agitated that he was obliged to request a friend to assist him in finishing it; and certainly a moment of greater importance will never be recorded in the annals of science.

But, leaving these observations for the present, let us now see in what way this doctrine is applicable to the subject in question. For this purpose, imagine the moon, at the first moment of its creation, to have been projected forward with a certain velocity in a right-lined direction; then as soon as it began to move, gravity would operate and impel it towards the centre of the earth. But, as a body impelled by two forces will follow the direction of neither, the moon, so circumstanced, would neither proceed directly forward, nor fall directly downward, but, keeping a middle course, would move round the earth in a curvilinear orbit.*

This idea will be more fully illustrated by attending to the motion of a ball, or other projec-

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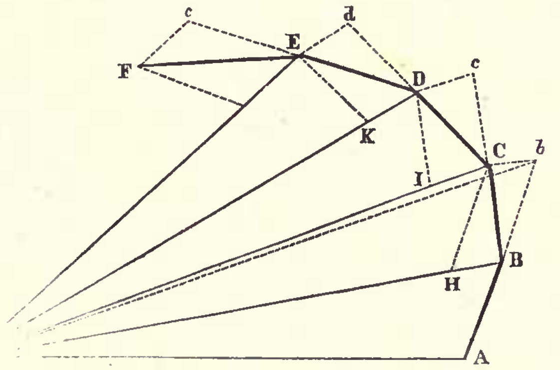
* If a particle of matter be subjected, at the same time, to the action of two moving forces, each of which would separately cause it to describe the side of a parallelogram in a given time, the particle will describe the diagonal in the same time. We shall not be expected to enter at any considerable length into the doctrines of physical astronomy. This subject requires for its full discussion ample space, and all the resources of the higher mathematics. The mere elements of geometry, however, are sufficient to indicate generally some of the fundamental principles. Let us suppose that S is a fixed point, and that a body moves in the direction A B, with an uniform velocity, at such a rate, that, if not disturbed by any external cause, it would move from B to *b* in a second of time. Let us also suppose, that, when the body arrives at B, it receives an impulse in the direction B S, and of such intensity, that, if acting alone, it would cause the body to move uniformly from B to H in a second. Complete the parallelogram H B *b* C, and draw the diagonal B C: the impulse at B, combined with the tendency to continue its motion in the line B *b*, will cause the body to move along the diagonal B C, so that, at the end of a second, it will actually be at the point C, and, if no external cause acted on the body, by the first law it would continue to move uniformly ever after in the direction B C *c*, so that, in the next second, it would describe a line C *c*, equal to B C. But now suppose that the body, when at C, receives a second impulse in the direction C S, by which it would be carried uniformly from C to I in a second; then, completing the parallelogram D I C *c*, the actual path of the body will be the diagonal C D, which will be uniformly described in a second; and, if undisturbed, the motion would be continued uniformly in the straight line C D *d*, the distance D *d* described in the next second being equal to C D. A third impulse at D in the direction D S, such as would carry the body uniformly from D to K in a second of time, would, when combined with the tendency to move in the direction D *d*, produce a motion along D E, the diagonal of the parallelogram E K D *d*, and a fourth impulse in the direction E S, would, when combined with the motion in the direction E *c*, produce a motion along the diagonal E F, and so on. In this way, by successive instantaneous impulses, a body may be made to describe the path A B C D E F, &c., which will be all in one plane.



Since the lines A B, B *b* are equal, the triangles A S B, B S *b* are equal; but, because C *b* is parallel to S B, the triangle B S *b* is equal to the triangle B S C, therefore the triangle B S C is equal to A S B. In like manner, it may be proved that C S D is equal to B S C, and D S E to C S D, and so on. Thus it appears that the triangles A S B, B S C, C SD, D S E, &c., are all equal. If we suppose a straight line to be drawn from the moving body to the fixed point S, and to be continually carried along with it, it is evident that this line will pass over or generate the equal areas A S B, B S C, C S D, D S E, &c., in equal intervals of time. It is also evident that the shorter the interval between the impulses communicated to the moving body, the greater will be the number of sides of the figure formed by the diagonals of the parallelograms, and the nearer will the line composed of these diagonals approach to a curve. If we suppose, therefore, that the body is urged towards F by a force acting, not at intervals, but incessantly, the body will move in that curve to which, as its limit, the line composed of the diagonals continually approaches, while the line drawn from the moving body A S, or radius vector, will continue to describe areas proportional to the times.

From the important conclusion to which we have now been led, we may infer, conversely, that, if a body revolve in a curvilinear path about a point, and if the radius vector drawn from that point describe round it areas proportional to the times, the body is deflected from the rectilineal path by a force directed to that point. Now this is exactly the case of the planets, both primary and secondary. The tile. A ball discharged from a cannon in a horizontal direction, does not fall to the ground till it has proceeded a considerable distance; and if it be projected from the top of a mountain, or other eminence, it will fly still farther before it comes to the earth. Increase the force, and the distance will be augmented accordingly. And thus, in imagination at least, we can suppose the ball to be discharged with such a velocity that it will circulate continually round the earth in the manner of a moon.

Newton did not content himself with stopping here, but began to generalize the problem, and, by means of mathematics, soon came to this important conclusion, that a body which moves in a curve round a fixed point, by virtue of a force directed to that point, describes equal areas in equal times. This is a law of nature which had been before discovered by Kepler from observation. The supposition, therefore, that the moon is under the influence of such a force, is confirmed both by science and experience; and every improvement that has since been made in the theory of its motion has been derived from these principles.

Gallileo had before discovered, that, on the supposition of gravity's acting in parallel lines, a body, projected with any force whatever, would describe a parabola if the medium had no resistance. But Newton extended this problem, and made it more general. He no longer considered the falling body as having a limited distance, nor the force of gravity as acting in parallel lines, but regarded the centre of the earth as the centre of attraction, and, taking into consideration the uniform lateral velocity of the projectile, he proved that it would move round the earth in an elliptical orbit, having the centre of the earth in one of its foci. Whence the projectile may be considered as a moon, moving round the earth, or as one of the satellites of Jupiter, Saturn, or Herschel, moving round those planets, the circumstances in either case being the same.

From the data above mentioned it was also easy to show that the moon is acted upon by gravity according to the law there stated, for the diameter of the earth in feet, and the mean distance of the moon in radii of the earth, being known, as well as the time of one lunar revolution, the circumference of the lunar orbit, and the measure of the arc which the moon describes in a given time, could be readily determined, and thence the versed sine of that arc, or the deflection from a tangent to the orbit at any point of the curve, which by calculation was found to be about $16\frac{1}{12}$ feet in a minute, or sixty seconds of time. So that, if the moon were deprived of the impulse by which it has a tendency to move in a right line from west to east, and the central force only remained, it would fall toward our globe, and describe the above-mentioned space in the first minute of its descent.

This being ascertained, Newton compared the space which would thus be described by the moon at its present distance, with that which it would have described in the same time if placed near the earth's surface, and found that, in the latter case, the space fallen through in one minute would be the square of 60 multiplied by $16\frac{1}{12}$ feet. Then, comparing the distance of the centre of the earth from the surface, or the radius of the earth with the distance of the moon from the same centre, which was known to be equal to 60 of those radii, he found that the force of gravity at the earth's surface was to its force at the distance of the moon as the square of 60 to 1, so that the force decreases as the square of the distance increases. In a similar manner, he found that the same law obtained with respect to the other planets, from which he concluded that they must be acted upon by gravity in a similar manner, and that the whole universe is governed by the same laws, it being evident that so exact a conformity, or rather such a perfect identity of effects, can only arise from an identity of causes.

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former describe curvilinear orbits round the sun, and, according to the second of Kepler's laws, the radius vector describes areas proportional to the times. Hence we may infer that each is retained in its orbit by a centripetal force, directed towards the sun, and that this force is counteracted by a centrifugal force, generated by the planet's motion in its orbit. In like manner, each secondary planet revolves about its primary, the areas described by the radius vector following the same law, so that the secondary must be acted upon by a centripetal force directed towards the primary planet.

These discoveries are, like the genius of their author, universal. But, before we proceed any farther, it will be proper to inquire a little into the nature of gravitation in general, that powerful agent which produces so many astonishing effects. It has been shown, that, by the action of this invisible power, a stone is made to fall to the ground, the moon to circulate about the earth, and the satellites of the other planets to revolve about their respective primaries. The Newtonian doctrine which proves the truth of these laws from mathematical principles, is called "the system of universal gravitation or attraction." But what is this occult principle of sympathy and union which gives life and motion to inanimate beings, and how does it act? The effects are visible, but the agent is hidden from our senses. It eluded the search of Newton. He who soared to the utmost regions of space, and looked through nature with an eagle eye, was unable to discover it.

That there is, however, such a principle is beyond a doubt. To deny its existence would be to deny the truth of facts, established both by experiment and demonstration. That two distant bodies will approach each other without any visible agent either drawing or impelling them, may be made manifest by various instances. The loadstone and a piece of iron mutually attract each other; and in electricity we have numberless experiments to show that bodies of various kinds have a like tendency to approach and adhere to each other. These bodies, it is true, act by particular laws, different from that of gravity; but they serve sufficiently well to illustrate the nature of that principle.

Lest these instances should be thought insufficient, it may be well to mention another, which, independently of mathematical demonstration, goes to show the universality of this property. Thus, according to the Newtonian theory, the principle of attraction pervades the minutest particles of matter, and the combined action of all the parts of the earth forms the attraction of the whole. Hence, for the same reason that a heavy body tends downwards in a perpendicular to the earth's surface, it must be attracted more or less toward the centre of any neighboring mountain according to the quantity of matter contained in it, and the effect of this attraction, or the accelerative force produced by it, must depend on the distance of the mountain from the gravitating body, because this force decreases as the square of the distance increases. Upon these principles, then, the plumb-line of a quadrant, or any other astronomical instrument, must be deflected from its proper situation by a small quantity towards the mountain, and the apparent altitudes of the stars taken with such an instrument must be altered accordingly, that is, if the zenith distance of a star were observed at two stations under the same meridian, one on the south side of the mountain and the other on the north, the star, on account of the plumb-line being attracted out of its vertical direction, must appear too much to the north by the observation at the southern station, and too much to the south by that at the northern station, and consequently the difference of the latitudes of the two stations resulting from these observations would be greater than it really is.

If, then, the true difference of the latitudes of the two stations be determined by means of a series of triangles, the excess of the difference found by the observations on the star above that found by the measurement will be the effect produced by the attraction of the mountain, and the half of it will be the effect of such attraction on the plumb-line of the instrument at each observation, provided the mountain attracts equally on both sides. The first idea of determining the quantity of this attraction was suggested by Newton; but nothing was done until Bouguer and La Condamine were employed, in 1738, in measuring an arc of a meridian near Quito, in Peru, when they thought they perceived a deflection in the plumb-line of their instrument from the effect of the attraction of Chimborazo, the highest mountain of the Andes, which, by a rough computation, founded upon a few observations similar to those above mentioned, they supposed to be equal to about the two thousandth part of the attraction of the whole earth. They, however, had neither the means nor the leisure to prosecute the inquiry, and nothing more was attempted till Maskelyne made a proposal to the Royal Society for this purpose, in 1772, in consequence of which he was deputed, in 1774, to make the trial, accompanied with proper assistants, and furnished with the most accurate instruments. The mountain selected by him for the scene of his operations was Schehallien, in Scotland, the direction of which is nearly east and west, its mean height above the surrounding valley about two thousand feet, and its highest part above the level of the sea three thousand five hundred and fifty feet. Two stations for observation were selected, one on the north and the other on the south side of the mountain, and every circumstance that could contribute to the accuracy of the experiment was regarded. From the observation of ten stars near the zenith, compared with a measurement by triangles formed from two bases on different sides of the mountain, it was found, in the way above stated, that the force of attraction drew the plumb-line of the instrument about six seconds out of its vertical direction.

This instance is sufficient to show that all bodies attract and are attracted; and it has been farther proved, by Newton, that their mutual actions upon each other are in exact proportion to the quantity of matter they contain.

"When we consider," says an ingenious writer, "that, according to the doctrine of Newton, every single satellite of Saturn must gravitate toward the other six, the other six toward the seventh, all the seven toward Saturn, and Saturn with all of them toward the sun, according to a particular law, what skill in geometry must have been requisite to unravel the intricacies of so many different relations! It was a daring attempt to undertake it, and one cannot perceive, without astonishment, that, from so abstract a theory, formed of so many particular theories, and each of them perplexed with innumerable difficulties, conclusions should always arise exactly conformable to fact and experience."

SECTION III.

Tides—Kepler's fanciful theory—Newton's theory—General course of the tides—Owing principally to the moon's attraction—In part to the sun's—Farther explanation of the tides—Cause of spring and neap tides—Priming and lagging of the tides—Declination of the sun and moon affect the tides—Establishment of a port—Exceptions to the general laws—Mediterranean and Baltic seas—Times of high water different in neighboring ports—Theory of Mr. Redfield.

Let us now descend into the world of waters. By what power or cause is it that this vast liquid body rises and falls alternately twice a day in a manner so constant and regular? The ancients considered it as one of the greatest mysteries of nature, and were utterly at a loss to account for it. Aristotle is represented as having thrown himself into the sea because he was unable to explain its motions; and it is said, that, when he was in India, he wished to follow the tide in its ebb to see where it would go.

Kepler, in one of his reveries, considered the earth as a living being, and the ebb and flow of the sea as its respiration. He fancied that men and other creatures were insects which fed upon this animal, bushes and trees the bristles on its back, and the waters of the seas and rivers a liquid circulating in its veins. Kepler, however, afterward adopted a more philosophical theory, which he thus explains in his "Physics of the Heavens." "The orb of the attracting power which is in the moon extends as far as the earth, and draws the waters under the torrid zone, acting upon places where it is vertical, insensibly on confined seas and bays, but sensibly on the ocean, whose beds are large, and in which the waters have the liberty of reciprocation, that is, of rising and falling." And in his Lunar Astronomy he says, "The cause of the tides in the sea appears to be the bodies of the sun and moon drawing the waters." This hint being given, Newton improved upon it, and wrote so amply on the subject as to make the theory in a manner his own, and discovered the cause of their rising on the side of the earth opposite the moon. Kepler believed that the presence of the moon occasioned an impulse that caused another in her absence.

The ocean, it is well known, covers a large part of the globe, and the body of water is in continual motion, ebbing and flowing without intermission. What connection these motions have with the moon we shall see as we proceed. But at present it will be sufficient to observe that they always follow a certain general rule. For instance, if the tide be now at high-water mark in any port or harbor which lies open to the ocean, it will presently subside and flow regularly back for about six hours, when it will be found at low-water mark; after this it will again gradually advance for six hours, and then return back in the same time to its former situation, rising and falling alternately twice a day, or in the space of about twenty-four hours.

The interval between the flux and reflux is, however, not precisely six hours, but about eleven minutes more; so that the time of high water does not always happen at the same hour, but is about three quarters of an hour later every day for thirty days, when it again recurs as before. For example, if it be high water to-day at noon, it will be low water at eleven minutes past six in the evening, and consequently, after two changes more, the time of high water to-morrow will be about three quarters of an hour after noon; the day following it will be at about half an hour after one, the day after at quarter past two, and so on for thirty days, when it will again be high water at noon, the same as on the day the observation was first made, which answers to the motion of the moon; for that planet rises every day about three quarters of an hour later than upon the preceding, and, by moving in this manner round the earth, completes her revolution in about thirty days, and then begins to rise about the same time as before.

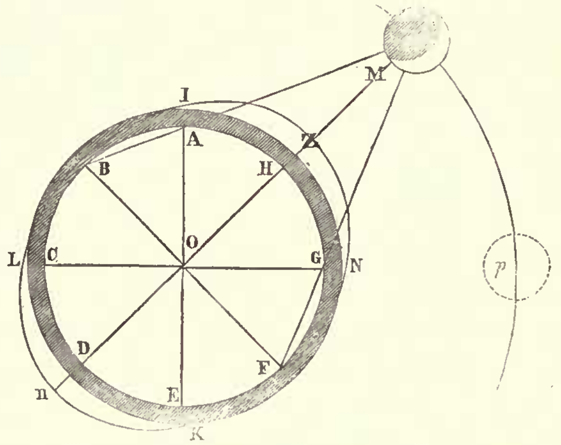
To make the matter plainer, suppose, that, at a certain place, it is high water at three o'clock in the afternoon upon the day of new moon; the following day it will be high water at three quarters of an hour after three, the day after at half past four, and so on till the next new moon, when it will again be high water at three o'clock as before. And, by observing the tides continually at the same place, they will always be found to follow the same rule, the time of high water upon the day of every new moon being nearly at the same hour, and three quarters of an hour later every succeeding day.

Such a perfect harmony of motions as is here pointed out could not possibly arise from the mere concurrence of accidental causes, or the uncertain operations of blind chance. They are in such exact conformity with the motions of the moon, that, independently of all mathematical considerations, we should be induced to look to that planet as their cause. Neglecting, therefore, for the present, all such exceptions as do not affect the truth of the theory, we will proceed to show that these phenomena are principally occasioned by the moon's attraction.

That the moon by her attraction should heap up the waters under her, seems to most persons very natural: that the same cause should, at the same time, heap them up on the opposite side of the earth, seems to many palpably absurd. Yet nothing is more evident when we consider that it is not by her *whole* attraction, but by the difference of her attractions at the two surfaces and at the centre, that the water is raised. A drop of water existing alone would take a spherical form by reason of the attraction of its parts; and if the same drop were to fall freely in a vacuum under the influence of an *uniform* gravity, since every part would be equally accelerated, the particles would retain their relative positions, and the spherical form be unchanged. But suppose it to fall under the influence of an attraction acting on each of its particles independently, and increasing in intensity at every step of the descent; then the parts nearer the attracting body would be attracted more than the central, and the central than the more remote parts, and the whole would be drawn out, in the direction of the motion, into an oblong form, the tendency to separation being, however, counteracted by the attraction of the particles on each other, and a form of equilibrium being thus established. Now, in fact, the earth is constantly falling to the moon, being continually drawn by it out of its path, the nearer parts more and the remoter less than the central parts; and thus, at every instant, the moon's attraction acts to force down the water on the sides at right angles to her direction, and raise it at the two ends of the diameter pointing towards her. Geometry corroborates this view of the subject, and demonstrates that the form of equilibrium assumed by a layer of water covering a sphere under the influence of the moon's attraction would be an oblong ellipsoid, having the semiaxis directed towards the moon longer by about fifty-eight inches than that transverse to it.

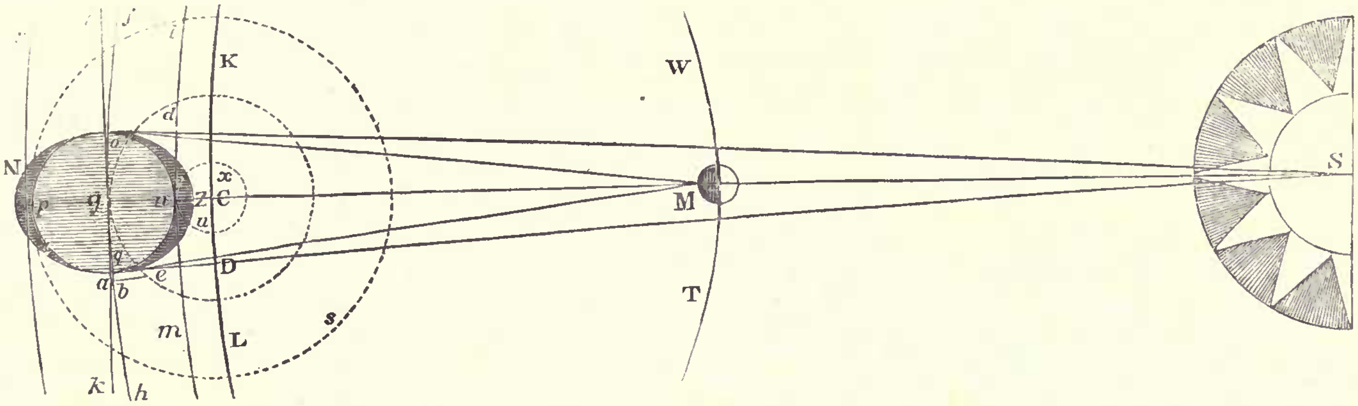
There is never time, however, for this spheroid to be fully formed. Before the waters can take their level the moon has advanced in her orbit, both diurnal and monthly, (for, in this theory, it will answer the purpose of clearness better if we suppose the earth's diurnal motion transferred to the sun and moon in the contrary direction,) the vertex of the spheroid has shifted on the earth's surface, and the ocean has to seek a new bearing. The effect is to produce an immensely broad and excessively flat wave, (not a circulating *current*,) which follows, or endeavors to follow, the apparent motions of the moon, and must, in fact, if the principle of forced vibrations be true, imitate all the periodical inequalities of that motion. When the higher or lower parts of this wave strike our coasts, they experience what we call high and low water. It will be convenient, as adding much to the simplicity of the subject, to consider the earth as a perfect sphere, wholly covered with an ocean of uniform density; then, as it is the peculiar nature of fluids to communicate in all directions the impressions they receive, it is manifest that the action of terrestrial gravity would cause the sea to become everywhere of the same depth, or to have its waters level throughout the whole extent of its globe; and as neither the diurnal rotation of the earth, nor its projectile motion, which act equally on all its particles, would cause any disturbance in this state of equilibrium, reason teaches us that it is to the action of some external force we are to look for the cause of the tides, and a little attention to the nature of the moon's attraction will convince us that we are right in ascribing the agency principally to that body.

The power of gravity, as we have stated in the preceding section, diminishes as the square of the distance increases, and therefore the waters at Z on the side of the earth A B C D E F G H next the moon M are more attracted than the central parts of the earth O by the moon, and the central parts are more attracted by her than the waters on the opposite side of the earth at *n*, and therefore the distance between the earth's centre and the waters on its surface under and opposite to the moon will be increased. For, let there be three bodies at H, O, and D: if they are all equally attracted by the body M, they will all move equally fast toward it, their mutual distances from each other continuing the same; if the attraction of M is unequal, then that body which is most strongly attracted will move fastest, and this will increase its distance from the other body. Therefore, by the law of gravitation, M will attract H more strongly than it does O, by which the distance between H and O will be increased, and a spectator on O will perceive H rising higher toward Z. In like manner, O being more strongly attracted than D, it will move farther towards M than D does; consequently the distance between O and D will be increased, and a spectator on O, not perceiving his own motion, will see D receding farther from him towards *n*, all effects and appearances being the same, whether D recedes from O, or O from D.



Suppose, now, there is a number of bodies, as A, B, C, D, E, F, G, H placed round O, so as to form a flexible or fluid ring; then, as the whole is attracted towards M, the parts at H and D will have their distance from O increased, whilst the parts at B and F, being nearly at the same distance from M as O is, will not recede from one another, but rather, by the oblique attraction of M, they will approach nearer to O. Hence, the fluid ring will form itself into an ellipse Z I B L *n* K F N Z, whose longer axis *n* O Z produced will pass through M, and its shorter axis B O F will terminate in B and F. Let the ring be filled with bodies so as to form a fluid sphere round O; then, as the whole moves toward M, the fluid sphere being lengthened at Z and *n*, will assume an oblong or oval form. If M is the moon, O the earth's centre, A B C D E F G H the sea covering the earth's surface, it is evident, by the above reasoning, that, whilst the earth by its gravity falls toward the moon, the water directly below her at Z will swell and rise gradually towards her, also the water at D will recede from the centre, (strictly speaking, the centre recedes from D,) and rise on the opposite side of the earth, whilst the water at B and F is depressed, and falls below the former level. Hence, as the earth turns round its axis from the moon to the moon again in twenty-four hours and three quarters, there will be two tides of flood and two of ebb in that time, as we find by experience.

As this explanation of the ebbing and flowing of the sea is deduced from the earth's constantly falling toward the moon by the power of gravity, some may find a difficulty in conceiving how this is possible when the moon is full, or in opposition to the sun, since the earth revolves about the sun, and must continually fall towards it, and therefore cannot fall contrary ways at the same time; or if the earth is constantly falling towards the moon, they must come together at last. To remove this difficulty, let it be considered that it is not the centre of the earth that describes the annual orbit round the sun, but the common centre* of gravity of the earth and moon together, and that, whilst the earth is moving round the sun, it also describes a circle round that centre of gravity, going as many times round it in one revolution about the sun as there are lunations or courses of the moon round the earth in a year, and therefore the earth is constantly falling towards the moon from a tangent to the circle it describes round the said common centre of gravity. Let M be the moon, T W part of the moon's orbit, and C the centre of gravity of the earth and moon. Whilst the moon goes round her orbit, the centre of the earth describes the circle *g e d* round C. To this circle *g a k* is a tangent; and therefore, when the moon has gone from M to a point but little beyond W, the earth has moved from *g* to *e*, and in that time has fallen towards the moon from the tangent at *a* to *e*, and so round the whole circle.



The sun's influence in raising the tides is but small in comparison to the moon's, for though the earth's diameter bears a considerable proportion to its distance from the moon, it is next to nothing

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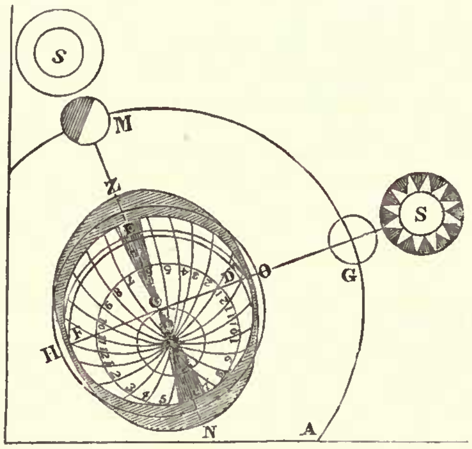
* This centre is as much nearer the earth's centre than the moon's as the earth is heavier, or contains a greater quantity of matter than the moon, namely, about forty times. If both bodies were suspended on it, they would hang in *equilibrium*. So that dividing the moon's distance from the earth's centre by the excess of the earth's weight above the moon's, the quotient will be the distance of the common centre of gravity of the earth and moon from the earth's centre.

when compared with the distance of the sun; and therefore the difference of the sun's attraction on the sides of the earth under and opposite to him is much less than the difference of the moon's attraction on the sides of the earth under and opposite to her, and consequently the moon must raise the tides much higher than they can be raised by the sun.

On this theory, so far as we have explained it, the tides ought to be highest directly under and opposite to the moon, that is, when the moon is due north and south. But we find, that, in open seas, where the water flows freely, the moon M is generally past the north and south meridian, as at *p*, (last figure but one,) when it is high water at Z and at *n*. The reason is obvious, for though the moon's attraction was to cease altogether when she was past the meridian, yet the motion of ascent communicated to the water before that time would make it continue to rise for some time after: much more must it do so when the attraction is only diminished, as a little impulse given to a moving ball will cause it still to move farther than otherwise it could have done, and as experience shows that the day is hotter about three in the afternoon than when the sun is on the meridian, because of the continual addition to the heat already accumulated.

The tides do not answer always to the same distance of the moon from the meridian at the same places, but are variously affected by the action of the sun, which brings them on sooner when the moon is in her first and third quarters, and keeps them back later when she is in her second and fourth quarters, because in the former case the tide raised by the sun alone would be earlier than the tide raised by the moon, and in the latter case later.

The moon goes round the earth in an elliptic orbit, and therefore she approaches nearer to the earth than her mean distance, and recedes farther from it, in every lunar month. When she is nearest she attracts strongest, and so raises the tides most: the contrary happens when she is farthest, because of her weaker attraction. When both luminaries are in the equator, and the moon at her least distance from the earth, she raises the tides highest of all, especially at her conjunction and opposition, both because the equatorial parts have the greatest centrifugal force from their describing the largest circle, and from the concurring actions of the sun and moon. At the change, the attractive forces of the sun and moon being united, they diminish the gravity of the waters under the moon, and their gravity on the opposite side is diminished by means of a greater centrifugal force. At the full, whilst the moon raises the tide under and opposite to her, the sun, acting in the same line, raises the tide under and opposite to him; whence their conjoint effect is the same as at the change, and in both cases occasion what we call the *spring tides.* But at the quarters, the sun's action on the waters at O and H diminishes the effect of the moon's action on the waters at Z and N, so that they rise a little under and opposite to the sun at O and H, and fall as much under and opposite to the moon at Z and N, making what we call the *neap tides,* because the sun and moon then act cross-wise to each other. But, strictly speaking, these tides happen not till some time after, because in this, as in other cases, the actions do not produce the greatest effect when they are at the strongest, but some time afterward.



Another effect of the combination of the solar and lunar tides is what is called the *priming* and *lagging* of the tides. If the moon alone existed, and moved in the plane of the equator, the *tide-day* (i. e. the interval between two successive arrivals at the same place of the same vertex of the tide-wave) would be the lunar day formed by the combination of the moon's sidereal period and that of the earth's diurnal motion. Did the sun exist alone, and move always in the equator, the tide-day would be the mean solar day. The actual tide-day, then, or the interval of the occurrence of two successive *maxima* of their superposed waves, will vary as the separate waves approach to or recede from coincidence; because, when the vertices of two waves do not coincide, their joint height has its maximum at a point intermediate between them. This variation from uniformity in the lengths of successive tide-days is particularly to be remarked about the time of the new and full moon.

The sea being thus put in motion, would continue to ebb and flow for several times, even though the sun and moon were annihilated, or their influence should cease; as if a basin of water were agitated, the water would continue to move for some time after the basin was left to stand still; or like a pendulum, which, having been put in motion by the hand, continues to make several vibrations without any new impulse.

The declination of the sun and moon materially affect the tides. We shall illustrate this effect as regards the moon. When the moon is in the equator, the tides are equally high in both parts of the lunar day, or time of the moon's revolving from the meridian to the meridian again, which is twenty-four hours and forty-eight minutes. But as the moon declines from the equator towards either pole, the tides are alternately higher and lower at places having north or south latitude. For the tide of the highest elevations, which is that under the moon, follows her towards the pole to which she is nearest, and the other declines towards the opposite pole, each elevation describing parallels as far distant from the equator, on opposite sides, as the moon declines from it to either side, and consequently the parallels described by these elevations of the water are twice as many degrees from one another as the moon is from the equator, increasing their distance as the moon increases her declination till it be at the greatest, when the said parallels are, at a mean state, forty-seven degrees from one another, and on that day the tides are most unequal in their heights. As the moon returns toward the equator, the parallels described by the opposite elevations approach towards each other until the moon comes to the equator, and then they coincide. As the moon declines toward the opposite pole, at equal distances, each elevation describes the same parallel in the other part of the lunar day which its opposite elevation described before. Whilst the moon has north declination, the greatest tides in the northern hemisphere are when she is above the horizon, and the reverse whilst her declination is south. Let N E S Q be the earth, N C S its axis, E Q the equator, T *r* the tropic of cancer, *t n* the tropic of capricorn, *a b* the arctic circle, *c d* the antarctic, N the north pole, S the south pole, M the moon, F and G the two eminences of water, whose lowest parts are at *a* and *d* Fig. 1, at N and S Fig. 2, and at *b* and *c* Fig. 3, always ninety degrees from the highest. Now, when the moon is in her greatest north declination at M, the highest elevation G under her is on the tropic of cancer T *r*, and the opposite elevation F on the tropic of capricorn *t n*, and these two elevations describe the tropics by the earth's diurnal rotation. All places in the northern

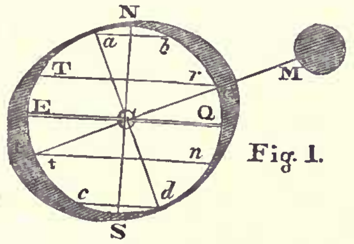


Fig. 1.

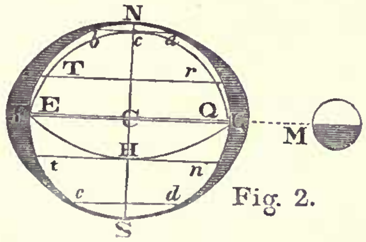


Fig. 2.

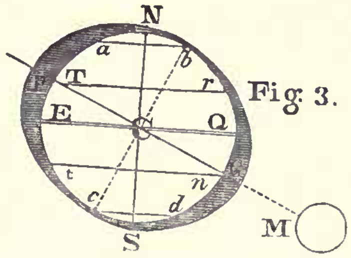


Fig. 3.

hemisphere E N Q have the highest tides when they come into the position *b r* Q under the moon, and the lowest tides when the earth's diurnal rotation carries them into the position *a* T E on the side opposite to the moon. The reverse happens at the same time in the southern hemisphere E S Q, as is evident to sight. The axis of the tides *a* C *d* has now its poles *a* and *d* (being always ninety degrees from the highest elevations) in the arctic and antarctic circles, and therefore it is plain that at these circles there is but one tide of flood, and one of ebb, in the lunar day; for when the point *a* revolves half round to *b* in twelve lunar hours it has a tide of flood, but when it comes to the same point *a* again in twelve hours more it has the lowest ebb. In seven days afterward, the moon M comes to the equinoctial circle, and is over the equator E Q, when both elevations describe the equator, and, in both hemispheres, at equal distances from the equator, the tides are equally high in both parts of the lunar day. All the phenomena being reversed when the moon has south declination to what they were when her declination was north, they require no farther description.

In the three last-mentioned figures, the earth is projected on the plane of the meridian; but, in order to describe a particular phenomenon, we project it on the plane of the ecliptic. Let H Z O N be the earth and sea, (see figure on page 254,) F E D the equator, T the tropic of cancer, C the arctic circle, P the north pole, and the curves 1, 2, 3, &c. twenty-four meridians or hour-circles intersecting each other in the poles. A G M is the moon's orbit, S the sun, M the moon, Z the water elevated under the moon, and N the opposite equal elevation. As the lowest parts of the water are always ninety degrees from the highest, when the moon is in either of the tropics (as at M) the elevation Z is on the tropic of capricorn, and the opposite elevation N on the tropic of cancer, the low-water circle H C O touches the polar circles at C, and the high-water circle E T P 6 goes over the poles at P, and divides every parallel of latitude into two equal segments. In this case, the tides upon every parallel are alternately higher and lower, but they return at equal times. The point T, for example, on the tropic of cancer (where the depth of the tide is represented by the breadth of the dark shade) has a shallower tide of flood at T than when it revolves half round from thence to 6, according to the order of the numeral figures; but it revolves as soon from 6 to T as it did from T to 6. When the moon is in the equinoctial, the elevations Z and N are transferred to the equator at O and H, and the high and low-water circles have moved into each other's former places, in which case the tides return in unequal times, but are equally high in both parts of the lunar day; for a place at 1, (under D,) revolving as formerly, goes sooner from 1 to 11 (under F) than from 11 to 1, because the parallel it describes is cut into unequal segments by the high-water circle H C O; but the points 1 and 11 being equidistant from the pole of the tides at C, which is directly under the pole of the moon's orbit M G A, the elevations are equally high in both parts of the day.

And thus it appears, that, as the tides are governed by the moon, they must turn on the axis of the moon's orbit, which is inclined twenty-three and a half degrees to the earth's axis at a mean state; and therefore the poles of the tides must be so many degrees from the poles of the earth, or in opposite points of the polar circles, going round these circles in every lunar day. It is true, that, according to Fig. 3, when the moon is vertical to the equator E C Q, the poles of the tides seem to fall in with the poles of the world N and S; but when we consider that F H G is under the moon's orbit, it will appear, that, when the moon is over H, in the tropic of capricorn, the north pole of the tides (which can be no more than ninety degrees from under the moon) must be at *c* in the arctic circle, not at N, the north pole of the earth, and, as the moon ascends from H to G in her orbit, the north pole of the tides must shift from *c* to *a* in the arctic circle, and the south pole as much in the antarctic.

It is not to be doubted but that the earth's quick rotation brings the poles of the tides nearer to the poles of the world than they would be if the earth were at rest and the moon revolved about it only once a month, for otherwise the tides would be more unequal in their heights and the times of their returns than we find they are. But how near the earth's rotation may bring the poles of its axis and those of the tides together, or how far the preceding tides may affect those which follow so as to make them keep up nearly to the same heights and times of ebbing and flowing, is a problem more fit to be solved by observation than by theory.

Those who have opportunity to make observations, and choose to satisfy themselves whether the tides are really affected in the above manner by the different positions of the moon, especially as to the unequal times of their returns, may take this general rule for knowing when they ought to be so affected:—When the earth's axis inclines to the moon, the northern tides, if not retarded in their passage through shoals and channels or affected by the winds, ought to be greatest when the moon is above the horizon, least when she is below it, and quite the reverse when the earth's axis declines from her, but in both cases at equal intervals of time. When the earth's axis inclines sidewise to the moon, both tides ought to be equally high; but they happen at unequal intervals of time. In every lunation, the earth's axis inclines once to the moon, once from her, and twice sidewise to her, as it does to the sun every year, because the moon goes round the ecliptic every month, and the sun but once in a year. In summer, the earth's axis inclines towards the moon when new, and therefore the day-tides in the north ought to be highest, and night-tides lowest, about the change; at the full the reverse. At the quarters, they ought to be equally high, but unequal in their returns, because the earth's axis then inclines sidewise to the moon. In winter, the phenomena are the same at full moon as in summer at new. In autumn, the earth's axis inclines sidewise to the moon when new and full; therefore the tides ought to be equally high, and unequal in their returns, at these times. At the first quarter, the tide of flood should be least when the moon is above the horizon, greatest when she is below it; and the reverse at her third quarter. In spring, the phenomena of the first quarter answer to those of the third quarter in autumn; and vice versa. The nearer any time is to either of these seasons, the more the tides partake of the phenomena of these seasons; and in the middle between any two of them, the tides are at a mean state between those of both.

The deviation of the time of high and low water at any port or harbor from the culmination of the luminaries, is called the "establishment" of that port. If the water were without inertia, and free from obstruction, either owing to the friction of the bed of the sea, the narrowness of channels along which the wave has to travel before reaching the port, their length, &c., &c., the times above distinguished would be identical. But all these causes tend to create a difference, and to make that difference not alike at all ports. The observation of the establishment of harbors, is a point of great maritime importance; nor is it of less consequence, theoretically speaking, to a knowledge of the true distribution of the tide-waves over the globe. In making such observations, care must be taken not to confound the time of *slack water* when the current caused by the tide ceases to flow visibly one way or the other, and that of *high* or *low water*, when the level of the surface ceases to rise or fall.

These are the principal phenomena of the tides; and, where no local circumstances interfere, the theory and facts will be found to agree nearly. It must be observed that what has been said generally relates only to such places as lie open to the ocean; for of all the causes of difference in the height of tides, local situation is the most influential. The variations from this cause are almost beyond belief. Thus the Mediterranean and Baltic seas have very small elevations, because the inlets by which they communicate with the ocean are so narrow that they cannot in a short time receive or discharge enough to raise or sink their surfaces much. While at Bristol, England, the tide sometimes rises *thirty feet*, and at Cumberland, in the Bay of Fundy, it is said to rise *seventy feet*.

There are, also, from the same cause, great variations in the time of the tides.

The tides are so retarded in their passage through different shoals and channels, and otherwise so variously affected by striking against capes and headlands, that to different places they happen at all distances of the moon from the meridian, consequently at all hours of the lunar day.

The time of full sea at Boston differs from that at New Bedford *three hours and a half*, and from that at Albany four hours and twelve minutes; and between the two last-mentioned places it differs seven hours and forty-two minutes, taking place three and a half hours earlier at New Bedford, and four and one fifth hours later at Albany, than at Boston.

What has been said of the ocean may likewise be applied to the air, for, the surface of the atmosphere being nearer to the moon than the surface of the sea, it is plain that the aerial tides must be more considerable than those of the ocean; and, on this account, it should seem to follow that the mercury in the barometer would sink lower than at other times when the moon passes the meridian, because the action on the particles of air must at that time make them lighter. Delicate observations have been able to render these aerial tides sensible and measurable. The effect, however, is extremely minute, which would be expected when it is considered, that, in proportion as these particles are rendered lighter, a greater number of them will be accumulated, and thus the pressure will be nearly the same as before, and the mercury will be scarcely affected at all.

We make the following extract from an article in one of the numbers of Silliman's Journal of Science relative to tides, by W. C. Redfield, who, after recapitulating some of the evidence showing the absence of the usual tides at the Society Islands, and in some other parts of the Pacific Ocean, continues as follows:—

"It must therefore be admitted that there is a suspension or neutralization of the lunar tide-wave in the region in which those islands are situated. We find, too, that in the Atlantic it is high water on the coast of Surinam about five o'clock on the days of the new and full of the moon, and the flood runs to the westward; at the windward islands of the West Indies, the tide is some one or two hours later, and, though exposed to the whole tide range of the Atlantic, the tides are very weak and irregular, not rising more than at the Society Islands; on the southern coast of the United States, and at the Island of Bermuda in the Atlantic, it is high water about seven o'clock, and the flood tide in the offing at the latter place *running to the northeast;* on the southern coast of Rhode Island and Massachusetts, it is high water from seven to eight o clock; on the south-eastern coast of Nova Scotia and Newfoundland, it is high water from eight to nine o'clock, the flood tide off the latter coast also running north-eastwardly; at the Azores, or Western Islands, in latitude thirty-eight degrees north, near the middle of the Atlantic, it is high water about twelve o'clock, and the *flood runs to the eastward*; finally, it is high water on the western coasts of Ireland and Spain about two o'clock—all on the same days. These statements are approximated from the American Coast Pilot and other authorities, care being taken to avoid the retarding effects of local obstructions as far as possible, by timing them from the most extraneous positions of coast towards the open ocean."

"Viewing these phenomena in connection with some other facts, I was led to suspect that the great tide-wave performs an actual circuit in each of the great oceanic basins on both sides of the equator, passing westwardly in the equatorial latitudes, and returning eastwardly in the higher latitudes, above twenty-five degrees or thirty degrees north and south, and analogous to the course which is pursued, as can be demonstrably shown, by the great *currents* both of the ocean and the atmosphere. If such *be* the operation of the tides, certain regions in mid-ocean would form the foci, or neutral points, in these great elliptical circuits, and would be but slightly, if at all, affected by the ordinary tides. The elaborate investigation of cotidal lines in which professor Whewell is engaged, will probably show whether the course of the great tide-wave be from the Southern Ocean, northwardly, through the entire length of the Atlantic, and in disregard of the direct lunar influence in this ocean, as would seem to be indicated in his late paper on that subject. The greatest difficulty attending the inquiry, is in procuring correct observations from those islands and external points of coast which bear most decidedly upon the question."

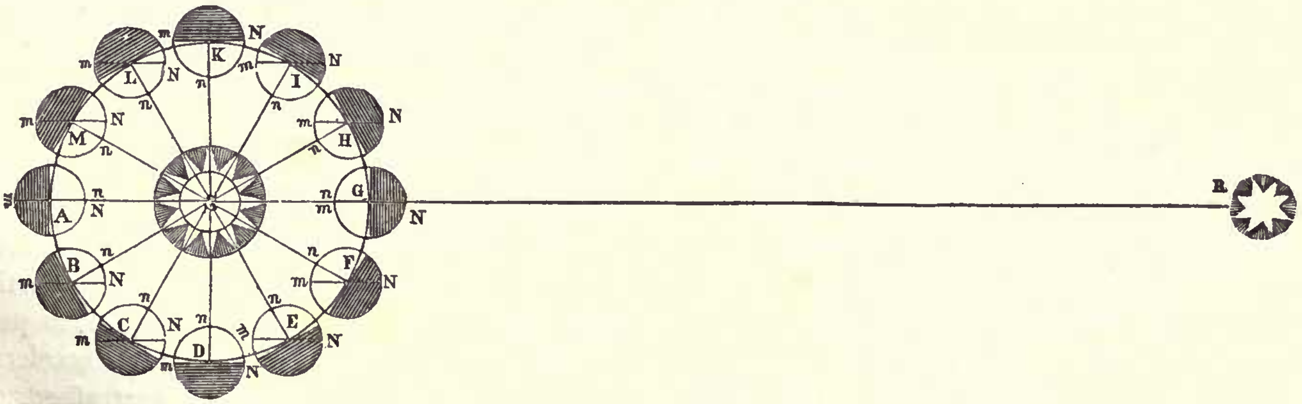
SECTION IV.

Solar and sidereal days—Equation of time—Inequality arising from the obliquity of the ecliptic—That caused by the unequal motion of the earth in its orbit—Deductions respecting the equation throughout the year—Mean and apparent time agree but four days in the year—Calendar—Standards of time—Their inconvenience—Gregorian method of correcting the calendar—Grecian calendar—Roman calendar—Its correction by Julius Cæsar—Persian calendar—Subdivisions of the year—Cycle—Dionysian period—Dominical letters—Julian period.

The fixed stars appear to go round the earth in twenty-three hours, fifty-six minutes, and four seconds, and the sun in twenty-four hours, so that the stars gain three minutes and fifty-six seconds upon the sun every day, which amounts to one diurnal revolution in a year; and, therefore, in three hundred and sixty-five days as measured by the returns of the sun to the meridian, there are three hundred and sixty-six days as measured by the stars returning to it. The former are called *solar days*, and the latter *sidereal.*

The diameter of the earth's orbit is but a physical point in proportion to the distance of the stars. For this reason, and the earth's uniform motion on its axis, a given meridian will revolve from any star to the same star again in each absolute revolution of the earth on its axis, without the least perceptible difference of time shown by a clock that goes exactly true.

If the earth had a diurnal, without an annual, motion, any given meridian would revolve from the sun to the sun again in the same space of time as from any star to the same star again, because the sun would never change his place with respect to the stars. But, as the earth advances almost a degree eastward in its orbit during the time that it is turning eastward round its axis, whatever star passes over the meridian on any day with the sun will pass over the same meridian on the next day when the sun is nearly a degree from it, or sooner than the sun by three minutes and fifty-six seconds. If the year contained only three hundred and sixty days, as the ecliptic does three hundred and sixty degrees, the sun's apparent place, so far as his motion is equable, would change a degree every day, and then the sidereal day would be just four minutes shorter than the solar.



Let A B C D E F G H I K L M be the orbit in which the earth goes round the sun every year according to the order of the letters, that is, from west to east, turning round its axis the same way from the sun to the sun again every twenty-four hours. Let S be the sun, and R a fixed star at such an immense distance that the diameter of the earth's orbit bears no sensible proportion to that distance. Let N*m* be any particular meridian of the earth, and N a given point or place upon that meridian. When the earth is at A, the sun S hides the star R, which would always be hidden if the earth did not remove from A, and consequently, as the earth turns round its axis, the point N would always come round to the sun and star at the same time. But when the earth has advanced, suppose a twelfth part of its orbit from A to B, its motion round its axis will bring the point N a twelfth part of a natural day, or two hours, sooner to the star than to the sun, (for the angle N B *n* is equal to the angle A S B,) and therefore any star which comes to the meridian at noon with the sun when the earth is at A, will come to the meridian at ten in the forenoon when the earth is at B. When the earth comes to C, the point N will have the star on its meridian at eight in the morning, or four hours sooner than it comes round to the sun, for it must revolve from N to *n* before it has the sun in its meridian. When the earth comes to D, the point N will have the star on its meridian at six in the morning; but that point must revolve six hours more from N to *n* before it has mid-day by the sun, for now the angle A S D is a right angle, and so is N D *n*—that is, the earth has advanced ninety degrees in its orbit, and must turn ninety degrees on its axis to carry the point N from the star to the sun, for the star always comes to the meridian when N *m* is parallel to R S A, because D S is but a point in respect of R S. When the earth is at E, the star comes to the meridian at four in the morning; at F, at two in the morning; and at G, the earth having gone half round its orbit, N points to the star R at midnight, it being then directly opposite to the sun, and therefore, by the earth's diurnal motion, the star comes to the meridian twelve hours before the sun. When the earth is at H, the star comes to the meridian at ten in the evening; at I, it comes to the meridian at eight, that is, sixteen hours before the sun; at K, eighteen hours before him; at L, twenty hours; at M, twenty-two; and at A, at the same time with the sun again.

Thus it is plain that an absolute revolution of the earth on its axis (which is always completed when any particular meridian comes to be parallel to its situation at any time of the day before) never brings the same meridian round from the sun to the sun again; for the earth requires as much more than one turn on its axis to finish a natural day, as it has gone forward in that time, which, at a mean state, is a 365th part of a circle. Hence, in three hundred and sixty-five days the earth revolves three hundred and sixty-six times round its axis; and, as a revolution of the earth on its axis completes a sidereal day, the number of sidereal days in a year must be one more than that of the solar days, be this last number what it may. This is true in respect to all the other planets as well as the earth, one revolution being lost with respect to the number of solar days in a year by the planet's going round the sun, just as it would be lost to a traveller who was going round the earth. He would lose one day by following the apparent diurnal motion of the sun, and consequently would reckon one day less at his return (let him take what time he would to go round the earth) than those who remained all the while at the place from which he set out. So, if there were two earths revolving equably on their axes, and if one remained at A until the other travelled round the sun from A to A again, *that* earth which kept its place at A would have its solar and sidereal days always of the same length, and would have had one solar day more than the other at its return. Hence, if the earth turned but once round its axis in a year, and if *that* turn was made the same way as the earth goes round the sun, there would be continual day on one side of the earth, and continual night on the other.

Tables divided into two parts have been constucted, showing first how much of the celestial equator passes over the meridian in any given part of a mean solar day, and secondly the accelerations of the fixed stars. The latter part affords us an easy method of knowing whether our clocks and watches go true; for if, through a small hole in a window-shutter, or in a thin plate of metal fixed to a window, we observe at what time any star disappears behind a chimney, or corner of a house, at a little distance, and if the same star disappears the next night three minutes fifty-six seconds sooner by the clock or watch, and on the second night seven minutes fifty-two seconds sooner, the third night eleven minutes forty-eight seconds sooner, and so on, it is an infallible sign that the time-piece goes true, otherwise it does not go true, and must be regulated accordingly; and, as the disappearing of a star is instantaneous, we may depend on this information to half a second.

A great number of the most important elements involved in astronomical researches are variable in their amount. Their variations, however, generally succeed each other in a certain order, and are confined within certain limits; and when these limits and all the varying values are ascertained, it is of course possible to take an average among them, and this average value is termed *a mean value.*

It is, indeed, always possible to take an average between any number of observations, or of ascertained values of a particular element; but, unless the observations are so taken that the whole course of the variation is included, it is not usual to call the average a mean value, or rather it is not the absolute mean value of the thing itself—it is only its average or mean value for a certain time. For instance, we have already seen that the length of the day, considered as the interval from sunrise to sunset, is continually varying, but that it goes through all its changes in the interval from one solstice to another. Its average duration for this whole time, then, is its mean value. It is a little more than twelve hours, and it is very nearly the same everywhere. It would be everywhere exactly twelve hours, if the sun always moved at the same rate, and there were no parallax or refraction. An average, however, might be taken of the lengths of this day for a portion only of this interval: for instance, from the vernal equinox to the summer solstice: the length of the shortest day would be a little more than twelve hours, and the average length, at Belle Isle, for example, about fourteen hours and three quarters. This would be a correct average of the lengths observed; but, as the time of observation would not comprehend all the variations of the element in question, it would not be the mean length of the day absolutely, though it might be called the mean length for the period of observation.

In the same manner as we have taken an instance of mean duration, we might have an instance of mean motion, that is to say, if a body moves with a variable motion; but if the whole course of its variation is ascertained, its average rate of motion during this whole course may be found, and this will be called *its mean motion.* A body moving with this mean motion, and of course moving uniformly during the whole time occupied by the whole series of the real motions, would move through the same space as the real body; but its place at many or all of the intermediate periods would be different from the place of the real body, on account of the difference between the real and mean motions. The place of a body so moving, or the place which the real body would occupy on the supposition that it moved uniformly, and described in the time occupied by the whole series of its real motions the same spaces which it actually does, is called *the mean place of the body.* In the same manner, any event that happens at various intervals which succeed each other in a certain and recurring order will have *a mean time* of occurrence.

Now it very generally happens in astronomy that it is less inconvenient first to compute the mean place of a body, or the mean time of an event, and then to ascertain the difference between the mean and the true, than to go through the computations necessary to find the true time and place in the first instance.

When once the mean values have been ascertained, the mean motion of a body during a known period, its mean place at a known time, the mean time of the occurrence of a given event are easily found; for the intervals of the mean time and the rate of the mean motion being always the same, we only want to know how often the event has occurred, or how long the motion has been continued. If, from a consideration of the manner in which the difference between the true and mean values arises, we can ascertain the amount of that difference in each particular instance, we can find what is to be added to, or subtracted from, the mean value to arrive at the true, and the quantity so added or substracted is called *an equation*. The mean value thus leads to the true value, and of course it furnishes an approximation to it; and as the subjects of astronomical inquiry generally have their variations confined within narrow limits so that the difference between the true and mean motions, times, and places is not very great, the approximation is not very distant.

We shall find several instances of the application of the terms above explained, and of the use made of these mean values and results, in treating of the equation of time, of which we are about to speak, and then the more obvious appearances of the sun, and their principal effects, will have been sufficiently explained.

The earth's motion on its axis being perfectly uniform, and equal at all times of the year, the sidereal days are always of the same length; and so would the solar or natural days be if the earth's orbit were a perfect circle, and its axis perpendicular to its orbit. But the earth's diurnal motion on an inclined axis, and its annual motion in an elliptic orbit, cause the sun's apparent motion in the heavens to be unequal, for sometimes he revolves from the meridian to the meridian again in somewhat less than twenty-four hours, as shown by a well-regulated clock, and at other times in somewhat more.

Tables of the equation of natural days are given in some astronomies, showing the time that ought to be pointed out by a well-regulated clock or watch, every day of the year, at the precise moment of solar noon, that is, when the sun's centre is on the meridian, or when a sun-dial shows it to be precisely twelve. By these we should find, for example, that, on the 5th of January, in leap-year, when the sun is on the meridian, it ought to be five minutes and fifty-one seconds past twelve by the clock, and on the 15th of May, when the sun is on the meridian, the time by the clock should be fifty-five minutes and fifty-seven seconds past eleven. In the former case, the clock is five minutes and fifty-one seconds faster than the sun; and in the latter case, the sun is four minutes and three seconds faster than the clock.

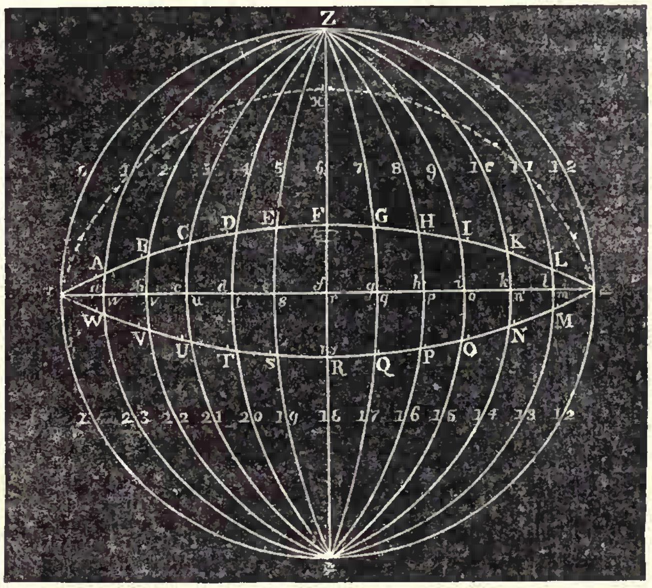
In order to set a sun-dial, it will be necessary to fix accurately the position of the meridian, and the easiest and most expeditious way of doing this is as follows: Make four or five concentric circles, about a quarter of an inch from one another, on a flat board about a foot in breadth, and let the outer circle be but little less than the board will contain. Fix a pin perpendicularly in the centre, and of such a length that its whole shadow may fall within the innermost circle for at least four hours in the middle of the day. The pin ought to be about an eighth part of an inch thick, and to have a round, blunt point. The board being set exactly level in a place where the sun shines, suppose from eight in the morning till four in the afternoon, (for about these hours the end of the shadow should fall within all the circles,) watch the times in the forenoon when the extremity of the shortening shadow just touches the several circles, and *there* make marks: then, in the afternoon of the same day, watch the lengthening shadow, and where its end touches the several circles in going over them make marks also: lastly, with a pair of compasses, find exactly the middle point between the two marks on any circle, and draw a straight line from the centre to that point. This line will be covered at noon by the shadow of a small upright wire, which should be put in the place of the pin. The reason for drawing several circles is, that, in case one part of the day should prove clear and the other part somewhat cloudy, if you miss the time when the point of the shadow should touch one circle, you may perhaps catch it in touching another. The best time for drawing a meridian line in this manner is about the summer solstice, because the sun changes his declination with the least, and his altitude with the greatest, rapidity at that time.

If the casement of a window on which the sun shines at noon be exactly upright, you may draw a line along the edge of its shadow on the floor when the shadow of the pin is exactly on the meridian line of the board; and, as the motion of the shadow of the casement will be much more sensible on the floor than that of the shadow of the pin on the board, you may know to a few seconds when it touches the meridian line on the floor, and so regulate your clock for the day of observation by that line and the equation tables before mentioned.

As the equation of time, or difference between the time shown by a well-regulated clock and a sun-dial, depends upon two causes, namely, the obliquity of the ecliptic, and the unequal motion of the earth in it, we shall explain first the effects of these causes separately considered, and then the united effects resulting from their combination.

The earth's motion on its axis being perfectly equable, or always at the same rate, and the plane of the equator being perpendicular to its axis, it is evident that in equal times equal portions of the equator will pass over the meridian, and so would equal portions of the ecliptic if it were parallel to, or coincident with, the equator. But, as the ecliptic is oblique to the equator, the equable motion of the earth on its axis carries unequal portions of the ecliptic over the meridian in equal times, the difference being proportional to the obliquity; and, as some parts of the ecliptic are much more obliquely situated with respect to the equator than others, those differences are unequal among themselves. Therefore, if *two suns* should start either from the beginning of Aries or Libra, and continue to move through equal arcs in equal times, one in the equator, and the other in the ecliptic, the equatorial sun would always return to the meridian in twenty-four hours of time measured by a well-regulated clock, but the sun in the ecliptic would return to the meridian sometimes sooner, and sometimes later, than the equatorial sun, and only at the same moments with him on four days of the year, namely, the 21st of March, when the sun enters Aries, the 21st of June, when he enters Cancer, the 23d of September, when he enters Libra, and the 21st of December, when he enters Capricorn. At these times, therefore, the difference between mean and apparent time caused by the obliquity of the ecliptic would be least, and about the 5th of February, the 6th of May, the 8th of August, and the 8th of November this difference would be greatest. As there is only one sun, and his apparent motion is always in the ecliptic, let us call him the *real* sun, and the other, which is supposed to move in the equator, the *fictitious* sun. To this last, the motion of a well-regulated clock always answers.

Let Z ♈ *z* ♎ be the earth, Z F R *z* its axis, *a b c d e*, &c. the equator, A B C D E, &c. the northern half of the ecliptic from ♈ to ♎ on the side of the globe next the eye, and M N O P, &c. the southern half on the opposite side from ♎ to ♈. Let the points at A, B, C, D, E, F, &c. quite round from ♈ to ♈ again bound equal portions of the ecliptic gone through in equal times by the real sun, and those at *a*, *b*, *c*, *d*, *e*, *f*, &c. equal portions of the equator described in equal times by the fictitious sun, and let Z ♈ *z* be the meridian.



As the real sun moves obliquely in the ecliptic, and the fictitious sun directly in the equator, with respect to the meridian, a degree, or any number of degrees, between ♈ and F on the ecliptic must be nearer the meridian Z ♈ *z*, than a degree, or any corresponding number of degrees on the equator from ♈ to *f*, and the more so as they are the more oblique; and therefore the true sun comes sooner to the meridian every day whilst he is in the quadrant ♈ F than the fictitious sun does in the quadrant ♈ *f*. For this reason, the solar noon precedes noon by the clock until the real sun comes to F and the fictitious sun to *f*, which two points, being equidistant from the meridian, both suns will come to it precisely at noon by the clock.

Whilst the real sun describes the second quadrant of the ecliptic F G H I K L from ♋ to ♎, he comes later to the meridian every day than the fictitious sun moving through the second quadrant of the equator from *f* to ♎, for the points at G, H, I, K, and L being farther from the meridian than their corresponding points at *g*, *h*, *i*, *k*, and *l*, they must be later in coming to it, and as both suns come at the same moment to the point ♎, they come to the meridian at the moment of noon by the clock.

In departing from Libra through the third quadrants, the real sun going through M N O P Q towards ♑ at R, and the fictitious sun through *m n o p q* towards *r*, the former comes to the meridian every day sooner than the latter until the real sun comes to ♑ and the fictitious sun to *r*, and then they both come to the meridian at the same time.

Lastly, as the real sun moves equably through S T U V W, from ♑ towards ♈, and the fictitious sun through *s t u v w*, from *r* towards ♈, the former comes later every day to the meridian than the latter until they both arrive at the point ♈, and then it is noon at the same time both by the clock and the sun.

This part of the equation of time may perhaps be somewhat difficult to understand by a figure, because both halves of the ecliptic seem to be on the same side of the globe, but it may be made very easy to any person who has a real globe before him. By putting small patches on every tenth or fifteenth degree both of the equator and ecliptic, beginning at Aries, he will, on turning the globe slowly round westward, see all the patches from Aries to Cancer come to the brazen meridian sooner than the corresponding patches on the equator; all those from Cancer to Libra will come later to the meridian than their corresponding patches on the equator; those from Libra to Capricorn sooner, and those from Capricorn to Aries later; and the patches at the beginnings of Aries, Cancer, Libra, and Capricorn, being either on, or even with those on the equator, show that the two suns either meet there, or are even with one another, and so come to the meridian at the same moment.

Let us suppose that there are two balls moving equably round a celestial globe by clock-work, (one always keeping in the ecliptic, and gilt with gold to represent the real sun, and the other keeping in the equator, and silvered to represent the fictitious sun,) and that whilst these balls move once round the globe according to the order of signs, the clock turns the globe three hundred and sixty-six times round its axis westward. The stars will make three hundred and sixty-six diurnal revolutions from the brazen meridian to the same again, and the two balls representing the real and fictitious suns, always going farther eastward from any given star, will come later than that star to the meridian every following day, and each ball will make three hundred and sixty-five returns to the meridian, coming equally to it at the beginnings of Aries, Cancer, Libra, and Capricorn: but in every other point of the ecliptic the gilt ball will come either sooner or later to the meridian than the silvered ball, like the patches above mentioned. This would be a good way of showing the reason why any given star, which, on a certain day of the year comes to the meridian with the sun, passes over that meridian sooner every following day, so that in a twelvemonth it comes to the meridian with the sun again; as also of showing the reason why the real sun comes to the meridian sometimes sooner, sometimes later, than noon as shown by the clock, and, on four days of the year, at the same time, whilst the fictitious sun always comes to the meridian when it is twelve at noon by the clock.

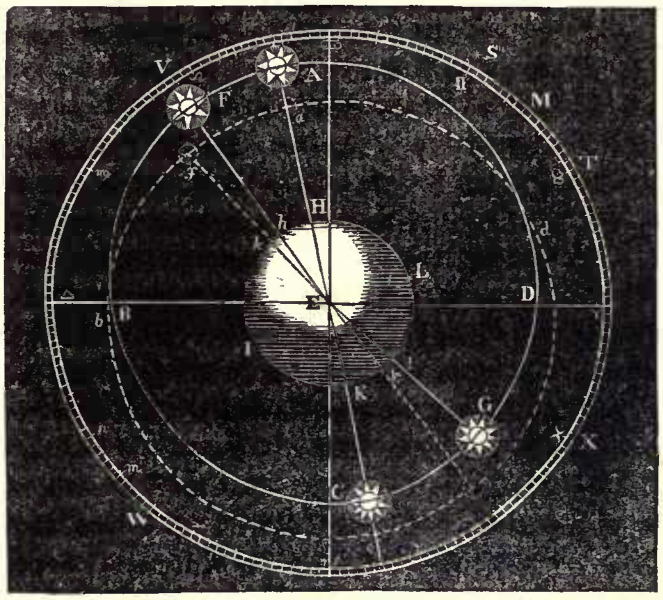
If the ecliptic were more oblique to the equator, the equal divisions from ♈ to *x* would come still sooner to the meridian Z *o* ♈ than those marked A, B, C, D, and E do; for two divisions containing thirty degrees, from ♈ to the second dot, a little short of the figure 1, come sooner to the meridian than one division containing only fifteen degrees, from ♈ to A, does, as the ecliptic now stands, and those of the second quadrant from x to ♎ would be as much later. The third quadrant would be as the first, and the fourth as the second. Also, where the ecliptic was most oblique, namely, about Aries and Libra, the difference would be greatest, and least about Cancer and Capricorn, where the obliquity was the least.

We proceed to explain the second cause of the difference between mean and apparent time, namely, the inequality of the sun's apparent motion, which is slowest in summer when the sun is farthest from the earth, and most rapid in winter when he is nearest the earth. But the earth's motion on its axis is equable all the year round, and is performed from west to east, the same way that the sun appears to change his place in the ecliptic.

If the sun's motion were equable in the ecliptic, the whole difference between the equal time as shown by a clock, and the unequal time as shown by the sun, would arise from the obliquity of the ecliptic. But the sun's motion sometimes exceeds a degree in twenty-four hours, though generally it is less; and when his motion is slowest any particular meridian will return sooner to him than when his motion is most rapid, overtaking him in less time when he advances a less space than when he moves through a greater.

If there were two suns moving in the plane of the ecliptic so as to go round it in a year, one describing an equal arc every twenty-four hours, and the other describing sometimes a less and sometimes a larger arc in twenty-four hours, and gaining at one time of the year what it lost at the opposite, it is evident that either of these suns would come sooner or later to the meridian than the other as it happened to be behind or before the other, and when they were both in conjunction they would come to the meridian at the same moment.

As the real sun moves unequably in the ecliptic, let us suppose a fictitious sun to move equably in a circle coincident with the plane of the ecliptic. Let A B C D be the ecliptic or orbit in which the real sun moves, and the dotted circle *a b c d* the imaginary orbit of the fictitious sun, each going round in a year according to the order of letters, or from west to east. Let H I K L be the earth turning round its axis the same way every twenty-four hours; and suppose both suns to start from A and *a* in a right line with the plane of the meridian E H at the same moment, the real sun at A being then at his greatest distance from the earth, at which time his motion is slowest, and the fictitious sun at *a*, whose motion is always equable because his distance from the earth is supposed to be always the same. In the same time that the meridian revolves from H to H again according to the order of the letters H I K L, the real sun moves from A to F, and the fictitious with a quicker motion from *a* to *f* through a larger arc: therefore the meridian E H will revolve sooner from H to *h* under the real sun at F, than from H to *k* under the fictitious sun at *f*, and consequently it will then be noon by the sun-dial sooner than by the clock.



As the real sun moves from A towards C, the rapidity of his motion increases all the way to C. Yet the fictitious sun gains so much upon the real sun soon after his departure from A, that the increasing velocity of the real sun does not bring him up with the fictitious sun till the former comes to C, and the latter to *c*, when each has gone half round its respective orbit; and then, both suns being in conjunction, the meridian E H, revolving to E K, comes to them at the same time, and therefore it is noon by them both at the same moment.

But the increased velocity of the real sun, being now at its maximum, carries him before the fictitious sun, and therefore the same meridian will come to the latter sooner than to the former; for while the fictitious sun moves from *c* to *g*, the real sun moves through a greater arc from C to G, consequently the point K has its noon by the clock when it comes to *k*, but not its noon by the sun till it comes to *l*. And although the velocity of the real sun diminishes all the way from C to A, and the fictitious sun by an equable motion is still coming nearer to the real sun, yet they are not in conjunction till the one comes to A, and the other to *a*, and then it is noon by them both at the same moment.

Thus it appears that the solar noon is always later than noon by the clock whilst the sun goes from C to A, sooner whilst he goes from A to C, and at these two points, the sun and clock being equal, it is noon by them both at the same moment.

The point A is called the sun's apogee, because when there he is at his greatest distance from the earth; the point C his perigee, because when there he is at his least distance from the earth; and a right line, as A E C, drawn, through the earth's centre, from one of these points to the other, is called the line of the apsides.

The distance that the sun has departed at any time from his apogee (not the distance he has to go to arrive at it, though ever so little) is called *his anomaly*, and is reckoned in signs and degrees, allowing thirty degrees to a sign. Thus, when the sun has gone suppose one hundred and seventy-four degrees from his apogee at A, he is said to be five signs and twenty-four degrees from it, which is his anomaly; and when he has departed three hundred and fifty-five degrees from his apogee, he is said to be eleven signs and twenty-five degrees from it, although he is but five degrees short of A in coming round to it again. The distance that the sun would be at any time from apogee provided he moved uniformly in a circle is called his *mean anomaly*, and the period between his leaving and returning to a given situation with respect to the apogee is therefore called the *anomalistic year.*

From what has been said above, it will be perceived that when the sun's anomaly is less than six signs, that is, when he is any where between A and C, in the half of his orbit A B C, the solar noon precedes the clock noon; but when his anomaly is more than six signs, that is, when he is any where between C and A, in the half of his orbit C D A, the clock noon precedes the solar. When his anomaly is nothing, that is, when he is in apogee at A, or when his anomaly is six signs exactly, that is, when he is in perigee at C, he comes to the meridian at the same moment with the fictitious sun, and then it is noon by them both at the same instant.

Tables have been constructed showing that part of the equation of time which depends on the earth's unequal motion in its orbit. These, together with the before-mentioned tables containing that part of the equation which results from the obliquity of the ecliptic, will enable us to calculate the *absolute* equation of time. If both of these equations show the sun to be faster or slower than the clock, their sum is the absolute equation of time; but if by one the sun is faster, and by the other slower, their difference is the absolute equation. Thus, suppose the equation depending on the sun's place be six minutes and forty-one seconds slow, and the equation depending on the sun's anomaly be four minutes and twenty seconds slow, their sum is the absolute equation, viz. eleven minutes and one second slow. But if one had been six minutes and forty-one seconds fast, and the other four minutes and twenty seconds slow, their difference would have been the equation, viz. two minutes and twenty-one seconds fast, because the greater quantity is too fast.

We may now collect our results thus: In the course of the year there are four days, and only four, (namely, December 24th, April 15th, June 15th, and September 1st,) when the apparent and mean time are the same, or the equation of time is nothing; and in the interval between the first and second of these, and again in that between the third and fourth, the apparent is always later than the mean time, or the clock before the sun; and between the second and third, and again between the fourth and first, the apparent is always earlier than the mean time, or the clock after the sun. These results correspond with those in the common tables of the equation of time.

It is evident, also, from the manner in which these results have been deduced, that they depend entirely on the relative positions of the apogee and of the equinoxes. If these are fixed points, or hold always the same relative position, the results we have obtained will serve alike for every year. If they vary, the equation of time will vary also, and this consideration leads us to inquire whether there be any motion of the equinoxes, and whether the apogee and perigee be or be not fixed points. As far, also, as the magnitude of the equation is concerned, it is evident that any variation in the inclination of the ecliptic to the equator would affect it; for the angle formed by lines drawn from Aries to the true and mean suns, and the declination of the sun at any point of the ecliptic, would both be affected by this change, and both these quantities are involved in the solution of that part of the question which arises from the motion of the sun in a plane inclined to the equator.

In point of fact, it is found that the inclination of the ecliptic and equator does undergo some slight variation. This is not sufficient to produce any material alteration in the results, or to call for more extended notice here; but it furnishes one reason why the results obtained for the equation of time cannot, as far as their numerical values are concerned, apply accurately except to the particular periods for which they are computed.

Time, like distance, may be measured by comparison with standards of any length, and all that is requisite for ascertaining correctly the length of any interval is to be able to apply the standard to the interval throughout its whole extent, without overlapping on the one hand, or leaving unmeasured vacancies on the other; to determine, without the possible error of a unit, the number of integer standards which the interval admits of being interposed between its beginning and end; and to estimate precisely the fraction over and above an integer which remains when all the possible integers are subtracted.

But though all standard units of time are equally possible, theoretically speaking, all are not, practically, equally convenient. The tropical year and the solar day are natural units, which the wants of man and the business of society force upon us, and compel us to adopt as our greater and lesser standards in the measurement of time for all the purposes of civil life, and that, in spite of inconveniences, which, did any choice exist, would speedily lead to the abandonment of one or the other. The principal of these are their *incommensurability*, and the want of perfect uniformity in one, at least, of them.

The mean lengths of the sidereal day and year, when estimated on an average sufficiently large to compensate the fluctuations arising from nutation in the one and from inequalities of configuration in the other, are the two most invariable quantities which nature presents us with—the former by reason of the uniform diurnal rotation of the earth, the latter on account of the invariability of the axes of the planetary orbits. Hence it follows that the mean solar day is also invariable. It is otherwise with the tropical year. The motion of the equinoctial points varies not only from the retrogradation of the equator on the ecliptic, but also partly from that of the ecliptic on the orbits of all the other planets. It is therefore variable, and this produces a variation in the tropical year, which is dependent on the place of the equinox. The tropical year is actually above $4^{s}.21$ shorter than it was in the time of Hipparchus. This absence of the most essential requisite for a standard, viz. *invariability*, renders it necessary, since we cannot help employing the tropical year in our reckoning of time, to adopt an arbitrary or artificial value for it so near the truth as not to admit of the accumulation of its error for several centuries producing any practical mischief, and thus satisfying the ordinary wants of civil life, while, for scientific purposes, the tropical year, so adopted, is considered only as the representative of a certain number of integer days and a fraction, the day being, in effect, the only standard employed. The case is nearly analogous to the reckoning of value by guineas and shillings, an artificial relation of the two coins being fixed by law, near to, but scarcely ever exactly coincident with, the natural one, determined by the relative market price of gold and silver, of which either the one or the other, whichever is really the most invariable, or the most in use with other nations, may be assumed as the true theoretical standard of value.

The other inconvenience of the standards in question is their incommensurability. In our measure of space, all our subdivisions are into aliquot parts: a yard is three feet, a mile eight furlongs, &c. But a year is no *exact* number of days, nor an integer number with any exact fraction (as one third or one fourth) over and above; but the surplus is an incommensurable fraction, composed of hours, minutes, seconds, &c., which produces the same kind of inconvenience in the reckoning of time that it would do in that of money if we had gold coins of the value of twenty-one shillings, with odd pence and farthings, and a fraction of a farthing over. For this, however, there is no remedy but to keep a strict register of the surplus fractions, and, when they amount to a whole day, cast them over into the integer account.

To do this in the simplest and most convenient manner is the object of a well-adjusted calendar. In the Gregorian calendar, which we follow, it is accomplished with remarkable simplicity and neatness by carrying a little farther than is done above the principle of an assumed or artificial year, and adopting *two* such years, both consisting of an exact integer number of days, (viz. one of three hundred and sixty-five, and the other of three hundred and sixty-six,) and laying down a simple and easily-remembered rule for the order in which these years shall succeed each other in the civil reckoning of time, so that during the lapse of at least some thousands of years the sum of the integer artificial or Gregorian years elapsed shall not differ from the same number of real tropical years by a whole day. By this contrivance, the equinoxes and solstices will always fall on days similarly situated and bearing the same name in each Gregorian year, and the seasons will forever correspond to the same months, instead of running the round of the whole year, as they must do upon any other system of reckoning, and used, in fact, to do before this was adopted.

The Gregorian rule is as follows:—The years are denominated from the birth of Christ, according to one chronological determination of that event. Every year whose number is not divisible by four without a remainder consists of 365 days; every year which *is* so divisible, but is not divisible by 100, of 366; every year divisible by 100, but not by 400, again of 365; and every year divisible by 400, again of 366. For example, the year 1837, not being divisible by four, consists of 365 days; 1840 of 366; 1800 and 1900 of 365 each; but 2000 of 366. In order to see how near this rule will bring us to the truth, let us see what number of days 10000 Gregorian years will contain, beginning with the year one. Now, in 10000 the numbers not divisible by four will be three-fourths of 10000, or 7500; those divisible by 100, but not by 400, will in like manner be three-fourths of 100, or 75; so that, in the 10000 years in question, 7575 consist of 365, and the remaining 2425 of 366, producing in all 3652425 days, which would give for an average of each year, one with another, $365^{d}.2425$. The actual value of the tropical year reduced into a decimal fraction is 365.24224; so the error of the Gregorian rule on 10000 of the present tropical years is 2.6, or $2^{d}\ 14^{h}\ 24^{m}$, that is to say, less than a day in 3000 years, which is more than sufficient for all human purposes, those of the astronomer excepted, who is in no danger of being led into error from this cause. Even this error might be avoided by extending the wording of the Gregorian rule one step farther than its contrivers probably thought it worth while to go, and declaring that years divisible by 4000 should consist of 365 days. This would take off two integer days from the above-calculated number, and 2.5 from a larger average, making the sum of days in 100000 Gregorian years 36524225, which differs only by a single day from 100000 real tropical years, such as they exist at present.

As any distance along a high road might, though in a rather inconvenient and roundabout way, be expressed, without introducing error, by setting up a series of milestones at intervals of unequal lengths, so that every fourth mile, for instance, should be a yard longer than the rest, or according to any other fixed rule, taking care only to mark the stones so as to leave room for no mistake, and to advertise all travellers of the difference of lengths and their order of succession, so may any interval of time be expressed correctly by stating in what Gregorian years it begins and ends, and *whereabouts in each.* For this statement, coupled with the declaratory rule, enables us to say how many integer years are to be reckoned at 365, and how many at 366 days. The latter years are called bissextiles, or leap-years, and the surplus days thus thrown into the reckoning are called *intercalary* or *leap days.*

The arrangement of their calendar was a subject with which the astronomers of Greece were occupied, with various success, during several centuries. The difficulties arose from the perseverance with which they attempted to conciliate the motions of the sun and moon. The month being determined by a lunar, and the year by a solar revolution, they must soon have perceived that the former was not contained any integral number of times in the latter. Their object, then, was to find a number of years, or period, at the end of which a restitution would be effected, and the beginning of the month and the year again correspond. This problem was more difficult than they seem to have imagined; for, in the first place, the two revolutions are, strictly speaking, incommensurable, and, secondly, the moon's mean motion is subject to a secular acceleration, which, even if an accurate period could be found, would, in the course of time, render it inexact. However, it was not impossible to find some practical solution which would be tolerably accurate for a time of no very great length, and to this object their attention was directed.

The first period of the kind alluded to was one of eight years, proposed by Cleostratus of Tenedos. To understand its advantages and defects it is necessary to observe that the Greek lunar year was composed of three hundred and fifty-four days, divided into twelve months, alternately of twenty-nine and thirty days. Cleostratus proposed in the course of the eight years to insert three intercalary months, of thirty days each, at the end of the third, fifth, and eighth years respectively. He thus had a period of 2922 days, comprising ninety-nine lunar revolutions. But, in reality, ninety-nine lunar revolutions are performed in somewhat more than 2923 days and 12 hours, so that at the end of the period there was an error of thirty-six hours on the place of the moon.

Various methods were proposed to rectify this defect, but none with much success till we come to the time of Meton. This astronomer immortalized himself by the invention of a new cycle, which, taking into account its accuracy compared with the number of years contained in the period, may be considered as the most perfect ever proposed; for it is clear that it is one of the great merits of a cycle of this kind, intended for the purposes of civil life, to comprise as small a number of years as possible. The cycle of Meton was composed of nineteen lunar years, in which seven months of thirty days were intercalated, namely, in the third, sixth, eighth, eleventh, fourteenth, seventeenth, and nineteenth years. Besides this, some alteration was made in the distribution of the ordinary months: instead of having them alternately of twenty-nine and thirty days, there were one hundred and ten only of the former, and one hundred and twenty-five of the latter, in the period. To judge of the accuracy of the Metonian cycle, we must consider that nineteen solar years comprise very nearly 6939 days, 14 hours, 25 minutes, and two hundred and thirty-five lunar revolutions comprise 6939 days, 16½ hours nearly, so that at the end of this time the moon was only about two hours behind the sun. The cycle of Meton comprising 6940 days, after one period the sun had already commenced his revolution nine hours and a half, the moon seven hours and a half. The great accuracy and convenience of this invention procured it universal approbation. It was adopted throughout Greece, and obtained the name, which it still bears, of the golden number. The first cycle began in the year 422 B. C.

Callippus, about a century later, proposed to remedy the slight defect of the cycle of Meton by subtracting one day every seventy-six years. This was done by changing, after four periods of nineteen years, one of the months of thirty days into one of twenty-nine. Callippus thus had a period of seventy-six years, comprising 27759 days. Now we may estimate that nine hundred and forty revolutions of the moon make $27758^d\ 18^h\ 6^m$; seventy-six revolutions of the sun $27758^d\ 9^h\ 42^m$. The error on the place of the moon then was $5^h\ 54^m$; on the sun $14^h\ 18^m$. It was the accumulation of this error that entailed the necessity of the Gregorian reform.

Hipparchus appears to have composed one of four Callippic periods, or three hundred and four years, at the end of which he subtracted a day. By reference to what has been said, it will be seen that this will almost destroy any error on the moon's place, though it will leave one of more than a day on that of the sun. However, this period never seems to have been much used even among astronomers. Ptolemy, though a follower and admirer of Hipparchus, employs in preference that of Callippus.

If the Gregorian rule, as above stated, had always been adhered to, nothing would be easier than to reckon the number of days elapsed between the present time and any historical recorded event. But this is not the case, and the history of the calendar, with reference to chronology, or to the calculation of ancient observations, may be compared to that of a clock, going regularly when left to itself, but sometimes forgotten to be wound up, and, when wound, sometimes set forward, sometimes backward, and that often to serve particular purposes and private interests. Such, at least, appears to have been the case with the Roman calendar (in which our own originates) from the time of Numa to that of Julius Cæsar, when the lunar year of thirteen months, or three hundred and fifty-five days, was augmented at pleasure to correspond to the solar (by which the seasons are determined) by the arbitrary intercalations of the priests, and the usurpations of the decemvirs and other magistrates, till the confusion became inextricable. An important change took place in the forty-fifth year before Christ, which was the first regular year commencing on the 1st of January, being the day of the new moon immediately following the winter solstice of the year before. We may judge of the state into which the reckoning of time had fallen by the fact, that, to introduce the new system, it was necessary to enact that the previous year (46 B. C.) should consist of four hundred and fifty-five days, a circumstance which obtained for it the epithet of "the year of confusion."

When Julius Cæsar, and his adviser Sosigenes, determined that, in the Roman calendar, every fourth year should be bissextile, they seem to have supposed the year to have been composed of exactly 365 days and 6 hours. Yet Hipparchus had proved, a century before, that this value was about five minutes too great, and even his determination was considerably in excess, as the real length was not more than 365 days, 5 hours, 48 minutes, and 45 seconds, and consequently the excess of the Julian above the tropical year amounted to more than eleven minutes. At the end of a century the difference had accumulated to more than eighteen hours, and at the end of fifteen centuries to nearly eleven days, by which the seasons had moved from the places in which they were originally fixed. Thus, the vernal equinox, which, at the institution of the calendar by Julius Cæsar, fell on the 21st of March, had retrograded to the 10th, and, if no steps had been taken to correct this, in the course of time spring would have commenced in December, summer in March, autumn in June, and winter in September. In process of time, the equinox, having passed successively through all the intermediate months, would have returned again to that of March. But before this took place a great many centuries would have elapsed, and, even supposing the derangement to have been much more rapid, it may be questioned whether it would have caused any practical inconvenience. The ancient Egyptians knew that the solar year comprised about 365 days and a quarter, yet they made their civil year of 365 days only; the consequence of which was that each month corresponded in succession to different seasons, a complete restitution being effected in about 1461 years. It is probable that the principal motive which induced many well-informed men, in the sixteenth century, to urge a reformation of the calendar, was a desire to fix in a more correct way the day on which the festival of Easter ought to be celebrated. This celebration having been connected with the equinox by a decree of the council of Nice, it became of importance to the church to fix definitely the place of the equinox in the calendar. A proof that religious and not civil considerations led to the reform may be found in the extent of the changes effected. It may be said that a certain degree of inconvenience would result to the public from having a movable instead of a fixed year; and though, in the Julian system, the anticipation of the seasons is so slow that the inconvenience must be nearly inappreciable, yet there could have been no objection to fixing permanently the different seasons, as it might have been effected without difficulty by adopting a different intercalation for the future. But, on the other hand, the time at which the year shall be made to begin is entirely arbitrary, and in practice a matter of perfect indifference. In the age of Cæsar, the year began a few days after the winter solstice, and the vernal equinox fell on the 21st of March. In the age of pope Gregory XIII., this equinox fell on the 10th. Here it might have been fixed for the future without any inconvenience; but the Pope and his astronomers took the very unnecessary step of suppressing altogether eleven days in the year 1582, in order to bring the equinox to the 21st. This uncalled-for measure had the inconvenience of introducing into Europe two styles or modes of reckoning dates, as the new calendar was for a long time rejected by the Protestant states of Europe, and to this day has not been received in the empire of Russia. In the north of Germany it was not admitted till the year 1699, nor in England till 1751, one hundred and sixty-nine years after its publication by Gregory at Rome.

The equinox being once brought to the 21st of March, the object of those who effected the reform was to keep it as nearly as possible to that day by a proper system of intercalation, and to effect this the Julian calendar was modified as before stated.

It is a singular fact that the Persians have been for several centuries in possession of a calendar constructed on much more scientific principles, than Europe, with her superior knowledge, can boast of. It has been stated, by La Place, Montucla, and Bailly, that the Persian intercalation consisted in the insertion of eight days in thirty-three years. This, if true, would at once be a much more accurate and simple method than the Gregorian; but the fact is, that the Persians combine two periods, each of considerable accuracy, the one erring a little in excess, the other in defect. The first period is one of twenty-nine years, in which they intercalate seven days. This is followed by four successive periods of thirty-three years, in each of which they intercalate eight times, forming a whole period of 161 years, which includes thirty-nine intercalary days. To show the extreme accuracy of this method, it is only necessary to remark that it supposes the length of the year to be $365^d\ 5^h\ 48^m\ 49^s.1875$, the real length being $365^d\ 5^h\ 48^m\ 49^s.7$. The difference is less than a second, while in the Gregorian calendar it amounts to more than twenty-one seconds. The first year of the Persian era began with the vernal equinox, A. D. 1070. The astronomers of that country have very wisely avoided subjecting themselves to the unnecessary and embarrassing condition that the equinox should always coincide with the first day of the year. However, in their system it never can be far from it, while in the Gregorian the real equinox, which ought to fall on the 21st of March, may sometimes fall on the 19th. There can then be little doubt that the Persian system is the most elegant and scientific of any that has hitherto been used.

The principal objection to it is, that the intercalations cannot follow a law so simple as those in the Gregorian calendar. On the other hand, it surpasses the latter in accuracy, as it does that adopted during the revolution in France, by being freed from the extreme complication consequent on making the beginning of the year invariably coincide with the equinox.

It is fortunate for astronomy that the confusion of dates, and the irreconcilable contradictions which historical statements too often exhibit when confronted with the best knowledge we possess of the ancient reckonings of time, affect recorded observations but little. An astronomical observation of any striking and well-marked phenomenon, carries with it, in most cases, abundant means of recovering its exact date when any tolerable approximation is afforded to it by chronological records, and, so far from being abjectly dependent on the obscure and often contradictory dates which the comparison of ancient authorities indicates, is often itself the surest and most convincing evidence on which a chronological epoch can be brought to rest. Remarkable eclipses, for instance, now that the lunar theory is thoroughly understood, can be calculated back for several thousands of years without the possibility of mistaking the day of their occurrence; and whenever any such eclipse is so interwoven with the account given by an ancient author of some historical event as to indicate precisely the interval of time between the eclipse and the event, and at the same time completely to identify the eclipse, that date is recovered and fixed forever.

The days thus parcelled out into years, the next step to a perfect knowledge of time is to secure the identification of each day by imposing on it a name universally known and employed. Since, however, the days of a whole year are too numerous to admit of loading the memory with distinct names for each, all nations have felt the necessity of breaking them down into parcels of a more moderate extent, giving names to each of these parcels, and particularizing the days in each by numbers, or by some especial indication. The lunar month has been resorted to in many instances, and some nations have, in fact, preferred a lunar to a solar chronology altogether, as the Turks and Jews continue to do to this day, making the year consist of thirteen lunar months, or three hundred and fifty-five days. Our own division into twelve unequal months is entirely arbitrary, and often productive of confusion, owing to the equivoque between the lunar and calendar month. The intercalary day naturally attaches itself to February as the shortest.

The first month of the Jewish year fell, according to the moon, in our August and September, the second in September and October, and so on. The first month of the Egyptian year began on the 18th of our August. The first month of the Arabic and Turkish year began the 6th of July. The first month of the Grecian year fell, according to the moon, in June and July, the second in July and August.

A month is divided into four parts called weeks, and a week into seven parts called days, so that in a Julian year there are thirteen such months, or fifty-two weeks, and one day over. The ancients gave the names of the sun, moon, and planets to the days of the week: To the first, the name of the sun; to the second, of the moon; to the third, of Mars; to the fourth, of Mercury; to the fifth, of Jupiter; to the sixth, of Venus; and to the seventh, of Saturn.

A day is either natural or artificial. The natural day contains twenty-four hours: the artificial day is the time from sunrise to sunset. The natural day is either astronomical or civil. The astronomical day begins at noon, because the increase and decrease of days terminated by the horizon are very unequal among themselves, and this inequality is augmented by the inconstancy of the horizontal refractions; therefore the astronomer takes the meridian for the limit of diurnal revolutions, reckoning noon (that is, the instant when the sun's centre is on the meridian) for the beginning of the day. The Americans, British, French, Dutch, Germans, Spaniards, Portuguese, and Egyptians begin the civil day at midnight; the ancient

Greeks, Jews, Bohemians, Silesians, with the modern Italians and Chinese, at sunset; the ancient Babylonians, Persians, Syrians, with the modern Greeks, at sunrise.

An hour is a certain determinate part of the day, and is either equal or unequal. An equal hour is the twenty-fourth part of a mean natural day, as shown by well-regulated clocks and watches; but these hours are not quite equal as measured by the returns of the sun to the meridian, because of the obliquity of the ecliptic and sun's unequal motion in it. Unequal hours are those by which the artificial day is divided into twelve parts, and the night into as many.

An hour is divided into sixty equal parts called minutes, a minute into sixty equal parts called seconds, and these again into sixty equal parts called thirds. The Jews, Chaldeans, and Arabians divide the hour into ten hundred and eighty equal parts called scruples,—a number which contains eighteen times sixty, so that one minute contains eighteen scruples.

A *cycle* is a perpetual round, or circulation of the same parts of time of any sort. The *cycle of the sun* is a revolution of twenty-eight years, in which time the days of the months return again to the same days of the week, the sun's place to the same signs and degrees of the ecliptic on the same months and days so as not to differ one degree in one hundred years, and the leap-years begin the same course over again with respect to the days of the week on which the days of the months fall. The *cycle of the moon*, commonly called the *golden number*, is a revolution of nineteen years, in which time the conjunctions, oppositions, and other aspects of the moon are within an hour and a half of being the same as they were on the same days of the months nineteen years before. The *indiction* is a revolution of fifteen years, used only by the Romans for indicating the times of certain payments made by the subjects to that republic. It was established by Constantine, A. D. 312.

Our Savior's birth, according to the common era, was in the 9th year of the solar cycle, and the 1st year of the lunar cycle; and the 312th year after his birth was the first year of the Roman indiction. Therefore, to find the year of the solar cycle, add nine to any given year of Christ, and divide the sum by twenty-eight; the quotient is the number of cycles elapsed since his birth, and the remainder is the cycle for the given year; if nothing remains, the cycle is twenty-eight. To find the lunar cycle, add one to the given year of Christ, and divide the sum by nineteen; the quotient is the number of cycles elapsed in the interval, and the remainder is the cycle for the given year; if nothing remains, the cycle is nineteen. Lastly, subtract three hundred and twelve from the given year of Christ, and divide the remainder by fifteen, and what remains after this division is the indiction for the given year; if nothing remains, the indiction is fifteen.

The *cycle of Easter*, also called the *Dionysian period*, is a revolution of five hundred and thirty-two years, found by multiplying the solar cycle twenty-eight by the lunar cycle nineteen. If the new moons did not anticipate upon this cycle, Easter-day would always be the Sunday next after the first full moon that follows the 21st of March; but, on account of the anticipation, to which no proper regard was had before the alteration of the style, the ecclesiastic Easter was several times a week different from the true Easter. This inconvenience is now remedied by making the table in the Common Prayer Book, which used to find Easter forever, of no longer use than the lunar difference from the new style will admit of.

The earliest Easter possible is the 22d of March, the latest the 25th of April. Within these limits are thirty-five days, and the number belonging to each of them is called the *number of direction*, because thereby the time of Easter is found for any given year.

The first seven letters of the alphabet are commonly placed in the almanacks to show on what days of the week the days of the months fall throughout the year; and because one of those seven letters must necessarily stand against Sunday, it is printed in a capital form, and called the Dominical letter, the other six being inserted in small characters to denote the other six days of the week. Now, since a common Julian year contains three hundred and sixty-five days, if this number be divided by seven (the number of days in a week) there will remain one day. If there had been no remainder, it is plain that the year would constantly begin on the same day of the week; but since one remains, it is as plain that the year must begin and end on the same day of the week, and therefore the next year will begin on the day following. Hence, when January begins on Sunday, A is the Dominical or Sunday letter for that year; then, because the next year begins on Monday, the Sunday will fall on the seventh day, to which is annexed the seventh letter G, which, therefore, will be the Dominical letter for all that year; and, as the third year will begin on Tuesday, the Sunday will fall on the sixth day, and therefore F will be the Sunday letter for that year;—whence it is evident that the Sunday letters will go annually in a retrograde order thus, G, F, E, D, C, B, A. In the course of seven years, if they were all common ones, the same days of the week and Dominical letters would return to the same days of the months; but because there are three hundred and sixty-six days in a leap-year, if this number be divided by seven, there will remain two days over and above the fifty-two weeks of which the year consists, and, therefore, if the leap-year begins on Sunday, it will end on Monday, and the next year will begin on Tuesday, its first Sunday falling on the 6th of January, to which is annexed the letter F, and not G, as in common years. By this means, the leap-year returning every fourth year, the order of the Dominical letters is interrupted, and the series cannot return to its first state till after four times seven, or twenty-eight years, and then the same days of the months return in order to the same days of the week as before.

From the multiplication of the solar cycle of twenty-eight years into the lunar cycle of nineteen years and the Roman indiction of fifteen years, arises the great *Julian period*, consisting of 7980 years, which had its beginning 764 years before Strauch's supposed year of the creation, (for no later could all the three cycles begin together,) and it is not yet completed, and therefore it includes all other cycles, periods, and eras. There is but one year in the whole period that has the same numbers for the three cycles of which it is made up, and, therefore, if historians had remarked in their writings the cycles of each year, there would have been no dispute about the time of any action recorded by them.

The Dionysian or common era of Christ's birth was about the end of the year of the Julian period 4713, and consequently the first year of his age, according to that account, was the 4714th year of the said period. Therefore, if to the current year of Christ we add 4713, the sum will be the year of the Julian period: so the year 1837 will be found to be the 6550th year of that period. Or, to find the year of the Julian period answering to any given year before the first year of Christ, subtract the number of that given year from 4714, and the remainder will be the year of the Julian period. Thus, the year 585 before the first year of Christ (which was the 584th before his birth) was the 4129th year of the said period. Lastly, to find the cycles of the sun, moon, and indiction for any given year of this period, divide the given year by twenty-eight, nineteen, and fifteen; the three remainders will be the cycles sought, and the quotients the numbers of cycles run since the beginning of the period. So in the above 4714th year of the Julian period, the cycle of the sun was ten, the cycle of the moon two, and the cycle of indiction four, the solar cycle having run through 168 courses, the lunar 248, and the indiction 314.

The common era of Christ's birth was not settled till the year 527, when Dionysius Exiguus, a Roman abbot, fixed it, as above stated, at the end of the 4713th year of the Julian period. This was four years too late, for our Savior was born before the death of Herod, who sought to kill him as soon as he heard of his birth, and, according to the testimony of Josephus, there was an eclipse of the moon in the time of Herod's last illness, which eclipse appears, by our astronomical tables, to have been in the year of the Julian period 4710, March

13th, at three hours past midnight, at Jerusalem. Now, as our Savior must have been born some months before Herod's death, since in the interval he was carried into Egypt, the latest time in which we can fix the true era of his birth is about the end of the 4709th year of the Julian period.

CHAPTER IX.

SECTION I.

Mensuration of the earth—Standard of measure—Astronomy teaches how to obtain the dimensions of the globe—Richer's observations on the pendulum—Their consequences—Laws of the pendulum—Oblate form of the earth confirmed by analogy—Early attempts to measure the earth—Riccioli's method—Snellius—Norwood—and others—Opposite theories of Newton and Huygens—Maupertuis measures a degree in Sweden, and Godin in Peru—Result—Explanation of the method of measuring the earth.

To measure the earth, and thence to determine its magnitude and figure, is one of the most astonishing enterprises that was ever undertaken. Confined to a particular spot, without any other scale or model than his own proper dimensions, how is man to find the distances of places which he can never visit, and to embrace the circumference of the globe? The space he has passed through may be estimated by the number of steps he has taken, and this will furnish him with some of the most simple measures, such as the foot and yard. The cubit is the length of his arm from the elbow to the tip of his middle finger, and the fathom or toise is his height, or the distance he can reach with his arms extended. But what are these small measures in comparison to the perimeter of the earth? Instead of being confounded by the inadequacy of his natural powers, man finds a resource in his intelligence which supplies their defect. He multiplies small measures till he arrives at the greatest, and forms to himself a unit to which he refers all the parts of the universe.

By means of cords or chains, which are certain multiples of the toise or the yard, he obtains an artificial measure more convenient than the natural one, and with this new standard, repeated a certain number of times in the same manner as before, he forms furlongs, miles, and leagues, and undertakes to measure such distances as would otherwise be indeterminable. But if it were required to trace the whole circumference of the earth in order to obtain its measure, the thing would be impossible. Mountains, rivers, and seas would be perpetual obstacles in the way, and uninhabitable climates would put a stop to our progress. In order to surmount these difficulties we must have recourse to astronomy, which furnishes a method of measuring the whole globe by ascertaining the length of a small arc of one of its great circles.

A little before the discovery of America, the notion of the earth's having a globular form was treated by many as an impious absurdity. The voyage of Columbus restored to the earth its spherical figure, and the belief became general that it was a *perfect globe*, and the observed simplicity of nature seems to favor this idea. It however proved to be false. Richer, in a voyage made to Cayenne, among other observations found that the pendulum of his clock no longer vibrated so frequently as it had done at Paris. It was necessary to shorten it considerably in order to make it agree with the times of the stars' passages over the meridian.

Who could have believed, that, from an observation so trifling in appearance, there should have originated so sublime and philosophic a truth! A pendulum, like any other falling body, is acted upon by the force of gravity, and, in consequence of Richer's discovery, it was observed, that, since the gravity of bodies is the less powerful the farther they are removed from the centre of the earth, the region of the equator must be more elevated than that of France, and therefore the figure of the earth cannot be a sphere.

The most intense summer heat will lengthen an iron rod of thirty feet long only about the eleventh part of an inch; but the alteration in a pendulum rod of little more than three feet long was found to be nearly twice as great as this. It was therefore evident that the variation must have been owing to some other cause. This was confirmed by the French academicians in the expedition to Peru. They inform us, that, about Quito, *at a time when it froze*, they were obliged *to shorten the pendulum for seconds about a sixth part of an inch.* The same phenomenon has been frequently observed at various places, and it was found in all that the alteration was greater the nearer they were to the equator. This being the case, we can no longer hesitate in believing it to be caused by an actual diminution of gravity in those places where the experiment was made. This discovery, trifling as it may seem, opened a new field of speculation, and there are, perhaps, few facts in the circle of the sciences from which so many curious and useful consequences have been derived.

Newton and Huygens seized the new truth with avidity, and, by following it through all its consequences, obtained the solution of a problem that seemed beyond the reach of human abilities. This was the determination of the figure of the earth, which they discovered from mathematical considerations only.

It is a property of the pendulum that all its vibrations, when made in small arcs at the same place, are performed in the same sensible time, and that the periods in which each vibration is performed is proportional to the square root of the length of the rod. Thus in the latitude of fifty-two degrees a pendulum of thirty-nine inches and an eighth in length makes its vibrations in a second, and one of about nine inches and three quarters makes its vibrations in half a second, so that the shorter the pendulum the swifter it moves.

But the time also depends on the intensity of the force which impels the pendulum toward the centre of the earth. If this force be diminished, the body, having a less tendency to motion, will employ a longer time to move through the same space, and, therefore, in order that each vibration may be made in the same time as it was before, the rod must be shortened. This was the case at Cayenne. It was necessary to shorten the rods of the pendulums to make them perform their vibrations in the same time as at Paris. But what is the cause that renders gravity less powerful under the equator than at Paris? The diurnal rotation of the earth is performed round an imaginary line which passes through the poles, and, as the equator is farther from this axis of motion than any parallel circle, it is evident that those parts which lie under the equator will move with a greater velocity than those which are nearer the poles, and of course the equatorial will become more elevated than the polar regions, so that if the entire earth were a fluid, and this fluid met with no obstacles in its progress, it would flow from the poles toward the equator until an equilibrium was produced.

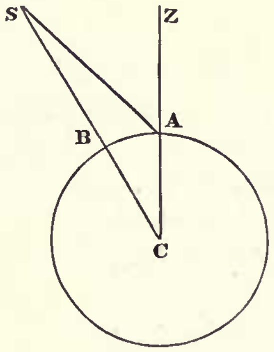
This tendency of bodies to fly from the centre (which was spoken of in a former section) may be made evident in various ways. When a stone is whirled round swiftly by means of a sling, the arm finds itself stretched by a force that is exerted upon it by the stone in its endeavors to recede from the centre, and if the stone be suddenly disengaged from the sling, it will immediately manifest the tendency which it has to leave this constrained circular motion by flying off in a straight line. Again, suppose a car on a railroad, moving in a right line, should arrive at a curve of small radius; the tendency of the car would be to proceed straight onward, but the flanges of the wheel detain it on the track, and, provided the propelling force be not too great, nor the flanges weak, it will follow the curve of the road. But suppose the velocity of the car excessive, or the flanges incapable of sustaining the pressure upon them; then the wheels will be lifted from the track, or the flanges be broken, and the car will manifest its centrifugal tendency by leaving its constrained orbit, and moving on in the direction of a tangent to the curve of the road, i. e. it will run off the track. Now this tendency to proceed onward in a right line has been imparted to all the heavenly bodies; no one can explain how; we believe by divine impulse. But the centripetal force, (represented in the example of the sling by the thong, and in that of the car by the flanges of the wheels,) that is, the force of gravity, tends to make these bodies rush to their centres of motion—the secondaries to their primary, the primaries to the sun. The same tendency which the moon has to the earth, and the earth to the sun, exists in all bodies near the earth to fall towards its centre, and the same tendency to fly off exists in them: between these two tendencies we have a constant rotation of all of them around the earth's axis. The nearer a body is to the axis of motion, the more strongly will it be drawn toward that axis, and the less will be the tendency to fly off, because the motion is less: from both these causes, then, the tendency of the particles would be to recede from the poles, and accumulate at the equator. The experiments of Richer, at Cayenne, seemed well accounted for by the variation of gravity at different parts of the earth's surface, occasioned by their greater or less distance from the axis of motion, and by the difference of centrifugal force in different latitudes, owing to the various velocities in the motion of different parts of the earth; on both which accounts, a diminution of the weight of bodies must necessarily take place in the equatorial regions, and cause them to tend to the centre with less force than at places near the poles. This variation more particularly manifests itself in the vibrations of a pendulum, which is the instrument that first led to the discovery here spoken of, and is still the most accurate that we possess for measuring the intensity of gravity in different situations; for its oscillations being immediately accelerated or retarded by the slightest alteration in this force, the continual repetition of them for a sufficient length of time renders the minutest change obvious by means of the clock to which the pendulum is attached. Every part of the globe from the centre to the circumference is subject to the action of centrifugal force; and supposing the primitive figure of the earth to have been a perfect sphere, which shape we might believe it would naturally assume from the mutual attraction of its parts, the constant rotation would change it into an oblate spheroid. This was the figure ascribed to it by Newton.

Such is the wonderful connection and secret dependence of things. Nature is uniform in all her operations, and it is her peculiar excellence that she often produces the greatest effects from the most apparently trivial causes.

The elliptical figure of the earth, however, is a mathematical truth, which is confirmed by analogy, for by means of a good telescope we can perceive that the planets Jupiter and Saturn are flattened at their poles. What exists in one planet is *possible* in another, and it is natural to infer the effect in the earth from a similar cause. But as their rotations are more rapid than that of the earth, so the alterations in their figure is much more considerable.

We are assured, from the testimony of Herodotus and other early historians, that attempts had been made to discover the true figure of the earth by many of the most celebrated mathematicians of antiquity. Ptolemy, in his writings, has preserved the measures of several persons* who lived before

* It is now about two thousand years since Eratosthenes attempted to resolve this important problem. He knew that, on the day of the summer solstice, the sun illumined the bottom of a well at Syene. At the same instant, he observed at Alexandria that the sun was seven degrees and twelve minutes from the zenith, and it was supposed that Syene was due south from that place, and therefore that both were under the same meridian. Let C be the earth's centre, A Alexandria, Z its zenith in the heavens, B Syene, and S the sun at the instant when it illuminated the bottom of the well, and consequently was in the zenith of that place. The angular measure of the celestial arc Z S, or the corresponding terrestrial arc A B, is the angle Z C S at the earth's centre. Eratosthenes observed the angle Z A S, which, by the elements of geometry, is less than the former by the angle A S C. However, this difference is so small that it may be altogether neglected in the present case, and thus the angle A C B will be nearly seven degrees and twelve minutes, that is, one fiftieth part of three hundred and sixty degrees, and consequently the arc A B of the terrestrial meridian one fiftieth of the earth's circumference. The distance between Alexandria and Syene had been determined to be five thousand stadia: hence it immediately followed that the earth's circumference was two hundred and fifty thousand stadia. As it could not be supposed that



the Christian era, and, from what Bailly has advanced in his "History of Astronomy," it appears highly probable that this singular enterprise had been undertaken in the still more remote ages of the world.

But as the determinations of the ancients are uncertain on account of our not being acquainted with the length of their principal measure, we shall pass over their peculiar methods, and proceed to those of the moderns, which are far more scientific.

Riccioli, an Italian, attempted to measure the earth according to a method mentioned by Kepler. As a plumb-line tends to the centre of the earth, and as the distance of any two places upon the surface may be taken for the base of a triangle whose vertex is at the centre, he measured a large base line of this kind in the most accurate manner he could, and found the angles which it made with a plumb-line at each of its extremities. The sum of these angles being subtracted from one hundred and eighty degrees, gave him the angle at the vertex. Then it was easy, by proportion, to find the whole circumference.

This method, however ingenious, is not accurate. He attempted to measure the earth without having recourse to celestial observations, an independence not to be attained. It is principally to the heavens that we are indebted for all that we know of the earth. Riccioli's error amounted to near six thousand toises in the length of a degree. The next who attempted to find the circumference of the earth was Snellius, a Dutchman. He measured a certain distance, and, by taking the celestial arc corresponding thereto, he found the length of a degree to be fifty-five thousand one hundred toises. His error appears to have been about two thousand toises in the length of a degree, most of which may have arisen from the use of poor instruments in measuring the celestial arc.

In 1635, Norwood, an Englishman, engaged in the same enterprise. He took the sun's altitude when it was in the summer solstice both at London and York, and by this means found the difference of latitude between these two cities to be two degrees and twenty-eight minutes. He then measured their distance in the usual manner, and, having reduced it to an arc of the meridian, he found it to contain twelve thousand eight hundred and forty-nine chains, which distance, compared with the difference of latitude, gave him about sixty-five miles to a degree.

All the measures, however, that had been hitherto taken were subject to many inaccuracies. The means of precision, which have since been found so requisite to an exact investigation of this delicate subject, were then wanting.

The Academy of Sciences, at Paris, perceiving from these and other considerations the necessity of a new measure of the earth, appointed Picard to perform this important duty, who, after immense labor, fixed the length of a degree at fifty-seven thousand and sixty toises, or about sixty-nine and a half English miles.

It was afterward determined by the French king that the whole arc running through France should be measured. This great work was undertaken by Picard, La Hue, and Cassini, and was finished in the year 1718. The length of a degree was decided to be as Picard had found it by his previous measurement.

These surveys had all been undertaken on the supposition that the earth was a perfect sphere; but the truth of this doctrine began to be controverted. Newton and Huygens had shown, from the known laws of gravitation, that the figure of the earth was an oblate spheroid. Cassini, on the other hand, depending more on the accuracy of his own measures than upon deductions drawn from theory, asserted it to be a prolate spheroid, that is, a sphere protuberant at the poles, and flattened at the equator.

To settle this question, it was decided that a degree should be measured at or near the equator, and at or near the polar circle. For this purpose, Maupertuis and others were sent to the north of Europe to measure the remotest degree they could reach; Godin and others to Peru. The first company began their operations at Tornea, near

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this result was very accurate, Eratosthenes reckoned the circumference to be two hundred and fifty-two thousand stadia, which give in round numbers seven hundred stadia to the length of a degree.

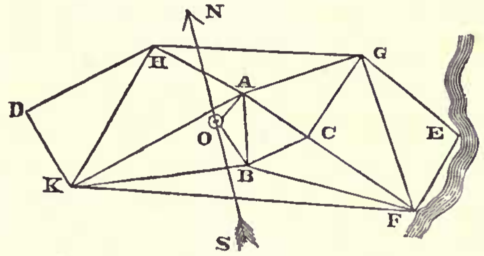
the Gulf of Bothnia, on the 8th of July, 1736, and finished them about the 1st of June, 1737. The result was, that the length of a degree of the meridian near the polar circle is one hundred and seven thousand six hundred sixty-six and a quarter English feet. The other party set off for Peru a twelve month earlier than their friends had for Lapland, yet did not finish their survey till 1741. In the province of Quito, they measured an arc of the meridian of three degrees and seven minutes, and the degree was found to be equal to one hundred and six thousand four hundred eleven and seven eighths English feet, being twelve hundred fifty-four and three eighths feet less than a degree at the polar circle.

These measures afforded a complete demonstration that the earth is flattened at the poles, and protuberant at the equator. For had the figure of it been a perfect globe, a degree of the meridian, in every latitude, would have been found of the same length; and had the figure been that assigned by Cassini, a degree at the polar circle would have been found less than one at the equator.

The measurement of different degrees has since been performed many times in different countries, as again in France, and also at the Cape of Good Hope, by La Caille; in Italy, by Maire, Boscovich, and Beccaria; in Pennsylvania, by Mason and Dixon; in Hungary, by Liesganig; in India, by Lambton.

We have heretofore spoken mostly of results; we shall now proceed to give the reader some general idea of the method of measuring the earth technically called *geodesic operations*. The ground to be surveyed is divided into a series of triangles, at the angles of which are stations conspicuously visible from each other. Of these triangles, the angles only are measured by means of a theodolite, with the exception of one side of one triangle, which is called a base, and which is measured with every refinement that ingenuity can devise, or expense command. This base is of moderate extent, rarely surpassing six or seven miles, and purposely selected in a perfectly horizontal plane, otherwise conveniently adapted for purposes of measurement. Its length between its two extreme points (which are dots on plates of gold or platina let into massive blocks of stone, and which are, or at least *ought to be*, in all cases preserved with almost religious care as monumental records of the highest importance) is then measured with every precaution to insure precision,* and its position with respect to the meridian, as well as the geographical positions of its extremities, carefully ascertained.

The annexed figure represents such a chain of triangles. A B is the base, O, C stations visible from both its extremities, (one of which, O, we will suppose to be an observatory, with which it is an object that the base should be as closely and immediately connected as possible,) and D, E, F, G, H, K other stations, remarkable points in the country, by whose connection its whole surface may be covered, as it were, with a network of triangles. Now it is evident, that, the angles of the triangle A, B, C being observed, and one of its sides, A B, measured, the other two sides A C, B C may be calculated by the rules of trigonometry, and thus each of the sides A C and B C becomes in its turn a *base* capable of being employed as known sides of other triangles. For instance, the angles of the triangles A C G and B C F being known by observation, and their sides A C and B C, we can thence calculate the lengths A G, C G, and B F, C F. Again, C G and C F being known, and the included angle G C F, G F may be calculated, and so on. Thus may all the stations be accurately determined and laid down, and this process may be carried on to any extent.



Now, on this process there are two important remarks to be made. The first is, that it is neces-

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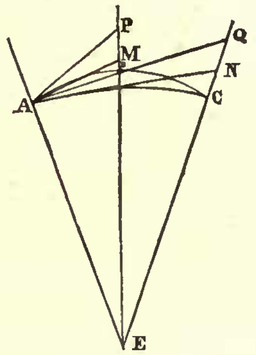
* The greatest *possible* error in the Irish base of between seven and eight miles, near Londonderry, is supposed not to exceed two inches.

sary to be careful in the selection of stations, so as to form triangles free from any *very* great inequality in their angles. For instance, the triangle K B F would be a very improper one to determine the situation of F from observations at B and K, because the angle F being very acute, a small error in the angle K would produce a great one in the place of F *upon the line B F.* Such *ill-conditioned* triangles, therefore, must be avoided. But if this be attended to, the accuracy of the determination of the calculated sides will not be much short of that which would be obtained by actual measurement if it were practicable; and, therefore, as we recede from the base on all sides as a centre, it will speedily become practicable to use *as bases* the sides of *much larger* triangles, such as G F, G H, H K, &c., by which means the next step of the operation will come to be prosecuted on a much larger scale, and embrace far greater intervals, than it would have been safe to do (for the above reason) in the immediate neighborhood of the base. Thus it becomes easy to divide the whole face of a country into *great triangles* of from thirty to one hundred miles in their sides, according to the nature of the ground, which, being once well determined, may be afterwards, by a second series of subordinate operations, broken up into smaller ones, and these again into others of a still minuter order, till the final filling in is brought within the limits of personal survey and draftsmanship, and till a map is constructed with any required degree of detail.

The next remark we have to make is, that all the triangles in question are not, rigorously speaking, *plane*, but *spherical*, existing on the surface of a sphere, or rather, to speak correctly, of an ellipsoid. In very small triangles, of six or seven miles in the side, this may be neglected, as the difference is imperceptible; but in the larger ones it must be taken into consideration.

It is evident, that, as every object used for pointing the telescope of a theodolite has some certain *elevation*, not only above the *soil*, but above the level of the *sea*, and as, moreover, these elevations differ in every instance, a *reduction to the horizon* of all the measured angles would appear to be required. But, in fact, by the construction of the theodolite, which is nothing more than an altitude and azimuth instrument, this reduction *is made* in the very act of reading off the horizontal angles. Let E be the centre of the earth; A, B, C the places on its *spherical surface* to which three stations A, P, Q, in a country, are referred by radii E, A, E B P, E C Q. If a theodolite be stationed at A, the axis of its horizontal circle will point to E when truly adjusted, and its plane will be a tangent to the sphere at A, intersecting the radii E B P, E C Q at M and N, *above* the spherical surface. The telescope of the theodolite, it is true, is pointed in succession to P and Q; but the readings off of its azimuth circle give, *not* the angle P A Q between the directions of the telescope, or between the objects P, Q, as seen from A, *but the azimuthal angle* M A N, which is the measure of the angle A of the spherical triangle B A C. Hence arises this remarkable circumstance, that the sum of the three observed angles of any of the great triangles in geodesical operations is always found to be rather *more* than one hundred and eighty degrees. Were the earth's surface a *plane*, it ought to be exactly one hundred and eighty degrees; and this *excess*, which is called the *spherical excess*, is so far from being a proof of incorrectness in the work that it is essential to its accuracy, and offers at the same time another palpable proof of the earth's sphericity.



The true way, then, of conceiving the subject of a trigonometrical survey, when the spherical form of the earth is taken into consideration, is to regard the network of triangles with which the country is covered as the bases of an assemblage of pyramids converging to the centre of the earth. The theodolite gives *us the true measures of the angles included by the planes of these pyramids*, and the surface of an imaginary sphere on the level of the sea intersects them in an assemblage of spherical triangles, above whose angles, in the radii prolonged, the real stations of observation are raised by the superficial inequalities of mountain and valley. The operose calculations of spherical trigonometry which this consideration would seem to render necessary for the reductions of a survey, are dispensed with in practice by a very simple and easy rule called the *rule for the spherical excess*, which is to be found in most works on trigonometry. If we would take into account the ellipticity of the earth, it may also be done by appropriate processes of calculation, which, however, are too abstruse to dwell upon in a work like the present.

Whatever process of calculation we adopt, the result will be a reduction to the level of the sea of all the triangles, and the consequent determination of the geographical latitude and longitude of every station observed.

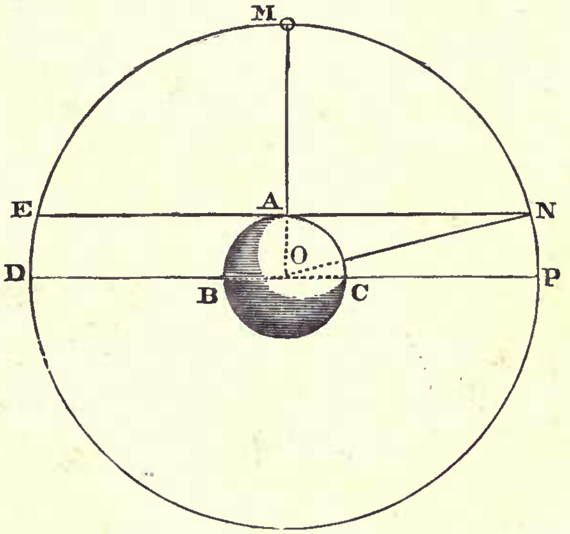
SECTION II.

Methods of finding the moon's parallax and distance—Difficulty in finding the sun's parallax—Transits of Mercury and Venus—Sun's parallax found by the transit of Venus—The sun's distance—Distances of the planets—Method of finding the diameters and magnitudes of the sun and planets—Method of finding their masses and densities.

Astronomy furnishes a variety of methods for determining the distances of the heavenly bodies; but as many of them are involved in long and difficult calculations, we shall confine ourselves to those that admit of the most familiar explanation. We shall begin with the moon, for the method of finding the distance of this our neighboring planet being once known, it will be easy to perceive that the same method may be extended to the other planets.

In the method about to be described, the first thing is to find the difference between the moon's place when it appears in the horizon to a spectator on the earth's surface, and that which it would appear to occupy to a person at the earth's centre, or, which is the same thing, to find the apparent semidiameter of the earth to an observer at the moon's centre. This may be shown to be practicable without entering into the minutiæ of the matter.

For this purpose, let us suppose an observer to be placed upon any point A of the equator B A C at the time the moon is moving in the celestial equator D M P; then, as the latter circle is in the plane of the former, the moon will pass directly over his head, and descend perpendicularly to the horizon E N. In this situation of the spectator at A, the moon will appear to have described a quarter of a circle, or ninety degrees, in passing from the zenith to the sensible horizon at N, while, to a spectator at O, the centre of the earth, it would not appear to have described a quarter of a circle till it reached the rational horizon at P.

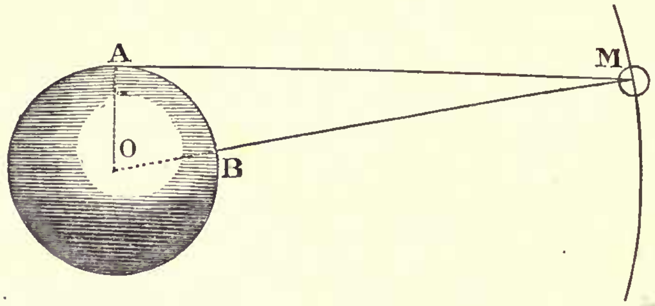


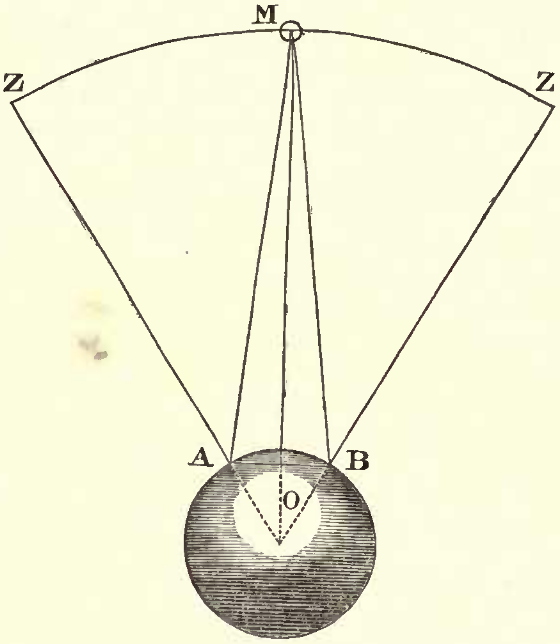
But the moon appears to revolve round the earth in about twenty-four hours and forty-eight minutes. It will therefore revolve from M to P in six hours and twelve minutes; and if the time required in moving from M to N be found by observation, and subtracted from six hours and twelve minutes, the time of moving from M to P, the remainder will be the time requisite to describe the arc N P. Having found the measure of N P in time, it is easily converted into degrees by allowing at the rate of fifteen degrees to an hour. Now the angle N O P contains the same number of degrees as the arc N P, and N O P is equal to A N O. This last angle A N O is called the moon's horizontal parallax.

Thus, in the triangle O N A, we have ang. A N O, the side A O equal to the semidiameter of the earth, and the angle O A N equal to ninety degrees. From these we can easily calculate the side O N, which here represents the moon's distance from the centre of the earth.

But the true quantity of the moon's horizontal parallax cannot be accurately determined by this method, on account of the varying declination of that body, and the perpetual changes in the state of the atmosphere. Astronomers have therefore thought of the following method, which is free from those objections, and is sufficient for determining the parallax and distance of the moon with some degree of precision.

Suppose two observers were placed under the same meridian at A and B, so distant from each other that the one at A sees the moon M in his horizon whilst the other at B sees it in his zenith. Now the angle at O is equal to the difference of latitude of the two observers, the angle A is ninety degrees, and the side A O is the semidiameter of the earth. These three things being given in the triangle A O M, it will be easy to find the side O M, the moon's distance. If the angle O be subtracted from ninety degrees, we shall have the angle at M, which is the moon's horizontal parallax. We hope our readers will readily comprehend this, as it is the simplest solution the problem admits. We shall add a more general method by which the distance of the moon can be determined when the observers are at any two distant places under the same meridian. Suppose the two observers were at the points A and B, whose distance A B, or difference of latitude, is already known; then measure the moon's distances from the zeniths Z and *z* at the moment it passes the celestial meridian Z *z*. The distance M O of the moon may be determined as follows :—





In the triangle A B O, A O and O B are each equal to the earth's semidiameter, and the angle A O B contains the same number of degrees as the arc A B, which is known. These three things being known, the side A B and the angles A B O and B A O can be calculated. If the angles M A Z and M B *z* (which contain the same number of degrees as the zenith distances already measured) be subtracted from one hundred and eighty degrees, the remainders will be the angles O A M and O B M. From the angles thus found subtract the angles B A O and A B O, (found before,) and there will remain the angle B A M and A B M; so that in the triangle A B M we have these two angles and the side A B; consequently the side M B may be found. Now, in the triangle O M B having the two sides B M and B O, and the angle O B M, we can easily find O M, the distance of the moon from the centre of the earth.

The distance of the sun from the earth might be determined in nearly the same manner as that of the moon, were not its horizontal parallax so small as to be scarcely perceptible; for the angle under which the semidiameter of the earth appears at the sun does not exceed nine seconds, and as a mistake of one second in so small an angle would occasion an error of no less than seven millions of miles in the distance, it may easily be perceived that an extraordinary degree of skill is requisite to surmount the difficulties attending this delicate subject. By means of the transits of Venus over the sun's disc, this problem has been solved with a degree of precision unlooked for by the astronomers of ancient times.

When Dr. Halley was at St. Helena, whither he went for the purpose of making a catalogue of the stars in the southern hemisphere, he observed a transit of Mercury over the sun's disc, and, by means of a good telescope, it appeared to him that he could determine the time of the ingress and egress without its being subject to an error of one second,* upon which he immediately concluded that the sun's parallax might be determined, by such observations, from the difference of the times of the transit over the sun at different places upon the earth's surface. But this difference is so small in Mercury that it would render the conclusion subject to a great degree of inaccuracy. In Venus, however, whose parallax is nearly four times as great as that of the sun, there will be a very considerable difference between the times of the transits seen from different parts of the earth, by which the accuracy of the conclusion will be proportionably increased. Halley, therefore, proposed to determine the sun's parallax from the transit of Venus over the sun's disc, observed at different places on the earth; and, as it was not probable that he himself should live to observe the next transits, which happened in 1761 and 1769, he very earnestly recommended the attention of them to the astronomers who should be alive at that time. Astronomers were therefore sent from England and France to the most proper parts of the earth to observe both those transits, from the result of which the parallax has been determined to a very great degree of accuracy.

Kepler was the first person who predicted the transits of Venus and Mercury over the sun's disc. He foretold the transit of Mercury in 1631, and the transits of Venus in 1631 and 1761. The first time Venus was ever seen upon the sun was in the year 1639, on November 24, at Hoole, near Liverpool, by Horrox. He was employed in calculating an Ephemeris from the Lansberg Tables, which gave, at the conjunction of Venus with the sun on that day, its apparent latitude less than the semidiameter of the sun. But as these tables had so often deceived him, he consulted the tables constructed by Kepler, according to which the conjunction would be at eight hours and one minute A. M., at Manchester, and the planet's latitude fourteen minutes and ten seconds south; but, from his own corrections, he expected it to happen at three hours and fifty-seven minutes P. M., with ten minutes south latitude. He accordingly gave this information to his friend Crabtree, at Manchester, desiring him to observe it; and he himself also prepared to make observations upon it by transmitting the sun's image through a telescope into a dark chamber. He described a circle of about six inches diameter, and divided the circumference into three hundred and sixty degrees, and the diameter into one hundred and twenty equal parts, and caused the sun's image to fill up the circle. He began to observe on the 23d, and repeated his observations on the 24th till one o'clock, when he was unfortunately called away by business; but returning at fifteen minutes after three o'clock, he had the satisfaction of seeing Venus upon the sun's disc, just wholly entered on the left side, so that the limbs perfectly coincided. At thirty-five minutes after three, he found the distance of Venus from the sun's centre to be thirteen minutes and thirty seconds; and at forty-five minutes after three, he found it to be thirteen minutes. The sun setting

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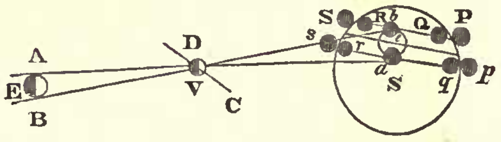
* Hence Dr. Halley concluded, that, by a transit of Venus, the sun's distance might be determined with certainty to the 500th part of the whole; but the observations upon the transits which happened in 1761 and 1769, showed that the time of contact of the limbs of the sun and Venus could not be determined with that degree of certainty.

at fifty minutes after three o'clock, put an end to his observations. From these observations, Horrox endeavored to correct some of the elements of the orbit of Venus. He found Venus had entered upon the disc at about sixty-two degrees and thirty minutes from the vertex towards the right on the image, which by the telescope was inverted. He measured the diameter of Venus, and found it to be to that of the sun as 1.12 : 30 as near as he could measure. Crabtree, on account of the clouds, got only one sight of Venus, which was at three hours and forty-five minutes. Horrox wrote a treatise entitled "Venus seen upon the sun," but did not live to publish it. It was, however, afterwards published by Hevelius. Gassendus observed the transit of Mercury which happened on November 7, 1631, and this was the first which had ever been observed. He made his observations in the same manner that Horrox did after him. Since his time, several transits of Mercury have been observed, as they frequently happen; whereas only two transits of Venus have happened since the time of Horrox.

The transits of Venus are of very rare occurrence, taking place alternately at intervals of eight and of one hundred and thirteen years, or thereabouts. As astronomical phenomena, they are, however, extremely important, since they afford the best and most exact means we possess of ascertaining the sun's distance or its parallax. Without going into the niceties of calculation of this problem, which, owing to the great multitude of circumstances to be attended to, are extremely intricate, we shall here explain its principle, which, in the abstract, is very simple and obvious. Let E be the earth, V Venus, and S the sun, and C D the portion of Venus's relative orbit which she describes while in the act of transiting the sun's disc. Suppose A B two spectators at opposite extremities of that diameter of the earth which is perpendicular to the ecliptic, and, to avoid complicating the case, let us lay out of consideration the earth's rotation, and suppose A, B to retain that situation during the whole time of the transit. Then, at any moment when the spectator at A sees the centre of Venus projected at *a* on the sun's disc, he at B will see it projected at *b*. If one or other spectator could then suddenly transport himself from A to B, he would see Venus suddenly displaced on the disc from *a* to *b;* and if he had any means of noting accurately the place of the points on the disc, either by micrometrical measures from its edge, or by other means, he might ascertain the angular measure of *a b* as seen from the earth. Now, since A V *a*, B V *b* are straight lines, and therefore make equal angles on each side of V, *a b* will be to A B as the distance of Venus from the sun is to its distance from the earth, or as sixty-eight to twenty-seven, or nearly as two and a half to one: *a b*, therefore, occupies on the sun's disc a space two and a half times as great as the earth's diameter, and its angular measure is therefore equal to about two and a half times the earth's apparent diameter at the distance of the sun, or, which is the same thing, to five times the sun's horizontal parallax. Any error, therefore, which may be committed in measuring *a b*, will entail only *one fifth* of that error on the horizontal parallax concluded from it.



The thing to be ascertained, therefore, is, in fact, neither more nor less than the breadth of the zone P Q R S, *p q r s*, included between the extreme apparent paths of the centre of Venus across the sun's disc from its entry on one side to its quitting it on the other. The whole business of the observers at A, B, therefore, resolves itself into this,—to ascertain, with all possible care and precision, each at his own station, this path, where it enters, where it quits, and what segments of the sun's disc it cuts off. Now, one of the most exact ways in which (conjoined with careful micrometric measures) this can be done, is by noting the *time* occupied in the whole transit; for the relative angular motion of Venus being, in fact, very precisely known from the tables of her motion, and the apparent path being very nearly a straight line, these times give us a measure, *on a very enlarged scale*, of the lengths of the chords of the segments cut off, and the sun's diameter being known also with great precision, their versed sines, and therefore their difference, or the breadth of the zone required, becomes known. To obtain these times correctly, each observer must ascertain the instants of ingress and egress of the *centre*. To do this, he must note, 1st, the instant when the first visible impression or notch on the edge of the disc at P is produced, or the *first external contact;* 2dly, when the planet is just wholly immersed, and the broken edge of the disc just closes again at Q, or the first *internal* contact; and, lastly, he must make the same observations at the egress at R, S. The mean of the internal and external contacts gives the entry and egress of the planet's centre.

The modifications introduced into this process by the earth's rotation on its axis, and by other geographical stations of the observers thereon than here supposed, are similar in their principles to those which enter into the calculation of a solar eclipse, or the occultation of a star by the moon, only more refined. Any consideration of them here, however, would lead us too far; but in the view we have taken of the subject, it affords an admirable example of the way in which minute elements in astronomy may become magnified in their effects, and, by being made subject to measurements on a greatly-enlarged scale, or by substituting the measure of time for space, may be ascertained with a degree of precision adequate to every purpose, by only watching favorable opportunities, and taking advantage of nicely-adjusted combinations of circumstances. So important has this observation appeared to astronomers, that, at the last transit of Venus, in 1769, expeditions were fitted out, on the most efficient scale, by the British, French, Russian, and other governments to the remotest corners of the globe for the express purpose of performing it. The celebrated expedition of captain Cook to Otaheite was one of them. The general result of all the observations made on this most memorable occasion gives 8″.5776 for the sun's horizontal parallax.

Having found the parallax of the sun from a transit of Venus over that luminary, the same method may be applied to find its distance from the earth as was used to find the moon's distance. And, as we have before stated this distance at mean is found to be about ninety-five millions of miles,—a distance so immense that a cannon ball (which, with a certain charge, is known to move at the rate of about eight miles a minute) would be more than twenty-two years in going from the earth to the sun; and if a spectator could be placed in the sun, and was to look at the semi-diameter of the earth, this line, which is nearly four thousand miles in length, would appear to him under an angle of only eight and a half seconds. Consider this, and you will find it a subject worthy of admiration and wonder.

The distance of the earth from the sun being thus found, the distance of all the rest of the planets may be determined by the stated laws of nature,—laws that have been mentioned as the discoveries of Kepler. Suppose, for example, we wished to find the distance of Saturn from the sun; this may be found by proportion as follows: As the square* of the earth's period of revolution is to the square of Saturn's period, so is the cube† of the earth's mean distance to the cube of Saturn's mean distance. The cube root of this last number being found, will be the mean distance of Saturn from the sun.

In a manner equally easy may the real diameters of the sun and planets be determined from their apparent diameters and their distances.‡ Also, having found the real diameter of any heavenly body, its magnitude may be deduced therefrom. Thus, since the diameter of the earth is known to be seven thousand nine hundred and twelve miles, and that of the sun eight hundred and

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* A square is the product of a number by itself. Thus, four times four is sixteen: sixteen is the square of four.

† A cube is the product of a number by itself twice. Thus, four times four is sixteen, and four times sixteen is sixty-four: sixty-four is the cube of four, and four is the cube root of sixty-four.

‡ Thus, for example, if A B C be the sun, whose mean apparent diameter as seen from the earth E is thirty-two minutes and three

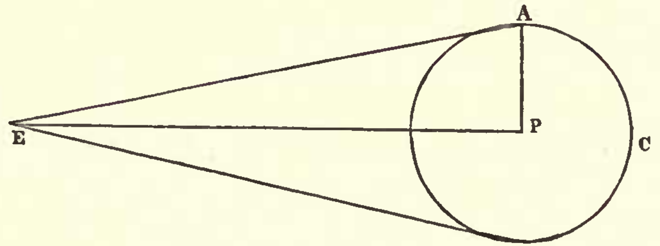
eighty-two thousand miles, and as the magnitudes of spherical bodies are to each other as the cubes of their diameters, it would be seen, if we should compare the cube of the first number with the cubes of the sun's and moon's diameters, that the bulk of the sun is more than a million of times greater than that of the earth, and the bulk of the earth about fifty times greater than that of the moon. And in the same manner might the diameters and magnitudes of the other planets be determined, supposing their distances and apparent diameters already known.

Another problem equally curious with the last, and apparently involved in greater obscurity, is to determine the comparative densities of the sun and planets with respect to that of the earth. When we consider their immense distances from us, this seems too great an undertaking for the limited powers of the human mind. But difficulties presented to an active mind, instead of repressing its ardor and retarding its progress, serve only to stimulate it to greater exertions and nobler pursuits. We have already seen by what means the magnitudes and distances of the planets have been ascertained, and we shall endeavor to render the present subject equally clear. For this purpose, it will be proper to observe, that, by the densities of bodies is to be understood their degree of compactness, or the greater or less quantity of matter that is contained in them when compared, bulk for bulk, with each other. According to this definition, the quantities of matter in bodies will be as their densities when their magnitudes are equal, and as their magnitudes when their densities are equal; therefore the quantities of matter in any two bodies are jointly as the products of their magnitudes and densities, and, therefore, conversely, the densities of bodies of different magnitudes may be expressed by their masses divided by their magnitudes.

We must explain, therefore, by what means a knowledge of the masses of the heavenly bodies is obtained, since the rest may be found by common division. To do this, we must have recourse to the doctrine of gravitation, from which it is known that the quantity of matter in the sun and planets is as their attractive power at equal distances from their centres. If, therefore, we can ascertain the relative attractive powers of any two of those bodies, this will give their relative masses, from which, and their known magnitudes, their densities with respect to each other may be determined with facility.

The ratio of this attractive power between the earth and sun is easily ascertained, for a body at the earth's surface is known to fall through sixteen and one twelfth feet in the first second of its descent, and since the spaces described at different distances from the centre are reciprocally as the squares of those distances, it is easy to compute what space a body would fall through in a second toward the earth if it were placed at the distance of the sun. And as the diameter of the earth's orbit is known, and the time of its annual revolution, we can ascertain the arc described by this body in a second, and thence how much it is deflected from its tangent in a second by the attractive power of the sun, or, which is the same, through what space a body would descend in one second toward the sun were it placed at the distance of the earth. Whence, going through the calculation here mentioned, we shall have the spaces described by a body when placed at equal distances from the sun and earth respectively, and descending toward them during equal portions of time; and since the spaces fallen through, in this case, are as the attractive powers, and the latter are as the masses of the attracting bodies, we have at once, by com-

seconds, and its mean distance ninety-five millions of miles, the proportion will be, As the sine of ninety degrees is to E P, (ninety-five



million,) so is the sine of A E P sixteen minutes and one and a half seconds to P A, the double of which, or A B, is the diameter of the sun in miles.

paring the spaces so described, the relative proportion of the masses of the earth and sun, and, by dividing their relative masses by their absolute magnitudes, we obtain their proportional densities.

From this computation, it will appear that the density of the earth is to the density of the sun as four to one, and, as the density of the earth is known to be to the density of water as five and a half to one, it follows that the density of the sun is to that of water as one and three-eighths to one. We cannot, however, proceed in the same manner with the other planets, because we have no means of ascertaining their respective attractive powers at their surfaces; therefore we must have recourse to their satellites, and compare the deflection of each of them from its tangent with their respective distances from their primaries. For example, to find the relative densities of the earth and Jupiter, we must first estimate how much the moon is deflected from her tangent in one second by the attractive power of the earth, and how much it would be deflected in the same time if it were placed at the same distance from the centre of the earth as any one of Jupiter's satellites is from the centre of that planet, which distances are all known from their periodic times.

By this means, we shall have the absolute spaces described by two bodies, placed at the same distances, and falling in the same time toward the earth and Jupiter; and these spaces, as we have before seen, being as the attractive power of the two bodies, and the latter as their masses, it follows, that, by comparing, as above, the spaces described, we shall obtain the ratio of the masses, the division of which by their absolute magnitudes will give us their proportional densities. From this it will appear that the density of Jupiter is to that of the earth as $\frac{23}{100}$ to 1, being a little less than the density of the sun, and a little more than that of sea-water.

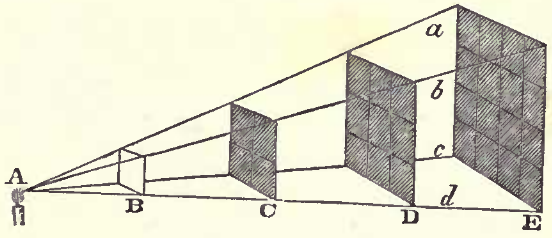
It is obvious that the same method may be employed for determining the density of Saturn and Herschel; but those planets which have no satellites cannot be submitted to the same calculation, nor would it be proper in this treatise to attempt to render the method used in these cases intelligible, as it requires a knowledge of some of the higher branches of mathematics.

SECTION III.

Nature of light unsettled—Its properties known—Refraction—Experiments illustrating refraction—Cause of twilight—Advantages and disadvantages of refraction—Knowledge of the atmosphere important to the astronomer—Amount of refraction at the zenith, the horizon, and at intermediate points—Explanation of the "sun drawing water"—Terrestrial refraction—Aberration—Bradley's observations—Inferences—Motion of light—Aberration confirms the motion of the earth in an orbit—Precession of the equinoxes—Nutation—Obliquity of the ecliptic—Its cause and effects.

There is, perhaps, no subject in natural philosophy that has been more controverted than that relating to the nature of light, some considering it as a fluid, and others as a principle consisting in pulsations, or vibrations, propagated from the luminous body through a subtle etherial medium, which affects the optic nerve in the same manner as sound affects the organ of hearing. But this uncertainty has not prevented astronomers from obtaining a knowledge of its properties.

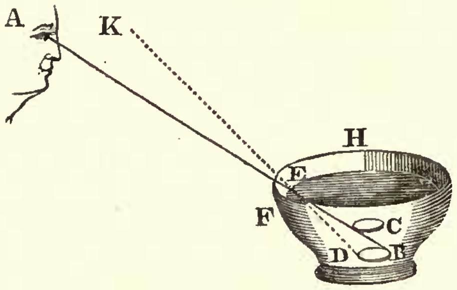
Light, so far as it depends on the sun's rays, decreases in proportion to the squares of the distances of the planets from the sun. This is easily demonstrated by a figure. Let the light which flows from a point A, and passes through a square hole B, be received upon a plane C parallel to the plane of the hole, or let the figure C be the shadow of the plane B, and when the distance C is double of B, the length and breadth of the shadow C will be each double of the length and breadth of the plane B, and treble when A D is treble of A B, and so on, which may be easily



examined by the light of a candle placed at A. Therefore the surface of the shadow C, at the distance A C, (double of A B,) is divisible into four squares, and at a treble distance into nine squares, severally equal to the square B, as represented in the figure. The light, then, which falls upon the plane B, being suffered to pass to double that distance, will be uniformly spread over four times the space, and consequently will be four times thinner in every part of that space; and at a treble distance it will be nine times thinner; and at a quadruple distance, sixteen times thinner than it was at first; and so on, according to the increase of the square surfaces B, C, D, E, built upon the distances A B, A C, A D, A E. Consequently the quantities of this rarefied light received upon a surface, of any given size and shape whatever, removed successively to these several distances, will be but one quarter, one ninth, one sixteenth of the whole quantity received by it at the first distance A B; or, in general words, the densities and quantities of light received upon any given plane are diminished in the same proportion as the squares of the distances of that plane from the luminous body are increased, and, on the contrary, are increased in the same proportion as these squares are diminished.

The more a telescope magnifies the disks of the moon and planets, they appear so much dimmer than to the naked eye, because the telescope cannot magnify the quantity of light as it does the surface, and, by spreading the same quantity of light over a surface so much larger than the naked eye beheld, just so much dimmer must it appear when viewed by a telescope than by the naked eye.

When a ray of light passes out of one medium* into another, it is refracted, or turned out of its first course, more or less as it falls more or less obliquely on the refracting surface which divides the two media. This may be proved by several experiments: 1st, in a basin F G H put a piece of money, as D B, and then retire from it, as to A, till the edge of the basin at E just hides the money from your sight; then, keeping your head steady, let another person fill the basin gently with water. As he fills it, you will see more and more of the piece D B, which will be all in view when the basin is full, and appear as if lifted up to C; for the ray A E B, which was straight whilst the basin was empty, is now bent at the surface of the water in E, and turned out of its rectilineal course into the direction E D; or, in other words, the ray D E K, that proceeded in a straight line from the edge D whilst the basin was empty, and went above the eye at A, is now bent at E, and, instead of going on in the rectilineal direction D E K, goes in the angled direction D E A, and, by entering the eye at A, renders the object D B visible. 2dly, place the basin where the sun shines obliquely, and observe where the shadow of the rim E falls on the bottom, as at B; then fill it with water, and the shadow will fall at D; which proves that the rays of light falling obliquely on the surface of the water are refracted or bent downwards into it.



The less obliquely the rays of light fall upon the surface of any medium, the less they are refracted; and if they fall perpendicularly thereon, they are not refracted at all. In the last experiment, the higher the sun rises the less will be the difference between the places where the edge of the shadow falls in the empty and full basin. And, 3dly, if a stick be laid over the basin, and the sun's rays be reflected perpendicularly into it from a looking-glass, the shadow of the stick will fall upon the same place of the bottom whether the basin be full or empty.

The same effects will also take place when the experiment is performed with any other fluid; but

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* Any substance through which light can pass, as water, air, glass, diamond, &c., is called a medium.

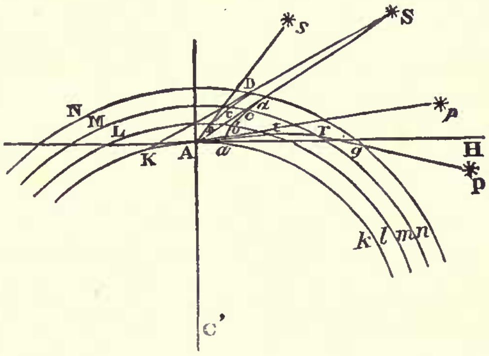
the denser the medium the more will the light be refracted in passing through it.

From these statements, it will readily appear that objects can seldom be seen in their true places. In consequence of this property of refraction, we enjoy the light of the sun while it is yet below the horizon, this being the cause that produces the morning and evening twilight. The sun's rays, in falling upon the higher part of the atmosphere, are refracted to our eyes, forming a faint light, which gradually augments till it becomes day. It is in those brilliant colors which paint the clouds before the rising of the sun that the poets have placed Aurora, or the goddess of the morn. She opens the gates of day with her rosy fingers, and the daughter of the air and the sun has her throne in the atmosphere.

Had we no atmosphere, the rays of light would come to us (if at all) in straight lines,* and the appearance and disappearance of the sun would be instantaneous. We should have a sudden transition from the brightest sunshine to the blackest darkness at sunset, and from the blackest darkness to an overwhelming blaze of light at sunrise. Without an atmosphere, only that part of the heavens in which the sun was situated would be bright; and if we could live without air, and should turn our backs toward the sun, the heavens we fronted would appear as black as the night, and the stars would be as visible as now they are in the nocturnal sky. How inconvenient and dangerous would such a state of things be to mortals constituted like the inhabitants of this earth! Refraction, therefore, is beneficial not only as it gradually prepares us for the light of the sun, but also as it prolongs the duration of the day. An ever-kind Providence has established these gradations to heighten our pleasures by variety: the scene is perpetually changing, but the order of things is immutable and eternal.

It is the power which air possesses, in common with all transparent media, of *refracting* the rays of light, or bending them out of their straight course, which renders a knowledge of the constitution of the atmosphere important to the astronomer. Owing to this property, objects seen obliquely through it appear otherwise situated than they would to the same spectator had the atmosphere no existence. It thus produces a false impression respecting their places, which must be rectified by ascertaining the amount and direction of the displacement so apparently produced on each before we can come at a knowledge of the true directions in which they are situated from us at any assigned moment.

Suppose a spectator placed at A, any point of the earth's surface K A *k*, and let L *l*, M *m*, N *n* represent the successive strata or layers of decreasing density into which we may conceive the atmosphere to be divided, and which are spherical surfaces concentric with K *k*, the earth's surface. Let S represent a star, or other heavenly body, beyond the utmost limit of the atmosphere; then, if the air were away, the spectator would see it in the direction of the straight line A S. But, in reality, when the ray of light S A reaches the atmosphere, suppose at *d*, it will, by the laws of optics, begin to bend *downwards* and take a more inclined direction, as *d c*. This bending will at first be imperceptible, owing to the extreme tenuity of the uppermost strata; but, as it advances downwards, the strata continually increasing in density, it will continually undergo greater and greater *refraction* in the same direction, and thus, instead of pursuing the straight line S *d* A, it will describe a curve S *d c b a*, continually more and more concave downwards, and will reach the earth, not at A, but at a certain point *a*, nearer to S. *This* ray,



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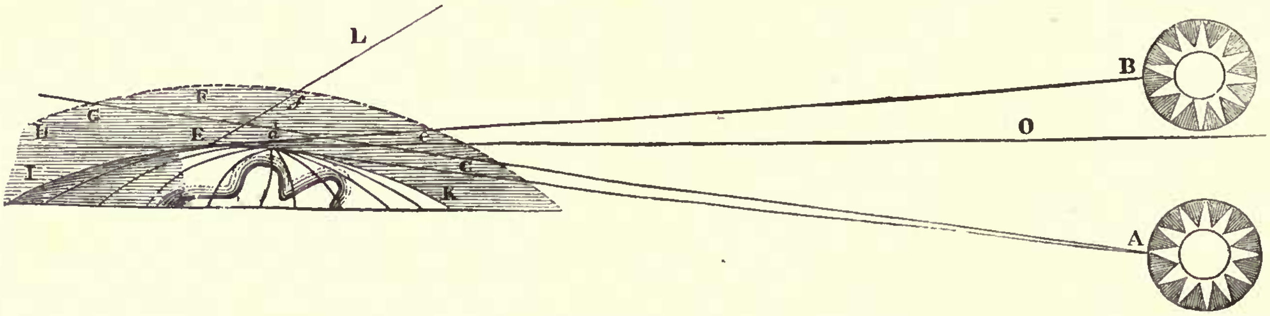
* We say "if at all," because it is probable that light is as much dependent on the atmosphere as on the body we call luminous.

consequently, will not reach the spectator's eye. The ray by which he will see the star, therefore, is not S *d* A, but another ray, which, had there been no atmosphere would have struck the earth at K, a point *behind* the spectator, but which, being bent by the air into the curve S D C B A, actually strikes on A. Now an object is seen in the direction which the visual ray has at the instant of *arriving at the eye*, without regard to what may have been otherwise its course between the object and the eye. Hence the star S will not be seen in the direction A S, but in that of A *s*, a *tangent* to the curve S D C B A, at A. But because the curve described by the refracted ray is concave downwards, the tangent A *s* will lie *above* A S, the unrefracted ray; consequently the object S will appear more elevated above the horizon A H when seen through the refracting atmosphere than it would appear were there no such atmosphere. Since, however, the disposition of the strata is the same in all directions around A, the visual ray will not be made to deviate *laterally*, but will remain constantly in the same vertical plane S A C', passing through the eye, the object, and the earth's centre.

The effect of the air's refraction, then, is to *raise* all the heavenly bodies higher above the horizon in appearance than they are in reality. Any such body, situated actually *in* the true horizon, will appear *above* it, or will have some certain apparent *altitude*, as it is called. Even some of those actually below the horizon, and which would therefore be invisible but for the effect of refraction, are, by that effect, raised above it.

The atmosphere refracts the sun's rays so as to bring him in sight every clear day before he really rises above the horizon, and to keep him in view for some minutes after he is really below it. At some times of the year, we see the sun ten minutes longer above the horizon than he would be if there were no refractions, and about six minutes every day at a mean rate.

To illustrate this, let I E K be a part of the earth's surface, covered with the atmosphere H G F C, and let H E O be the sensible horizon of an observer at E. When the sun is at A, really below the horizon, a ray of light A C proceeding from him comes straight to C, where it falls on the surface of the atmosphere, and there, entering a denser medium, it is turned out of its rectilineal course A C *d* G and bent down to the observer's eye at E, who then sees the sun in the direction of the refracted ray *e d* E, which lies above the horizon, and, being extended out to the heavens, shows the sun at B.



The higher the sun rises the less his rays are refracted, because they fall less obliquely on the surface of the atmosphere. Thus, when the sun is in the direction of the line E *f* L continued, he is so nearly perpendicular to the surface of the earth at E that his rays are but very little bent from a rectilineal course.

The exact estimation of the amount of atmospheric refraction, or the strict determination of the angle S A *s*, by which a celestial object at any assigned altitude, H A S, (last figure but one,) is raised in appearance above its true place, is a very difficult subject of physical inquiry, and one on which geometers are not yet entirely agreed. The difficulty arises from this, that the *density* of any stratum of air (on which its refracting power depends) is affected not *merely* by the superincumbent pressure, but also by its *temperature* or degree of heat. Now, although we know, that, as we recede from the earth's surface, the temperature of the air is constantly diminishing, yet the *law* or amount of this diminution at different heights is not yet fully ascertained. Moreover the refracting power of air is perceptibly affected by its *moisture;* and this, too, is not the same in every part of an aerial column. Neither are we acquainted with the laws of its distribution. The consequence of our ignorance on these points is to introduce a corresponding degree of uncertainty into the determination of the amount of refraction which affects, to a certain appreciable extent, our knowledge of several of the most important *data* of astronomy. The uncertainty thus induced, however, is confined within such extremely narrow limits as to be no cause of embarrassment, except in the most delicate inquiries.

A "Table of Refractions," as it is called, or a statement of the amount of apparent displacement arising from this cause at all altitudes, or in every situation of a heavenly body from the horizon to the *zenith*, and under all the circumstances in which astronomical observations are usually performed that may influence the result, is one of the most important and indispensable of all astronomical tables, since it is only by the use of such a table we are enabled to get rid of an illusion which must otherwise pervert all our notions respecting the celestial motions.

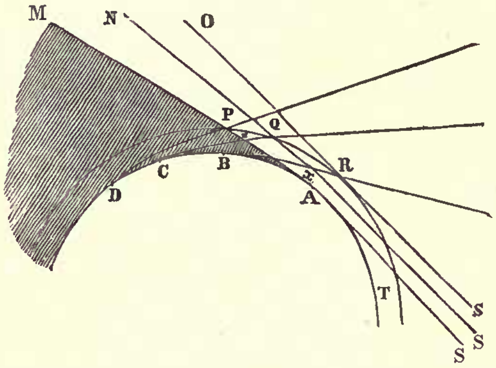
In the *zenith*, there is no refraction. A celestial object situated vertically overhead is seen in its true direction, as if there were no atmosphere.

In descending from the *zenith* to the horizon, the refraction continually increases, objects near the horizon appearing more elevated by it above their true directions than those at a high altitude.

The *rate* of its increase is nearly in proportion to the tangent of the apparent angular distance of the object from the zenith. But this rule, which is not far from the truth at moderate *zenith distances*, ceases to give correct results in the vicinity of the horizon, where the law becomes much more complicated in its expression.

The average amount of refraction for an object half-way between the zenith and horizon, or at an apparent altitude of forty-five degrees, is about one minute, a quantity hardly sensible to the naked eye; but at the visible horizon, it amounts to no less a quantity than thirty-three minutes, which is rather more than the greatest apparent diameter of either the sun or the moon. Hence it follows, that, when we see the lower edge of the sun or moon just *apparently* resting on the horizon, its whole disk is in reality below it, and would be entirely out of sight, and concealed by the convexity of the earth, but for the bending round it which the rays of light have undergone in their passage through the air.

It follows from this that one obvious effect of refraction must be to shorten the duration of night and darkness by actually prolonging the stay of the sun and moon above the horizon. But even after they are set, the influence of the atmosphere still continues to send us a portion of their light; not, indeed, by direct transmission, but by *reflection* upon the vapors and minute solid particles which float in it, and perhaps, also, on the actual material atoms of the air itself. To understand how this takes place, we must recollect that it is not only by the direct light of a luminous object that we see, but that whatever portion of its light is intercepted in its course and thrown back or laterally upon us, though it could not otherwise reach our eyes, becomes to us a means of illumination. Such reflective obstacles always exist floating in the air. The whole course of a sunbeam penetrating through the chink of a window-shutter into a dark room is *visible* as a bright line in the air; and even if it be stifled, or *let out* through an opposite crevice, the light scattered through the apartment from this source is sufficient to prevent entire darkness in the room. The luminous lines occasionally seen in the air in a sky full of partially-broken clouds, which many term "the sun drawing water," are similarly caused. They are sunbeams through apertures in clouds, partially intercepted and reflected by the dust and vapors of the air below. Thus it is with those solar rays which, after the sun is itself concealed by the convexity of the earth, continue to traverse the higher regions of the atmosphere above our heads, and pass through and out of it without directly striking on the earth at all. Some portion of them is intercepted and reflected by the floating particles above mentioned, and thrown back or laterally so as to reach us and afford us that secondary illumination which is twilight. The course of such rays will be immediately understood from the annexed figure, in which A B C D is the earth, A a point on its surface where the sun S is in the act of setting, its last lower ray S A M just grazing the surface at A, while its superior rays S N, S O traverse the atmosphere above A without striking the earth, leaving it finally at the points P Q R, after being more or less bent in passing through it, the lower most, the higher less, and that which (like S R O) merely grazes the exterior limit of the atmosphere not at all. Let us consider several points, A, B, C, D, each more remote than the last from A, and each more deeply involved in the *earth's shadow*, which occupies the whole space from A beneath the line A M. Now, A just receives the sun's last direct ray, and, besides, is illuminated by the whole reflective atmosphere P Q R T. It therefore receives twilight from the whole sky. The point B, to which the sun has set, receives no direct solar light, nor any, direct or reflected, from all that part of *its* visible atmosphere which is below A P M; but from the portion P R x, which is traversed by the sun's rays, and which lies above the visible horizon B R of B, it receives a twilight, which is strongest at R, the point immediately below which the sun is, and fades away gradually towards P, as the luminous part of the atmosphere thins off. At C, only the last or thinnest portion P Q z of the lenticular segment thus illuminated lies above the horizon C Q of that place. Here, then, the twilight is feeble, and confined to a small space in and near the horizon which the sun has quitted, while at D the twilight has ceased altogether.



From the explanation we have given of the nature of atmospheric refraction, and the mode in which it is produced in the progress of a ray of light through successive strata or layers of the atmosphere, it will be evident, that, whenever a ray passes *obliquely* from a higher level to a lower one, or *vice versa*, its course is not rectilinear, but concave downwards. Of course, any object seen by means of such a ray must appear deviated from its true place, whether that object be, like the celestial bodies, entirely beyond the atmosphere, or like the summits of mountains seen from the plains, or other terrestrial stations seen from each other at different levels, immersed in it. Every difference of level, accompanied as it must be with a difference of density in the aerial strata, must also have corresponding to it a certain amount of refraction—less, indeed, than what would be produced by the *whole* atmosphere, but still often of very appreciable and even considerable amount. This refraction between terrestrial stations is termed *terrestrial refraction* to distinguish it from that total effect which is only produced on celestial objects, or such as are beyond the atmosphere, and which is called celestial or astronomical refraction.

Another effect of refraction is to distort the visible forms and proportions of objects seen near the horizon. The sun, for instance, which, at a considerable altitude, always appears round, assumes a flattened or oval outline as it approaches the horizon, its horizontal diameter being visibly greater than that in a vertical direction. When very near the horizon, this flattening is evidently more considerable on the lower side than on the upper, so that the apparent form is neither circular nor elliptic, but a species of oval, which deviates more from a circle below than above. This singular effect, which any one may notice in a fine sunset, arises from the rapid rate at which the refraction increases in approaching the horizon. Were every visible point in the sun's circumference equally raised by refraction, it would still appear circular, though displaced; but the lower portions being *more* raised than the upper, the vertical diameter is thereby shortened, while the two extremities of its horizontal diameter are equally raised and in parallel directions, so that its apparent length remains the same. The dilated size (generally) of the sun or moon when seen near the horizon beyond what they appear to have when high up in the sky, has nothing to do with refraction. It is an illusion of the judgment arising from the terrestrial objects interposed or placed in close comparison with them. In that situation, we view and judge of them as we do of terrestrial objects—in detail, and with an acquired habit of attention to parts. Aloft, we have no associations to guide us, and their insulation in the expanse of sky leads us rather to undervalue than to overrate their apparent magnitudes. Actual measurement with a proper instrument corrects our error, without, however, dispelling our illusion. By this, we learn that the sun, when just on the horizon, subtends at our eyes almost exactly the same angle, and the moon one materially less, than when seen at a great altitude.

Aberration. But it is not from refraction only that a difficulty arises in finding the true places of celestial bodies. They are subject to one irregularity, among others, arising from the motion of light. This is a discovery of Dr. Bradley, and as the subject is exceedingly curious and important, we shall present the reader with an account of it nearly in his own words.

Bradley, in concert with another gentleman, in the year 1725, formed a project for verifying, by a series of new observations, those which Hooke had previously communicated to the public respecting the annual parallax of the fixed stars. The instruments were completed and ready for taking observations about the end of November; and on the 3d of December, a bright star, named Gamma in the head of the Dragon, was observed as it passed near the zenith, and its situation carefully taken with the instrument. The like observations were made on the fifth, eleventh, and twelfth of the same month, and no material difference of the star was observable. An observation, however, was taken on the seventeenth by Bradley, who perceived that the star now passed a little more southerly than when it was before observed. He at first concluded that this appearance was owing to the uncertainty of his observations; but repeating his observation on the twentieth, he found that the star passed still more southerly.

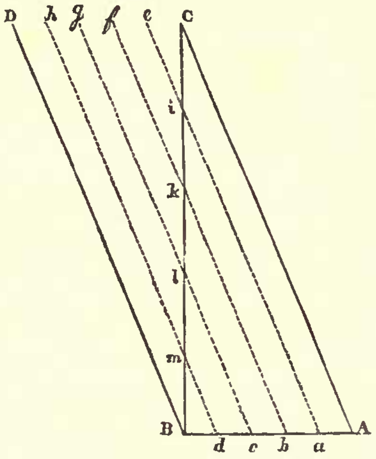
This sensible alteration was the more surprising because it was in a direction contrary to what it would have been had it proceeded from an annual parallax of the star. Well satisfied that it could not be entirely owing to a want of exactness in the observations, he began to think that some alteration in the materials of the instrument itself might have occasioned it. At length, by repeated trials, being fully convinced of the great accuracy of the instrument, and finding that there must be some regular cause to produce so regular an effect, he took care to examine nicely, at the time of each observation, how much the change of place amounted to, and about the beginning of March, 1726, the star was found to be twenty seconds farther south than at the first observation. It seemed now to have arrived at its utmost limit south, for, in several observations about this time, no variation could be detected in its situation. In the middle of April, it appeared to be returning toward the north, and about the beginning of June, it passed about the same distance from the zenith as it had done in the previous December. It continued to move northward till September, when it again became stationary, being nearly twenty seconds more northerly than it had been in March. From September, it returned south till it arrived, in December, at the same situation which it occupied a twelvemonth previous, allowing for the difference of declination caused by the precession of the equinoxes.

A nutation of the earth's axis was one of the things that occurred to his mind as a cause of this motion of the star; but, on consideration, it was found insufficient, for though the change of declination in the star Gamma of the Dragon might have been accounted for by it, it would not at the same time agree with the phenomena of the other stars, particularly with a small one nearly opposite in right ascension, and at about the same distance from the north pole of the equator, as it appeared, upon a comparison of the observations made upon the same days, at different seasons of the year, that the latter star changed its declination only about half as much as the former, when if nutation had been the cause, both stars would have experienced nearly equal alterations. Upon a farther comparison of the observations with each other, it was discovered, that, in both the stars before mentioned, the apparent difference of declination from the maxima was always nearly proportional to the versed sine of the sun's distance from the equinoctial points. Still no hypothesis was framed at that time sufficient to account for all the phenomena. Bradley erected another instrument, more suitable for the purpose of learning in what manner other stars were affected by the same cause.

His instrument being fixed, he immediately began to observe such stars as he thought most likely to give him an insight into the cause of the motion he had already witnessed in two. As there were no less than twelve that he observed, it was not long before he perceived that the notion he before entertained of the stars being farthest north and south when the sun was near the equinoxes was true of those only that were near the solstitial colure. After a time, he discovered, what he then supposed to be a general law, namely, that each of the stars became stationary, or was farthest north or south, when it passed over his zenith at six o'clock, either in the morning or evening. He perceived, also, that whatever situation the stars had with respect to the cardinal points of the ecliptic, the apparent motion of all tended the same way when they passed his instrument about the same hour: they moved southward when they passed in the day, and northward when they passed in the night, so that each was farthest north when it came about six o'clock in the evening, and farthest south when it came about six in the morning.

When the year was completed, Bradley began to examine and compare his observations; and having pretty well satisfied himself as to the general laws of the phenomena, he then endeavored to discover their cause. With singular sagacity, he conjectured that all the phenomena might proceed from the progressive motion of light and the earth's annual revolution in its orbit. He perceived, that, if the motion of light be progressive, the apparent place of a fixed object would not be the same when the eye is at rest as when it is moving in any other direction than that of the line passing through the eye and the object, and that, when the eye is moving in different directions, the apparent place of the object would be different.

That the aberration of the stars is occasioned by the motion of light may be shown by a figure. Let A B represent a part of the earth's orbit, and C B a ray of light falling from a star perpendicularly upon the line B A. If the eye be at rest at B, the object will appear in the direction B C, whether light be propagated in time or instantaneously; but if the eye be moving from A toward B, and light be propagated with a velocity that is to the velocity of the eye as C B is to A B, that particle of it by



which the object will be discerned when the eye comes to B will be at C when the eye is at A. The star, therefore, will appear in the direction A C, and, as the earth moves through equal parts of its orbit A *a*, *a b*, *b c*, &c., the light coming from the star will move through the equal divisions *c i*, *i k*, *k l*, &c., and the star will appear successively in the directions *a e*, *b f*, *c g*, &c., which are parallel to A C, so that, when the eye comes to B, the object will be seen in the direction B D.

The difference between the true and apparent places will be greater or less according to the proportion between the velocity of light and that of the eye. If the velocity of light be to the velocity of the earth's motion in its orbit as one thousand to one, it may be proved by trigonometry that the apparent place of the object from which the light proceeds will constantly differ from its true place about three minutes and a half, so that a star at the pole of the ecliptic would seem to describe round that pole a circle whose diameter would be seven minutes.

From a number of observations made by Bradley upon the same stars for three years, he found that their apparent differed from their true places by about twenty seconds, by which means it is proved that the velocity of light is about eight thousand seven hundred and ninety-four times greater than the velocity of the earth in its orbit. But the velocity of the earth is about sixty-eight thousand miles an hour, and therefore light will pass from the sun to the earth in a little more than eight minutes, and as this is nearly the same with that found by Roemer, (stated in another part of this treatise,) and was deduced from a different phenomenon, the progressive motion of light is placed beyond a doubt. It appears, from various observations, that the direct light of the sun and stars, as well as the reflected light of the planets and their satellites, traverses the spaces between them and us with the same uniform velocity, and that the light of the fixed stars proceeds with the same velocity, from whatever distance it comes.

The aberration of light is a direct proof of the motion of the earth in its orbit, and a new confirmation of the truth of the Copernican theory. And with those minds that require immediate and sensible proof of the earth's motion, that judge not from calculations but from facts, the observations of Bradley ought to have great weight. He has discovered that the motion of light, combined with that of the earth, produces an apparent difference in the places of the fixed stars; and as this motion is found to affect all the stars according to their situations, such a similarity of variations is sufficient to justify the truth of the cause on which they are supposed to depend, and to show that the Copernican theory of the world is conformable to nature and the order of things.

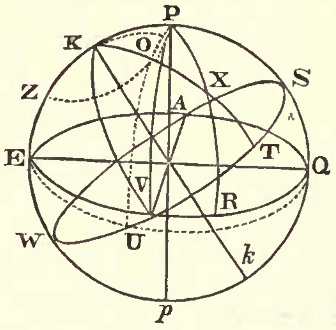
Precession of the Equinoxes and Nutation. The equinoxes, or equinoctial points, are those points where the ecliptic or apparent annual path of the sun crosses the equator. The same course of observations by which the path of the sun is traced among the fixed stars, determines the place of the equinox at that time. This is a point of great importance, as it is the zero point of right ascension. Now when this process is repeated at distant intervals of time, a very remarkable phenomenon is observed, viz. that the equinox does not preserve a constant place among the stars, but shifts its position, travelling continually and regularly, although with extreme slowness, backward along the ecliptic from east to west, or the contrary to that in which the sun appears to move in the same circle. The equinoctial point thus moving, as it were, to meet the sun in its apparent annual round, the earth arrives at the equinoctial point sooner, that is, the time of the equinox happens sooner, than it would otherwise do; hence the recession of the equinoctial point causes a precession in the time of the equinox. The amount of the motion by which the equinox travels backward on the ecliptic is fifty and one tenth seconds annually,—a minute quantity, but which, by its continual accumulation, at last makes itself very palpable, and that in a way very inconvenient to practical astronomers, by destroying in the lapse of a number of years the arrangement of their catalogues of stars, and making it necessary to reconstruct them. Since the formation of the earliest catalogue on record, the place of the equinox has retrograded about thirty degrees. The period in which it performs a complete tour of the ecliptic is 25,868 years.

The immediate effect of the precession of the equinoxes is to produce a uniform *increase of longitude* in all the heavenly bodies, whether fixed or erratic. For the vernal equinox being the initial point of longitudes as well as of right ascension, a retreat of this point on the ecliptic *tells* upon the longitudes of all alike, whether at rest or in motion, and produces, so far as its amount extends, the *appearance* of a motion in longitude common to all, *as if* the whole heavens had a slow rotation round the poles of the ecliptic in the long period above mentioned, similar to what they have in twenty-four hours round those of the equinoctial.

To form a just idea of this curious astronomical phenomenon, however, we must abandon, for a time, the consideration of the ecliptic, as tending to produce confusion in our ideas, for this reason, that the stability of the ecliptic itself among the stars is only approximate, and that, in consequence, its intersection with the equinoctial is liable to a certain amount of change, arising from *its* fluctuation, which mixes itself with what is due to the principal cause of the phenomenon. This cause will become at once apparent, if, instead of regarding the equinox, we fix our attention on the pole of the equinoctial, or the vanishing point of the earth's axis.

The place of this point among the stars is easily determined, at any epoch, by the most direct of all astronomical observations. By an astronomical instrument, we are enabled to ascertain, at every moment, the exact distance of the polar point from any three or more stars, and therefore to lay it down, by triangulating from these stars, with unerring precision, on a chart or globe, without the least reference to the position of the ecliptic, or to any other circle not naturally connected with it. Now, when this is done with proper diligence and exactness, it results, that, although for short intervals of time, such as a few days, the place of the pole may be regarded as not sensibly variable, yet in reality it is in a state of constant, although extremely slow motion; and, what is still more remarkable, this motion is not uniform, but compounded of one principal, uniform, or nearly uniform, part, and other smaller and subordinate periodical fluctuations, the former giving rise to the phenomena of *precession*, the latter to another distinct phenomenon called *nutation*. These two phenomena, it is true, belong, theoretically speaking, to one and the same general head, and are intimately connected together, forming part of a great and complicated chain of consequences flowing from the earth's rotation on its axis; but it will conduce to present clearness to consider them separately.

It is found, then, that, in virtue of the uniform part of the motion of the pole, it describes a circle in the heavens around the pole of the ecliptic as a centre, keeping constantly at the same distance of twenty-three degrees and twenty-eight minutes from it, in a direction from east to west, and with such a velocity that the annual angle described by it in this its imaginary orbit is $50''.10$, so that the whole circle would be described by it in the above-mentioned period of 25,868 years. It is easy to perceive how such a motion of the pole will give rise to the retrograde motion of the equinoxes; for in the figure, suppose the pole P, in the progress of its motion in the small circle P O Z round K, to come to O, then, as the situation of the equinoctial E V Q is determined by that of the pole, this, it is evident, must cause a displacement of the equinoctial, which will take a new situation, E U Q, ninety degrees distant in every part from the new position O of the pole. The point U, therefore, in which



the displaced equinoctial will intersect the ecliptic, *i. e.* the displaced equinox, will lie on that side of ♈, its original position, towards which the motion of the pole is directed, or to the westward.

The precession of the equinoxes thus conceived, consists, then, in a real but very slow motion of the pole of the heavens among the stars, in a small circle round the pole of the ecliptic. Now this cannot happen without producing corresponding changes in the apparent diurnal motion of the sphere, and the aspect which the heavens must present at very remote periods of history. The pole is nothing more than the vanishing point of the earth's axis. As this point, then, has such a motion as described, it necessarily follows that the earth's *axis* must have a conical motion, in virtue of which it points successively to every part of the small circle in question. We may form the best idea of such a motion by noticing a child's peg-top when it spins not upright, or that amusing toy the te-totum, which, when delicately executed and nicely balanced, becomes an elegant philosophical instrument, and exhibits, in the most beautiful manner, the whole phenomenon in a way calculated to give at once a clear conception of it as a fact, and a considerable insight into its physical cause as a dynamical effect. The reader will take care not to confound the variation of the *position of the earth's* axis *in space* with a mere shifting of the imaginary line about which it revolves in its interior. The whole earth participates in the motion, and goes along with the axis as if it were really a bar of iron driven through it. That such is the case is proved by the two great facts: 1st, that the latitudes of places on the earth, or their geographical situation with respect to the poles, have undergone no perceptible change from the earliest ages. 2dly, that the sea maintains its level, which could not be the case if the motion of the axis were not accompanied with a motion of the whole mass of the earth.

The visible effect of precession on the aspect of the heavens consists in the *apparent* approach of some stars and constellations to the pole and recess of others. The bright star of the Lesser Bear, which we call the pole-star, has not always been, nor will always continue to be, our cynosure. At the time of the formation of the earliest catalogues, it was twelve degrees from the pole. It is now only one degree and twenty-four minutes, and will approach yet nearer, to within half a degree, after which it will again recede, and slowly give place to others, which will succeed it in its companionship to the pole. After a lapse of about twelve thousand years, the star Alpha Lyræ, the brightest in the northern hemisphere, will occupy the remarkable situation of a pole-star, approaching within about five degrees of the pole.

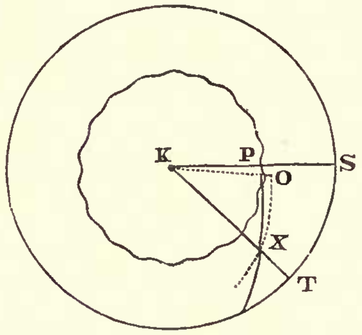
The *nutation* of the earth's axis is a small and slow subordinate gyratory movement, by which, if subsisting alone, the pole would describe among the stars, in a period of about nineteen years, a minute ellipsis, having its longer axis equal to 18″.5, and its shorter to 13″.74, the longer being directed towards the pole of the ecliptic, and the shorter, of course, at right angles to it. The consequence of this real motion of the pole is an *apparent* approach and recess of all the stars in the heavens to the pole in the same period. Since, also, the place of the equinox on the ecliptic is determined by the place of the pole in the heavens, the same cause will give rise to a small alternate advance and recess of the equinoctial points, by which, in the same period, both the longitudes and the right ascensions of the stars will be also alternately increased and diminished.

Both these motions, however, although here considered separately, subsist jointly; and since the pole, while it is describing its little ellipse of 18″.5 in diameter in virtue of the nutation, is carried by the greater and regularly-progressive motion of precession over so much of its circle round the pole of the ecliptic as corresponds to nineteen years, (that is to say, over an angle of nineteen times 50″.1 round the centre, which, in a small circle of twenty-three degrees and twenty-eight minutes in diameter, corresponds to six minutes and twenty seconds as seen from the centre of the sphere,) the path which it will pursue in virtue of the two motions subsisting jointly will be neither an ellipse nor an exact circle, but a gently-undulated ring, like that in the next figure, where, however, the undulations are much exaggerated.

These movements of precession and nutation are common to all the celestial bodies, both fixed and erratic, and this circumstance makes it impossible to attribute them to any other cause than a real motion of the earth's axis, such as we have described. Did they only affect the stars, they might, with equal plausibility, be urged to arise from a real rotation of the starry heavens, as a solid shell, round an axis passing through the poles of the ecliptic in 25,868 years, and a real elliptic gyration of that axis in nineteen years; but since they also affect the sun, moon, and planets, which, having motions independent of the general body of the stars, cannot without extravagance be supposed *attached to* the celestial concave,* this idea falls to the ground, and there only remains, then, a real motion in the earth by which they can be accounted for.

Precession and nutation, considered as affecting the apparent places of the stars, are of the utmost importance in practical astronomy. When we speak of the right ascension and declination of a celestial object, it becomes necessary to state what *epoch* we intend, and whether we mean the *mean* right ascension, (cleared, that is, of the periodical fluctuation in its amount which arises from nutation,) or the *apparent* right ascension, which, being reckoned from the actual place of the vernal equinox, is affected by the periodical advance and recess of the equinoctial points thence produced—and so of the other elements. It is the practice of astronomers to *reduce*, as it is termed, all their observations, both of right ascension and declination, to some common and convenient epoch, such as the beginning of the year for temporary purposes, or of the decade or the century for more permanent uses, by subtracting from them the whole effect of precession in the interval, and, moreover, to divest them of the influence of nutation by investigating and subtracting the amount of change, both in right ascension and declination, due to the displacement of the pole from the centre to the circumference of the little ellipse above mentioned. This last process is technically termed *correcting* or *equating* the observation for nutation, by which latter word is always understood, in astronomy, the getting rid of a periodical cause of fluctuation, and presenting a result, not as it *was* observed, but as it would have been observed had that cause of fluctuation had no existence.

For these purposes, in the present case, very convenient formulæ have been derived, and tables constructed; but they are of too technical a character for this work. We shall, however, point out the manner in which the investigation is conducted. Suppose the triangle K P X projected on the plane of the ecliptic as in the annexed figure.



In the triangle K P X, K P is the obliquity of the ecliptic, K X the *co-latitude*, or complement of latitude, and the angle P K X the *co-longitude* of the object X. These are the *data* of our question, of which the first is constant, and the two latter are varied by the effect of precession and nutation; and their variations (considering the minuteness of the latter effect generally, and the small number of years, in comparison to the whole period of 25,868, for which we ever require to estimate the effect of the former) are of that order which may be regarded as infinitesimal in geometry, and treated as such without fear of error. The whole question, then, is reduced to this:—In a spherical triangle K P X, in which one side K X is constant, and an angle K and adjacent side K P vary by given infinitesimal changes of the position of P, required

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* This argument, cogent as it is, acquires additional and decisive force from the law of nutation, which is dependent on the position, for the time, of the *lunar orbit*. If we attribute it to a real motion of the celestial sphere, we must then maintain that sphere to be kept in a constant state of *tremor* by the motion of the moon.

the changes thence arising in the other side P X, and the angle K P X. This is a problem of spherical geometry, and being resolved, it gives at once the reductions we are seeking; for P X being the polar distance of the object, and the angle K P X its right ascension *plus* ninety degrees, their variations are the very quantities we seek. It only remains, then, to express in proper form the amount of the precession and nutation in *longitude* and *latitude*, when their amount in right ascension and declination will immediately be obtained.

The precession in *latitude* is zero, since the latitudes of objects are not changed by it: that in longitude is a quantity proportional to the time, at the rate of 50″.10 per annum. With regard to the nutation in *longitude* and *latitude*, these are no other than the abscissa and ordinate of the little ellipse in which the pole moves.

Obliquity of the Ecliptic. The obliquity of the earth's orbit to the equator was long considered as a constant quantity. True, its values as assigned by astronomers in different ages do not agree with each other. They have been continually diminishing from the time of the earliest astronomers until now. Yet, as late as the end of the seventeenth century, this variation in the observations was generally attributed to their inaccuracy, and to a want of knowledge of the parallaxes and refraction of the heavenly bodies. These variations cannot be ascribed wholly to the imperfections of instruments and observations; for, had this been the case, the results obtained must have been sometimes too great as well as too small. There is no reason to suppose that all could have agreed in indicating a progressive diminution of the obliquity of the ecliptic, if this diminution were not real. Accordingly, it appears from the most accurate modern observations, made at great intervals, that this obliquity is diminishing; and the theory of universal gravitation fortunately supplies us with a satisfactory explanation of the phenomenon.

While the earth is revolving in the plane of the ecliptic, it is acted upon by all the planets of the solar system. The action of the planets, when situated in the plane of the ecliptic, have a tendency not only to alter the earth's gravity to the sun, or to accelerate and retard its motion; but as all the planets move in orbits inclined to the ecliptic, their action tends to bring the earth towards the plane of their orbits. The effect of this action, then, is to displace the ecliptic, or diminish the inclination of the earth's orbit to the plane of the orbit of the planet; but while the earth's orbit is thus changing its position, the equator of the earth is undergoing no change; consequently there will result a variation in the inclination of the ecliptic to the equator. This change, however, is very small, and scarcely becomes apparent till after the lapse of many years. According to the present disposition of the system, the inclination of the ecliptic to the equator must diminish about fifty-two minutes in a century, or about half a second in a year. In the following table, are contained observations, made at times widely distant, of the angle formed by the ecliptic with the equator.

Time of the observations.	Observed obliquity.	Time of the observations.	Observed obliquity.
B. C. 1100	23° 54′ 02″	A. C. 1279	23° 32′ 02″
350	23° 49′ 20″	1437	23° 31′ 48″
50	23° 45′ 39″	1756	23° 28′ 13″

On the 1st of January, 1837, the inclination was 23° 27′ 37″.89. The observations in the above table, taken together, put beyond all doubt the progressive diminution of the angle in question, and, from a comparison of their results with those of theory, it is rendered certain that the diminution is owing solely to the cause indicated by theory, viz. to the attraction of the sun upon the planets, and of the different planets upon each other.

The effect of this diminution is also perceived when the positions of the same stars with respect to the ecliptic at distant periods are compared. The effect is most remarkable in the stars situated near the summer and winter solstices.* Those which were formerly situated north of the ecliptic, near the summer solstice, are now found to be still farther north, and farther from this plane. On the contrary, those which, according to the testimony of ancient astronomers, were situated south of the

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* The solstices are the points where the ecliptic touches the tropics.

ecliptic, near the same solstice, have approached this plane, and some of them are now situated in it, or just on the north side of it. Similar changes have happened to those stars situated near the winter solstice. All the stars participate in this motion, but differently, and the less the nearer they are to the line of the equinoxes; so that this line appears to perform the part of a hinge, about which the rotation takes place. From these phenomena, it is natural to conclude that the plane of the ecliptic has an actual motion in the heavens, and that it thus produces the observed appearances of an apparent contrary motion in the stars; for it can scarcely be supposed that these motions really belong to the stars, since such a supposition would require among all the heavenly bodies a corresponding motion, which no one would think of maintaining.

It is important to observe, and theory lends confirmation to the truth of the remark, that the diminution of the obliquity of the ecliptic will not always continue. A period will arrive when this motion, growing less and less, will at length entirely cease, and the angle will for a time appear constant, after which the displacement will commence in the opposite direction. The ecliptic will then gradually diverge from the equator by the same degrees according to which it before approached, and these alternate states will constitute an endless oscillation, comprehended within fixed limits. These limits are not yet discovered; but it can be demonstrated, from the constitution of our globe, that such limits exist, and that they are very restricted. It may be affirmed that the plane of the ecliptic never has coincided, and never will coincide, with that of the equator,—a circumstance, which, if it could happen, would produce on the earth a perpetual spring.

The method used by astronomers for determining the inclination of the ecliptic, to the equator is by observing the greatest and least altitudes of the sun, one observation being taken at the summer, the other at the winter, solstice. Half of the difference of the altitudes will be the inclination sought.

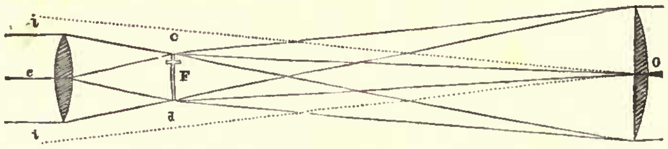
SECTION IV.

The telescope—Its invention—Its simplest form—Mode of finding the magnifying power of telescopes—Common astronomical telescopes—Difficulties encountered in their early construction—Huygens' improvement—Newton's lenses—Reflecting telescopes—The Newtonian—The Gregorian—The Cassegrainian—W. Herschel's—Ramage's—General remarks on telescopes—Impossibility of minute discoveries in the moon.

A *telescope* is an optical instrument employed for viewing distant objects by increasing the apparent angle under which they are seen without its assistance, and hence the effect on the mind of an increase in size, or, as commonly termed, *magnified* representation. The construction of the telescope is, perhaps, one of the most important acquisitions that the sciences ever attained, as it unfolds to our view the *wonders of the heavens*, and enables us to obtain *data* for astronomical and nautical purposes.

The invention of this instrument is somewhat uncertain, and is ascribed to different individuals, as John Baptista Porta, Jansen of Middleburg, and Galileo. The time of its first construction was about the year 1590.

The simplest construction of this instrument consists of two convex lenses, so combined as to increase the apparent angle under which distant objects are seen. If we place two convex lenses with a distance between them equal to the sum of their foci, a telescope will be formed, and the magnifying power will be in proportion to the focus of the two lenses. Let *o* be the object-lens, and suppose it eight inches focus, and *e* the eye-lens, of two inches focus. The distance between these two lenses must be ten inches if the object be at an infinite distance, as a star; but when the object is terrestrial, the distance between the two lenses must be increased to adjust them for distinct vision. On this account, the eye-lens is mounted in a tube, sliding within another tube in which the object-glass is fixed, and, therefore, can be drawn out for near objects. As the size of objects is dependent on



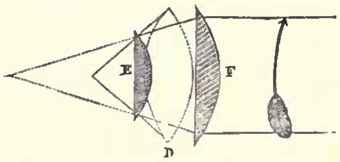
the angle under which they are seen, the image F, formed by the object-glass, will subtend, in the focus of the eye-glass e, the angle ced, which is four times the angle cod that the object subtends, for the distance Fo is four times Fe: hence the magnifying power may be found by dividing the focal length of the object-glass by the focus of the eye-glass, when the quotient will be the power. Objects seen through this telescope are inverted, and on that account it is inapplicable to land observation; but at sea, it is occasionally used at night, and in hazy weather when there is little light, and is hence called a night telescope.

The common *astronomical telescope* is of the same principle of construction as the preceding. The inversion of the object is immaterial in its application to celestial observations; but the disadvantage of this instrument is felt when very high powers are required, for then the objects are rendered dark and obscure, and if the aperture of the object-glass is increased to admit more light, the formation of the object is confused. Huygens, however, made a telescope of this construction, in which he was enabled to use an aperture of six inches, by making the focus of the object-glass one hundred and twenty-three feet in length. With this, by changing the eye-lenses, any required power was produced.

The field of vision, or number of objects, seen by the telescope above described, is very limited, the eye-lens not being sufficiently large, as is shown by the dotted lines $i\,i$ in the figure, which do not enter the eye-lens e, and are not received by the eye. Now, if the diameters of this lens were increased, the objects would be rendered indistinct, arising from the rays, spread over the surface of the lens from any point in the object, not being collected again in another point after refraction. This error is occasioned by the figure of the lens, and is called the spherical aberration by figure.

The great advantage of duly considering the aberration of lenses will be evident if we combine two lenses of twice the focal distance, instead of one, to produce any given power, as the aberration will be decreased to one quarter of that of a single lens of equivalent power, and, therefore, the aperture of the compound lens may be increased, while the error will be less than in a single lens. In the common telescopes, if two lenses were used instead of the single object and eye-glass, as shown in the above figure, the apertures of each might be increased, and consequently the instruments would be improved in light and field.

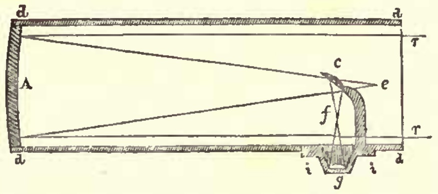
Huygens has demonstrated, that, when the greatest possible distinctness is required for the eye-piece of a telescope, it may be obtained by two plano-convex lenses, placed, as in the adjoining figure, with their plane sides outward, and the focus of the eye-lens E must be two thirds of that of the field-lens F, with a distance between them equal to the difference of their focal lengths. This combination, from the purpose it has been adapted to, is called the astronomical positive eye-piece; and the telescope, by this addition, will have four times the distinctness of a single lens D of equivalent power, while the distortion of the object will only be one fourth of that produced by a single lens; for the refraction of the object-lens brings the image of the marginal rays nearer to itself than the central, therefore the image will be formed convex next the lens F, as shown by the arrow, and as the radius of curvature of the lens F is twice that of the single lens D, the distortion will be decreased in the square of this ratio, or four times. On this account, a similar combination is used for the eye-pieces of telescopes for astronomical quadrants and other graduated instruments when the convex side of the field-lens is turned towards the eye-glass E, because equal divisions on a micrometer correspond with equal angles subtended by objects measured with this instrument. This combination, which is called Ramsden's Micrometical Eye-piece, has one great disadvantage, viz. that it requires the eye to be placed exceedingly near to the eye-lens E.



Being now in possession of a combination that will diminish the aberration produced by the eye-piece of a telescope, our limit of magnifying power and light will arise from the errors occasioned by the object-glass; and this may be diminished by having the curves of the two surfaces as one to six, with the most convex side outermost; for this lens has less aberration than any other. Secondly, by using two lenses of twice the focus in contact, to produce the required refraction, and thus diminish the error four times. But, although this error may, by the means here pointed out, be rendered very small and almost imperceptible, yet it is magnified in the same proportion as the objects; and when high powers are used, the indistinctness will become sensible.

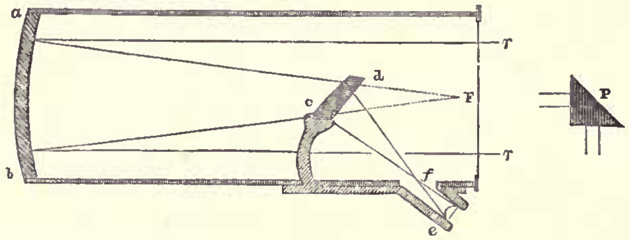
Sir Isaac Newton conceived that the surfaces of the lens might be formed of some mathematical curve which would entirely obviate this error; and by investigation he found that, if the surface were described by the revolution of a parabola, and the radiant or object be at an infinite distance, the rays would be collected to a point, and be free from all aberration. He afterwards formed tools to grind and polish lenses of this figure; but, when made, although the error by figure was perfectly corrected, it was discovered that the white heterogeneous pencils of light (before that time considered as homogeneous) in their passage through the lens were divided into their several constituents of red, orange, green, blue, and violet, in the same manner as by a prism, and hence lenses of this figure became useless.

With these disadvantages to contend against in refracting substances, Sir Isaac Newton, in the year 1666, turned his attention to reflected light, in which the angle of all the colored rays is equal. By pursuing this idea he entirely obviated the chromatic error. In the first telescope he made by reflection, the distinctness with which objects were seen through it was surprising when compared with the refracting telescopes of those times; for, though the focal distance of the metal was only six and one-third inches, it would carry a power of thirty-eight with equal distinctness to a four feet refractor. The form of the metal was spherically concave, but by investigation he ascertained that if the form had been that of a parabola, there would not have been any spherical aberration produced; and if we examine the spherical aberration by figure of a spherically concave metal, and compare it with that of a plano-convex lens ground in the same tool, the former will be four, while the latter is nine. But when it is considered that the focus of the glass lens is four times that of the metal, (for the focal distance of a plano-convex lens is twice the radius, and that of the concave reflector half the radius,) to make their foci equal, the curvature of the lens must be four times that of the speculum; and it has been shown that the error by figure increases inversely as the square of the radius; hence the aberration of the lens will be to that of the reflector as $4^2 \times 9$ to 4, or as 36 to 1, and the distinctness will be inversely as the areas of these circles, which are as the squares of their respective diameters; so that the distinctness of a reflector will be 1296 times greater than that of a lens of the same focus and aperture.



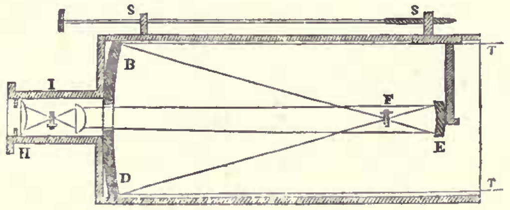
The Newtonian telescope consists of a concave parabolic metal A, fixed at the end of the tube *d d d;* the plane speculum *c* is fixed to a wire, having its other end attached to a dove-tailed sliding-piece *i i*, and the face of the plane metal is inclined to the axis of the tube and the large speculum at an angle of forty-five degrees. In the sliding-piece *i i*, opposite the small metal, is inserted a short tube to hold an eye-piece, which is a single lens with its flat side outermost, or the astronomical eye-piece; but as the color produced by these eye-lenses is not corrected, another combination, called the negative achromatic eye-piece, should be used. The adjustment of this instrument to distinct vision is made by a rack and pinion attached to the sliding-piece and great tube of the telescope, by which the eye-piece and small speculum are brought nearer or farther from the large metal. Let *r r* be the rays of light coming from a distant object, and falling on the large speculum A, these rays would be reflected to the focus *e;* but meeting with the oblique flat metal *c*, are reflected to *f*, where an image of the distant object will be formed, and is received by the eye-lens *g*, by which the rays are rendered parallel. The power of a Newtonian reflector is proportional to the relative focal distances of the concave metal and the eye-lens. For example, let the focal distance *A e* be forty inches, and the focus of the eye-lens *g* half an inch, the power will be eighty. It should here be observed, that the same instrument which is free from aberration for astronomical observation will not be so for terrestrial uses; for the rays in the former case are parallel, while they are divergent in the other. The curve, therefore, of the large speculum, when required for the latter purposes, should be elliptical, having the object in one focus, and the focus of the eye-lens in the other.

This telescope, which is more simple than other reflectors, may be greatly improved according to the method of Brewster, who has proposed (for telescopes of moderate size, where a front view cannot be used) to employ two glass prisms in place of the small plane. By the experiments of Kater, it appears that one-third of the rays of light is lost when reflected by a speculum at a vertical incidence, and probably not more than sixty-eight out of one hundred are reflected at an angle of forty-five degrees, as in the Newtonian small metal. In addition to this, the imperfection of surface and figure in metals, which makes the rays stray five or six times more than the same imperfection in a refracting surface, as well as the difficulty of working metals as perfect as glass, induced him to suggest this improvement. Let *a b* be the great speculum, and *r a*, *r b* parallel rays from a distant object reflected to a focus at F; the cone of rays, however, is intercepted by the achromatic prism *c d*, and refracted to *f*, where a distinct image is formed in the anterior focus of the eye-glass *e*, by which it is magnified. The double prism *c d* being composed of a prism of crown glass *c*, and another of flint *d*, united by a cement of mean refractive power, the loss of light by transmission through the two prisms, says Brewster, will not exceed six hundred rays out of ten thousand, as the light transmitted through a lens of glass, according to Herschel, is nine thousand four hundred and eighty-five out of ten thousand incident rays. Hence the light lost by the prism is only one-fifth of that lost by reflection.



The Newtonian telescopes made by Hadley had, in place of a plane metal, a right-angular prism P substituted, having its sides perpendicular to the incident and emergent rays. In this, as is accomplished by the two prisms of Brewster, the image will be erect, and a less quantity of light lost than by a mirror of the common kind.

Another class of reflecting telescopes was invented by Gregory, in 1660, but they were not made till some years after the Newtonian, from the difficulty of forming the metals. The Gregorian reflector is, however, preferred to the Newtonian, and is most commonly used, because the observer is stationed in a line with the object, whereas in the Newtonian he is at right angles to it. The annexed figure is a section of the Gregorian reflector. B D is a concave metal, whose surface should be formed by the revolution of the hyperbolic curve: this speculum has a small hole in its centre. E is another concave elliptical small metal placed in the axis of the



larger one, at a distance from it a little more than the sum of their focal distances. H are the eye-lenses, sliding in a tube fixed behind the large speculum: the adjustment is made by the screw *s s*, which moves the small metal to or from the great speculum. Let *r* B and *r* D be two parallel rays from a distant object, these will be reflected to the focus F of the large metal, where an image will be formed, and the rays, crossing each other, fall upon the small speculum E; and if the focus of this metal had coincided with the focus F, the rays would have been reflected parallel, but now they form a direct image at I, and this image is viewed by the eye-piece or a single lens at H. The magnifying power of this instrument may be computed thus:—suppose the focus B F of the large speculum is nine inches, and the focus of the small metal one and one-half inch: then will the angle be increased six times; but this must be multiplied by the ratio of the distances I H, the focus of the lens, and the distance I F; and if these are as one to eight, the amplification of the object will be $6 \times 8 = 48$ times.

The Cassegrainian reflector is constructed in the same way as the Gregorian, with the exception of a small convex spherical speculum, instead of one a little concave; and as the focus of this metal is negative, it is placed at a distance from the larger metal equal to the difference of their foci, and only one image is formed, viz. that in the focus of the eye-glass; on this account, the distinctness is considerably greater than in the Gregorian. Mr. Ramsden states, that this construction is preferable to either of the former reflectors, because the aberrations of the two metals have a tendency to correct each other; whereas in the Gregorian, both the metals being concave, any error in the specula will be doubled. By assuming such proportions of the foci of the specula as are generally employed in these instruments, which are about as one to four, he asserts that aberration or indistinctness occasioned by the figures of the reflectors in the Cassegrainian construction is to that in the Gregorian as three to five.

In sidereal observations of nebulæ and small stars, much light is necessarily required; and by whatever means a loss of light by reflection or refraction can be prevented, the adoption of such a construction would be advisable. Herschel, from an investigation of the loss of light occasioned by the small spectrum in reflectors, was enabled to construct an instrument that entirely obviated the use of the second metal. We shall here lay before our readers a description of this magnificent instrument, which may justly be ranked among the wonders of the world.

But it will not be amiss to mention first a few circumstances that led the way to the construction of this large telescope, in the execution of which two very material requisites were necessary; viz. the support of a very considerable expense, and a competent experience and practice in mechanical and optical operations. Herschel states that when he went to reside at Bath (England) he had long been acquainted with the theory of optics and mechanics, and only wanted experience in the practical part of these sciences. This he acquired by degrees at that place, where, in leisure hours, and by way of amusement, he made a great number of telescopes of different sizes and constructions. His way of preparing mirrors at that time, when the direct method of giving the figure of any of the conic sections to specula was still unknown to him, was to have many mirrors of each sort cast, and to finish them all as well as he could. Then he selected for use the best of them by trial, putting the rest by to be repolished. In the year 1781 he began to construct a thirty feet aerial reflector, and cast the mirror, which came out of the mould thirty-six inches in diameter. The composition of the metal being too brittle, it cracked in the cooling. He cast it a second time, but the furnace gave way and the metal ran into the fire. The discovery of the Georgian planet soon after introduced him to the patronage of the king, to whom the design of constructing a forty feet telescope was communicated, and by whom it was encouraged. In consequence of the king's support, Herschel was enabled to begin the construction of his immense telescope toward the close of the year 1785. He inspected the casting, grinding, and polishing of the great mirror, which being highly polished and put into the tube, he had the first view through it on February 19th, 1787. He did not, however, date the completion of the instrument till much later; for the first speculum was thinner on the centre of the back than was intended, and, on account of its weakness, a good figure could not be given to it. A second mirror was cast January 26th, 1788, but it cracked in cooling. On February 16th it was recast, with particular attention to the shape of the back, and it proved to be of the proper degree of strength. By October 24th it was brought to a good degree of polish, and the planet Saturn observed with it. Not being satisfied, Herschel continued the work of polishing till August 27th, 1789, when it was tried upon the fixed stars and found to give a pretty sharp image. Large stars were a little affected with scattered light, owing to many remaining scratches in the mirror. On the 29th of the same month, having brought the telescope to the parallel of Saturn, Herschel discovered a sixth satellite of that planet; he also saw the spots on Saturn better than he had ever seen them before; so that we may date the completion of the forty feet telescope from that time. The high magnifying power of Herschel's telescope made all the usual apparatus for its support extremely imperfect. But his judgment, ingenuity and fertility in resource were as eminent as his philosophical ardor. He contrived in this case an apparatus that had every desirable property. The motions, both vertical and horizontal, were effected with the utmost simplicity and firmness. It was one of the noblest monuments of philosophical zeal and princely munificence the world ever saw.

The frontispiece represents a view of this instrument (in a meridional situation) as it appeared when seen from a convenient distance by a person placed toward the southwest of it. The foundation in the ground consisted of two concentric circular brick walls, the outermost of which was forty-two feet in diameter, and the inner twenty-one feet. They were two feet six inches deep under ground, two feet three inches broad at the bottom, and one foot two inches at the top, and were capped with paving stones about three inches thick and twelve and three quarters broad. The bottom frame of the whole apparatus rested upon these two walls by twenty concentric rollers, and was movable upon a pivot, which gave a horizontal motion to the whole apparatus as well as to the telescope. In the centre was a large post of oak, framed together with braces under ground, and walled fast with brickwork so as to make it steady. Two central beams crossed each other over this post, and a strong iron pin (the pivot) passed through them both into a socket in the centre of the post, thus permitting the whole of the foundation timber to turn freely on this centre, a proper force being applied for that purpose.

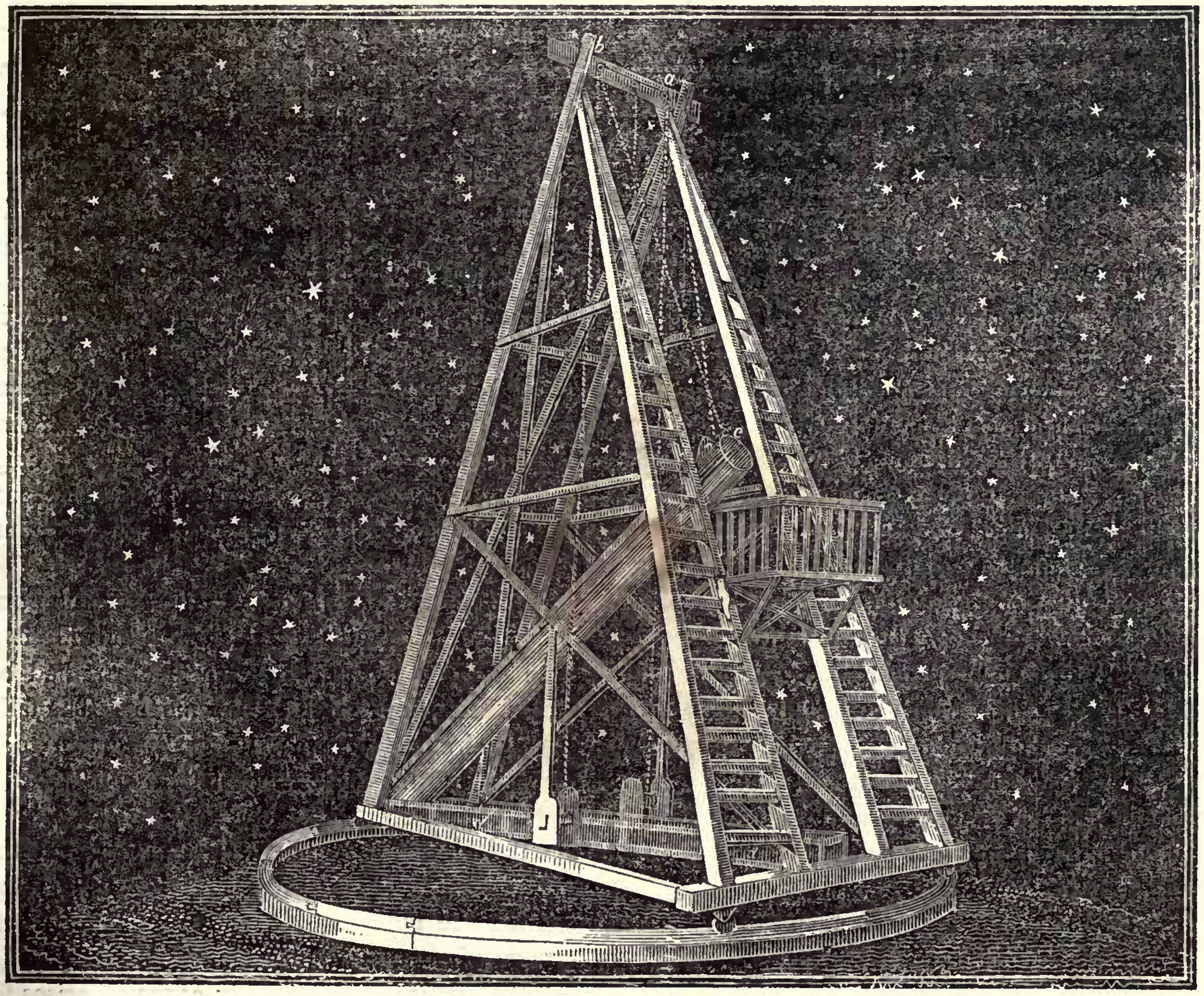
The construction of the tube of the telescope (though very simple in its form, being cylindrical) was attended with great difficulties. This is not to be wondered at, if its size and the materials of which it was made are taken into consideration. Its length was thirty-nine feet four inches, it measured four feet ten inches in diameter, and every part of it was of iron. Upon a moderate computation, the weight of a wooden tube must have exceeded the iron one by three thousand pounds at least, while its durability would have been far inferior to that of iron. The body of the tube was made of sheet iron, joined together without rivets, by a kind of seaming well known to those who make funnels for stoves. The whole outside was thus put together, in all its length and breadth, so as to make one sheet of near forty feet long and fifteen feet four inches broad. The tools, forms, and machines necessarily made for the construction were very numerous. In the formation of this large sheet, a kind of table built for its support was constantly enlarged as the sheet advanced, till when finished it was as large as the whole of it. When the whole sheet was formed, the sides were cut perfectly parallel, and bent over at the ends in contrary directions to be ready to receive each other. Very great mechanical skill was displayed in the contrivance of the apparatus by which the telescope was supported and directed. By means of two motions, a vertical and a horizontal, the telescope might be set to any altitude up to the very zenith; and in order to have the direction of it at command, a foot quadrant was fixed at the west side of the tube, near its end. Above this was planted a finder, or night-glass, about twenty-one inches long, with crosswires in the focus.

The method of observation with this telescope was called by Herschel the *front view*. The size of the instrument having been such as to allow of its being loaded with a seat, there was one fixed to the end of it. This seat was movable upward and downward through the space of one foot, not so much for the accommodation of different observers, as for the alteration required at different altitudes, which amounted to nearly twelve inches. One half of the seat was made to fall down in order to open an entrance at the back, and being enclosed at the front and sides, a bar, which shut up the back after the observer was in his place, secured the whole in such a manner as to render it perfectly safe and convenient. At the sides of the seat there were two strong iron quadrants with teeth, with a handle extending to within reach of the observer; and by turning this handle, the seat was brought to a horizontal position when any change in the altitude of the telescope required it. By making use of another handle, the observer could screw himself, the seat, and the telescope, back and forth in the space between the supporting ladders, and thus follow at will the object whose course he wished to trace. He might have ordered the whole frame to be moved with the great circular motion, and have kept his object in view by screwing the telescope back as fast as it advanced. Of the two houses represented in the plate, one contained the assistant's room, the other the working-room. A mode of ready communication from the observer to the assistant, and to the person who gave the required motions to the apparatus, was indispensable. But the distance between these rooms and the place of the observer was evidently too far for a conversation in the open air between them. A speaking-pipe was therefore constructed to convey the communications to their proper destination. This pipe was divided into two branches, one going into the observatory (assistant's room) by passing through the floor, the other into the working-room, where it ascended to the level of the workman's ear. Notwithstanding the passage of the sound through a pipe with many inflections and not less than one hundred and fifteen feet length, it required no particular exertion to be very well understood. In the observatory there was a sidereal time-piece;—close to it, and of the same height, a polar distance piece, with a dial-plate similar and equal in size to that of the time-piece. It was divided into sixty parts to express minutes of space. The degrees were shown in a square opening under the centre. This piece might have been set so as to show polar distance, zenith distance, declination, or altitude, by setting it differently, yet its construction was very simple.

The time and polar distance pieces were so placed that the assistant at the table sat facing them, with the speaking-pipe rising near, so that observations were very readily recorded. The place of new objects was also readily noted, as their right ascension and polar distance was before the assistant, so that nothing was required but to read them at the signal of the observer. By means of the speaking-pipe the workman might have been directed to "begin," "stop," "go faster, slower." These were generally all the orders necessary for him, which fact, being known to him and to the assistant, could occasion no mistake, although the pipes that went into the two apartments were united. The metal of the great mirror was forty-nine and a half inches in diameter, but on the rim there was an offset three-fourths of an inch broad and one inch deep, which reduced the concave face of it to a diameter of forty-eight inches of polished surface. The thickness, which was the same in every part of it, was, after the polishing, about three and a half inches. Its weight when it came from the cast was two thousand one hundred and eighteen pounds, of which it must have lost a small quantity in polishing. To put the mirror into the tube, a small narrow carriage was provided going on rollers. It had two upright sides, between which the speculum, when suspended vertically by a crane in the laboratory, was made to pass in at one end, and being let down, was bolted in.

This noble instrument, with proper eye-glasses, magnified above six thousand times, and was the largest telescope ever constructed. A full account of every part of the work which attended the formation and erection of this telescope, together with minute details of the mode of making observations, is contained in the Transactions of the London Philosophical Society for 1795. The date of the completion of this apparatus was fixed by Herschel, as before stated, at the 28th of August, 1789.

The frame of this instrument having greatly decayed, it was taken down, and another, of twenty feet focus and eighteen inches diameter, erected in its place, by Sir John F. W. Herschel, in 1822.



The largest front-view reflecting telescope at present in England, was erected at the Royal Observatory, at Greenwich, by Mr. Ramage, in 1820. The diameter of the concave reflector is fifteen inches, and its focus twenty-five feet; the mechanical arrangement of the stand is greatly simplified. A perspective view of the whole instrument is shown in the above figure. The tube is composed of a twelve-sided prism of deal, five-eighths of an inch thick; at the mouth *c* is a double cylinder of different diameters on the same axis; around this a cord is wound by a winch, and passes up from the small cylinder over a pulley *a*, and down through the pulley *b*, on to the larger cylinder at *c*. Now, when the winch is turned to raise the telescope, the endless cord is unwound from the smaller cylinder and wound on to the larger: the difference of the size of the two cylinders will be double the quantity raised, and a mechanical force to any extent may thus be obtained by duly proportioning the diameters of the two cylinders; by this contrivance the necessity for an assistant is superseded. The instrument, when not in use, is let down into the box *d d*, and covered with canvas, to prevent dust or moisture from tarnishing the speculum.

The applications of the telescope to the purposes of man are so numerous, that their details would far exceed the boundaries of our treatise. Amongst its principal uses, however, besides those accompanying the descriptions of the various modifications of that instrument, may be enumerated the following:—The accurate determination of the longitude of the various places on the earth's surface is ascertained by the telescope, by observing the immersions and emersions of the four satellites of the planet Jupiter; thence, by the aid of a good chronometer, with the time of any known place, the situation of the unknown spot is determined. Before the invention of the telescope, navigators were compelled to keep within sight of the coast in sailing from one country to another, and thus were often endangered while passing a hostile or rocky shore; by the assistance of this instrument, the voyage is made direct to the intended place without fear or danger.

To the astronomer the telescope is his principal and most important guide. It enables him to determine with precision the transits of the planets and stars across the meridian. The computation of astronomical and nautical tables, to determine the revolution of the planets on their axes, and their relative polar and equatorial diameters, is derived from observations by the telescope. We are by this instrument enabled to discover the analogy between the laws which govern the motions of the planets and those of our earth, their parallax, and thence their distances. The aberration of light, and the motions of the *sidereal* systems in space, unfold wonders which must excite the imagination of the most profound philosophers in the highest possible degree. The harmony and simplicity displayed in such immense worlds prove the design and wisdom by which they were created; and the wonderful facts thus ascertained raise the most ordinary mind up to a sublime contemplation of the great Creator.

In surveying land, the telescope is highly useful, and for this purpose is mounted on a stand, with a horizontal and vertical motion, registering, by divisions, the degrees and minutes of inclination or position of the instrument. For the more accurate *reading off* these divisions, the two limbs are furnished with a *Vernier's scale*. Spirit-levels and a magnetic needle are usually attached to the instrument; and, from the purposes to which it is applied, a telescope with this mounting is called a *theodolite*, derived from two Greek words meaning an instrument *for seeing or determining distances*. The method by which the distances and heights of remote objects are ascertained is by measuring the angles subtended by the object, and computing trigonometrically therefrom.

Some writers have much exaggerated the powers and penetration of the telescope; indeed, it has been gravely asserted that works of art had been recognised in our satellite, the moon. The fallacy of this circumstance may be easily shown to our readers by the following simple considerations. Let a person direct the tubes of a telescope (without the glasses) to any celestial object, and there fix them; he will soon find that in a short space of time the object will have removed from before the mouth of the tube. Now this motion of the celestial bodies, which is only *apparent*, arises from the revolution of our earth on its axis; and the quantity of this motion may be determined with facility thus:—the earth is known to revolve once about its axis in twenty-four hours; and as every circle is supposed to be divided into three hundred and sixty equal parts or degrees, the apparent time any celestial body takes to describe one degree will be found by dividing twenty-four hours by three hundred and sixty, which gives us four minutes as the time an object would pass the mouth of the tube if it only takes in one degree of the heavens.

Now, if we suppose the glasses to be placed in the tubes, the magnifying power of the instrument being sixty, and we direct it (as before) to an object, as the moon, whose diameter is about half a degree, the time of her passing or transit will be one minute, if the field of view be, as in the ordinary telescopes, about thirty minutes, which the moon would exactly occupy. If the power of the telescope be increased ten times, the eye-piece having the same angle of vision, only a hundredth part of the moon would be seen at once, one hundred being the square of ten, the increased power of the instrument; and the time in which this portion of the moon would pass the telescope is six seconds. Again, if we increase the power ten times, so that its linear amplification of an object is six thousand times, only a ten-thousandth part of the moon's surface could be seen in the field of view; or the planet Saturn, whose apparent diameter is ten seconds, would just fill it, and the time of their passing the instrument would be only six-tenths of a second.

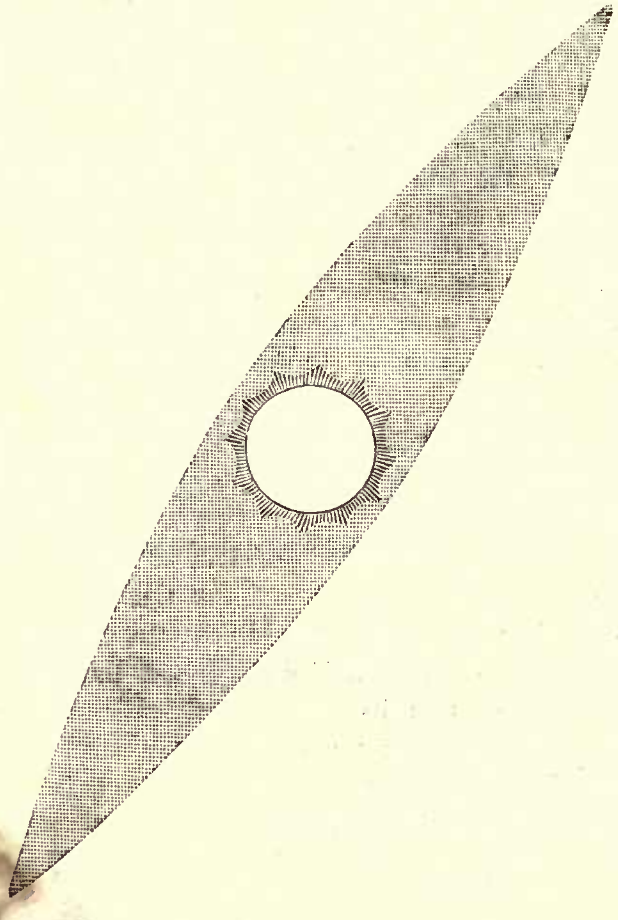
Having thus shown the amazing velocity with which a planet passes the mouth of a telescope with these high powers, we shall next proceed to point out the apertures and amplification necessary for observing some given measure on the surface of the moon. First, we must determine the angle every object must subtend to the eye in order to render it visible: this is found on an average for different sights to be one minute; that is, when an object is removed from the eye about three thousand times its own diameter it will only be just distinguishable. From this we can now determine the extent of the smallest part of the moon's surface discoverable by the unassisted eye. Its real diameter is two thousand one hundred miles, which, divided by the number of minutes that its apparent diameter subtends, viz. thirty gives us seventy miles as the measure of the least distinct spot seen by the naked eye; therefore we know that, if a telescope magnifies seventy times, we can just discern a spot one mile in diameter on the moon's surface; and to recognise any object ten feet in diameter, we shall find by this rule the magnifying power of the telescope must be thirty-seven thousand one hundred times; and the diameter of an object-glass or metal for such an instrument may also be found. If we suppose a pencil of rays one-fiftieth of an inch in diameter will admit sufficient light to the eye, the diameter of the speculum must be sixty-two feet, and its focal distance three hundred and nine feet, when an eye-glass of one-tenth of an inch is employed. These calculations must convince the reader of our inability to make such observations; for if the impossibility of procuring such enormous instruments were overcome, they would be so unwieldy as entirely to prevent our using them.

CHAPTER X.

Zodiacal light—Observed by Cassini in 1683—By Childrey previous to 1661—By others in 1707—By Professor Olmsted in 1834—Various theories—Aurora borealis—Appearances in the Shetland Islands—In Siberia—At Hudson's Bay—Sounds attending their appearance—Aurora seen by Capt. Ross—Southern lights observed by Forster—Northern lights as seen in England, March, 1716—Supposed height of these meteors—Theories respecting their cause—Halley's—Mairan's—Euler's—Franklin's—Kirwan's—Appearances in August and September, 1827—December and November, 1835—April, 1836.

The Zodiacal Light is a pyramid of light which sometimes appears in the morning before sunrise, and in the evening after sunset. It has the sun for its basis. Its sides are not straight, but a little curved, its figure resembling a lens edgewise. It is generally seen here about October and March, that being the time of our shortest twilight. It cannot be seen in the twilight, and when that lasts a considerable time, the zodiacal light is withdrawn before the twilight ceases. This light, which is something like the milky way, or that of a faint twilight, or like the tail of a comet, thin enough to allow stars to be seen through it, seems to surround the sun in the form of a lens, whose plane is nearly coincident with that of the sun's apparent path. It is seen stretched along the zodiac, and accompanies the sun in his annual course through the twelve signs; each end terminates in an angle of about twenty-one degrees; the extent in length from the sun to either of the angular points varies from fifty to one hundred degrees; it reaches beyond the orbit of Mercury, and probably of Venus; the breadth of it near the horizon being also variable from twelve to thirty degrees; near the sun it cannot be seen. This light is weaker in the morning, when day is coming on, than at night, when darkness is increasing. At the equator it is visible all the year round. In high latitudes it may be best seen after evening twilight about the last of February, or before morning-twilight at the beginning of October; because at these times it is nearly perpendicular to the horizon, and consequently clearer from the thick vapors near the horizon, and from the effects of a lingering twilight. It may be seen, but more dimly, during the whole of the winter. The figure in the right hand column represents the zodiacal light.

It was observed by Cassini in 1683, a little before the vernal equinox, in the evening, extending along the ecliptic from the sun. He thinks, however, that it had been seen before and afterward disappeared, from an observation of J. Childrey, in a book published in 1661, in which may be found the following passage:—"In the month of February, for several years, about six o'clock in the evening, after twilight, I saw a path of light tending from the twilight toward the Pleiades, as it were touching them. This is to be seen whenever the weather is clear, but best when the moon does not shine. I believe that this phenomenon has been before visible, and will hereafter appear, always at the above-mentioned period of the year; but the cause and nature of it I cannot guess, and therefore leave it to the inquiry of posterity." This phenomenon may be what the ancients called trabes, (beams,) which word they used for an impression of light in the air. Des Cartes speaks of an appearance of the same kind. Fatio de Duillier observed it immediately after the discovery by Cassini, and suspected "that it had always appeared." It was soon after observed by Kirch and Eimmart in Germany.



On the 3d of April, 1707, there was observed at Essex, England, in the western part of the heavens, about a quarter of an hour after sunset, a long slender pyramidal appearance perpendicular to the horizon. The sun seemed to be the base of this pyramid, and its apex reached twenty degrees above the horizon. It was throughout of a rusty red color, and quite vivid when first seen, but the upper part much fainter than the base. It became gradually weaker and weaker, so that in a quarter of an hour after it was first seen, its vertex was scarcely visible. The lower part remained vivid more than an hour, yet gradually decreasing in length all the time. The observer had never seen any thing like it, except the "pyramidal glade," which is now called the aurora borealis; it was like that, except in color and length. This was without doubt the zodiacal light.

On the eleventh of October, 1834, Professor Olmsted's attention was attracted to the appearance of the zodiacal light in the morning sky. At that time it presented a pyramidal form, resting its broad base on the horizon, and terminating in a faint, indefinite extremity near the nebula in the constellation of the Crab. It was then asked whether this light has any connection with falling stars, and whether it would sustain any change on or about the 13th of November. The change contemplated was, that about that time it would pass by the sun and become visible in the evening sky after twilight. It was observed in the morning until after the 13th of November. As soon after that as the absence of the moon permitted, viz. on the 19th, the extreme parts of the same luminous pyramid were recognised in the west immediately after twilight; but owing to the low angle made by the ecliptic with the western horizon at that time, the light was carried so near the horizon in the south-west as to have its distinctness much impaired; it could, however, be traced a little above the two bright stars in the head of Capricorn. From that time to the last of December it was seen, on every favorable evening, advancing, in the order of the signs, faster than the sun; on the evening of the 21st of December, in a peculiarly favorable state of the atmosphere, it was faintly discernible from six to seven o'clock, reaching nearly to the equinoctial colure, and of course ninety degrees from the sun measured on the ecliptic; it also continued visible in the morning sky, although evidently withdrawing to the other side of the sun.

Fatio conjectured this appearance to be owing to a collection of corpuscles encompassing the sun and reflecting its light. Cassini at first supposed that it might arise from an infinite number of small planets revolving about the sun; so that this light might owe its existence to these bodies, as the milky way does to an infinite number of fixed stars. He, however, soon rejected this for another solution, viz. that it is caused by particles incessantly flying off from the body of the sun, detached by the rotation of that luminary on its axis. The velocity of the equatorial parts of the sun, being the greatest, would throw the matter to the greatest distance; and on account of the diminution of velocity toward its poles, the height to which the matter would rise would be less; and as it might spread a little sideways, it would assume the form of a lens or double cone, whose section, perpendicular to its axis, would coincide with the sun's equator. This is an ingenious theory; but there is one great difficulty in thus accounting for the phenomenon. It is well known to astronomers that the centrifugal force at the sun's equator must be a great many times less than its gravity; it does not appear, therefore, how the sun from its rotation can detach any of its gross particles. If there be particles detached from the sun, they must be sent off by some other unknown force; in which case they would probably be sent off in all directions equally, which would not give the zodiacal light the figure it is observed to have. Brewster says, "It is settled that we may not regard this light as produced by a solar atmosphere, as the medium is of so rare a nature that it has no sensible effect on the light of the heavenly bodies." But Herschel the younger, who has written more recently, and on whose opinion we are most disposed to rely, does not think it a matter decided this way, but rather the reverse. He says, "The zodiacal light is a phenomenon which seems to indicate some degree of nebulosity about the sun, and even to place that body in the list of nebulous stars. It is manifestly in the nature of a thin, lenticularly-formed atmosphere surrounding the sun, and may be conjectured to be no other than the denser part of that medium, which, we have reason to believe, resists the motion of comets; loaded, perhaps, with the actual materials of the tails of millions of those bodies, of which they have been stripped in their successive perihelion passages, and which may be slowly subsiding into the sun."

AURORA BOREALIS.

The northern light is an extraordinary meteor, or luminous appearance, showing itself in the night-time, in the northern part of the heavens, and usually in frosty weather.

It is generally of a reddish color, inclining to yellow, and sends out frequent corruscations of pale light, which seems to rise from the horizon in a pyramidal undulating form, and shoots with great velocity up to the zenith.

This kind of meteor, which is more uncommon as we approach the equator, is almost constant in the polar regions during the long winter of that climate, and appears there with the greatest lustre.

In the Shetland Isles, *the merry dancers*, as they are there called, are the constant attendants of clear evenings, and afford great relief amidst the gloom of long winter nights. They commonly appear at twilight near the horizon, of a dun color, approaching to yellow. They sometimes continue in that state for several hours, without any perceptible motion, and afterward break out into streams of stronger light, spreading into columns, and altering slowly into ten thousand different shapes, and varying their colors from all the tints of yellow to the most obscure russets. They often cover the whole hemisphere, and then they exhibit the most brilliant appearance. Their motions at this time are inconceivably quick, and they astonish the spectator with the rapid change of their form. They break out in places where none were seen before, skimming briskly along the heavens; are suddenly extinguished, and succeeded by a uniform dusky tract. This again is brilliantly illuminated as before, and as suddenly left a dark space. Some nights they assume the appearance of dark columns, on one side of the deepest yellow, and on the other gradually changing, till they become undistinguishable from the sky. They have generally a strong tremulous motion from one end to the other, and this continues till the whole vanishes. As for us, who see only the extremities of these phenomena, we can have but a faint idea of their splendor and motions. According to the state of the atmosphere, they differ in color, and sometimes assuming that of blood, they present a terrific appearance. The rustic sages who observe them become prophetic, and terrify the spectators with alarms of war, pestilence, and famine; nor indeed were these superstitious presages peculiar to the northern islands. Appearances of a similar nature are of ancient date, and they were distinguished by the appellations of "phasmata," (sights,) "trabes," (beams,) and "bolides," (darts,) according to their different forms and colors. Pliny states that "out of the firmament there appeared at night a bright light at sundry times, rendering the night as bright as the day." In old times, however, they were more rare, or were less frequently observed; but when they were observed, they were supposed to portend great events, and the excited imagination formed of them aerial conflicts.

In high northern latitudes these phenomena are not only singularly beautiful in their appearance, but afford travellers, by their almost constant effulgence, a very beautiful light during the whole night. In Hudson's Bay they diffuse a variegated splendor which is said to equal that of a full moon. In the north-eastern parts of Siberia, according to the description of Gmelin, they are observed to begin with single bright pillars, rising in the north, and almost at the same time in the north-east, and, gradually increasing till they comprehend a large space of the heavens, rush about from place to place with inconceivable velocity, and finally almost cover the whole sky up to the zenith, and produce an appearance as if a vast tent was expanded in the heavens, glittering with gold, rubies, and sapphire. A more beautiful spectacle cannot be painted; but whoever should see such a northern light for the first time, could not behold it without

terror. For however fine the illumination may be, it is attended with such a hissing, cracking, and rustling noise through the air as if the largest fireworks were playing off. To describe what they then hear, the people say "spolochi chodjat," that is, "the raging host is passing." The hunters, who pursue the white and blue foxes on the confines of the Icy Sea, are often overtaken in their course by the northern lights. Their dogs are then so much frightened that they will not move, but lie obstinately on the ground till the noise has ceased. Clear and calm weather commonly follows this kind of northern lights. This account has been confirmed by the uniform testimony of many persons who have spent part of several years in very high northern latitudes, and inhabited different countries, from the river Yenissei to the Lena. This region seems to be the true birthplace of the lights. A person who had resided seven years at Hudson's Bay, spoke with admiration of the fine appearance and brilliant colors of the auroras, and particularly of their rushing noise, which he had frequently heard, and he compared it to the sound produced by swiftly whirling a stick at the end of a string. A similar noise has been heard in Sweden. A person at Northampton, (England,) when the lights were remarkably bright, was confident that he heard a hissing or whizzing sound. Cavallo states that the crackling noise is distinctly audible, and that he has heard it more than once. Mr. Belknap, at Dover, New Hampshire, testified that he heard a noise of a similar kind, during the appearance of the northern light. The following is his letter to a friend on the subject, and dated the 31st of March, 1783. "Did you ever, in observing the aurora, perceive a sound? I once looked upon the idea as frivolous and chimerical, having heard it at first from persons whose credulity I supposed exceeded their judgment; but, upon hearing it repeatedly asserted by others, whom I thought judicious and curious, I began to entertain an opinion in favor of it.

"I was strengthened in this opinion about two years ago, by listening with attention to the flashing of a luminous arch, which appeared on a calm frosty night, when I thought I heard a faint rustling noise like the brushing of silk. Last Saturday evening I had full auricular demonstration of the reality of this phenomenon. About ten o'clock, the hemisphere was all in a glow; the vapors ascended from all points, and met in a central one near the zenith. All the difference between the north and south parts of the heavens was, that the vapor did not begin to ascend so near the horizon in the south as in the north. There had been a small shower with a few thunder-claps and a bright rainbow in the afternoon, and there was a gentle western breeze in the evening, which came in flaws with intervals of two or three minutes. In these intervals, I could plainly perceive the rustling noise, which was quite distinguishable from the sound of the wind, and could not be heard except when the flaws subsided. The flashing of the vapor was extremely quick; whether accelerated by the wind or not, is beyond my power to say. But from the quarter where the greatest quantity of vapor seemed to be in motion, the sound was plainest, and that quarter was the eastern during my observation. The scene lasted about half an hour, though the whole night was as light as when the moon is in her quarter."

Perhaps the most extraordinary northern light for regularity and beauty ever witnessed, was that seen at Lynn Regis, England, on the 5th of September, 1718, at ten o'clock in the evening, when the appearance was as represented in the accompanying figure. On the next evening, between eight and ten o'clock, several columns of light were observed like those represented in the same

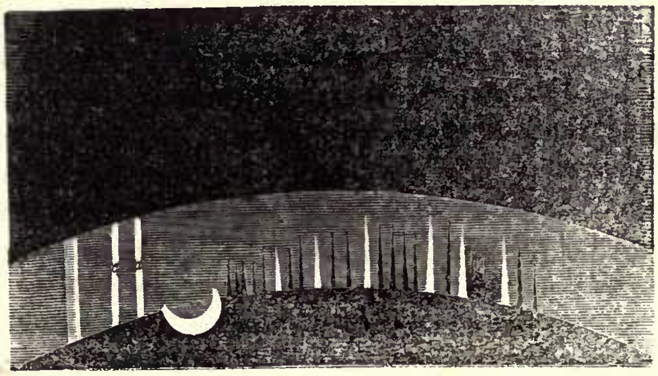


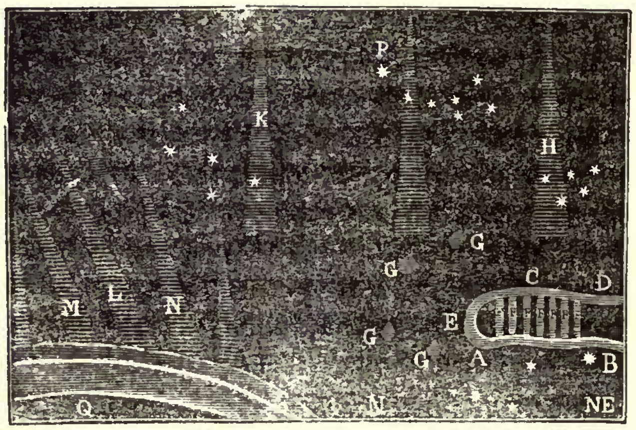
figure at *a a*, not so bright as the pyramids of the evening before, which were carried toward the west, while these were carried toward the east. The rays arose out of a seemingly black cloud, though there was in reality no cloud there, for the stars shone plainly, and the moon was very bright in the midst of the blackness.

Captain Ross speaks of numerous northern lights witnessed by him while on his second voyage of discovery in the North Sea. One he particularly describes as follows:—"1829, November 24th. There was a brilliant aurora to the south-west, extending its red radiance as far as the zenith. The wind vacillated on the following day, and there was a still more brilliant aurora in the evening, increasing in splendor till midnight, and persisting till the following morning. It constituted a bright arch, the extremities of which seemed to rest on two opposed hills, while its color was that of the full moon, and itself seemed not less luminous, though the dark and somewhat blue sky by which it was backed was a chief cause, I have no doubt, of the splendor of its effects. We can conjecture what the appearance of Saturn's ring must be to the inhabitants of that planet; but here the conjecture was perhaps verified, so exactly was the form and light of this arch what we must conceive of that splendid planetary appendage, when crossing the Saturnian heavens. It varied however, at length, so much as to affect this fancied resemblance, yet with an increase of brilliancy and interest. While the mass or density of the luminous matter was such as to obscure the constellation of the Bull, it proceeded to send forth rays in groups, forming such angular points as are represented in the stars of jewelry, and illuminating objects on land by their corruscations. Two bright nebulæ of the same matter afterwards appeared beneath the arch, sending forth similar rays, and forming a still stronger contrast with the dark sky near the horizon. About one o'clock it began to break up into fragments and nebulæ, the corruscations becoming more frequent and irregular, until it suddenly vanished at four."

Similar appearances, called *southern lights*, (auroræ australes,) were long ago observed toward the south pole, and their existence was confirmed by Mr. Forster, who asserts, that in his voyage round the world with Captain Cook, he observed them in high southern latitudes, though attended with phenomena somewhat different from those which are seen here. On February 17th, 1773, in south latitude 58°, "a beautiful phenomenon (he says) was observed during the preceding night, which appeared again for several successive nights. It consisted of long columns of a clear white light, shooting up from the horizon to the eastward, almost to the zenith, and gradually spreading over the whole southern part of the sky. These columns were sometimes bent sideways at their upper extremities, and though in most respects similar to the northern lights of our hemisphere, yet they differed from the last in being always of a whitish color, whereas ours assume various tints, especially those of a fiery and purple hue. The sky was generally clear when they appeared, and the air sharp and cold, the thermometer standing at the freezing point."

The periods of the appearance of the northern lights are very inconstant. In some years they occur very frequently, and in others they are more rare. It has been observed that they are more common about the time of the equinoxes than at other seasons of the year.

On Tuesday the 17th of March, 1716, about dusk, (seven o'clock,) "not only in London, but in all parts of England" where the beginning of this wonderful phenomenon was seen, there arose very long, luminous rays, perpendicular to the horizon and extending to the zenith, out of what seemed a dusky cloud in the north-east part of the heavens. The edges of this cloud were tinged with a reddish yellow, as if the moon were hid behind it. The reddish cloud spread rapidly along the northern horizon to the north-west, and immediately sent forth rays from all parts, now here, now there, they observed no rule or order in their rising. Many of these rays seemed to unite near the zenith, forming there a crown, or image, that drew the attention of all spectators. Some said that it resembled the representation of glory with which painters surround the name of God in churches; others, those radiating stars that glitter on the breast of the nobility; others would have it like the flame of an oven reverberating and rolling against its arched roof; others, again, thought it more like that tremulous light which is cast against a ceiling when the sun's beams are reflected from the surface of agitated water; but all agreed that this spectrum remained but a few minutes, and was variously tinged with colors, yellow, red, and green. The crown soon dispersed, and did not appear again. But still, without any order as to time, place, or size, luminous rays continued to rise perpendicularly, now in one spot, now in another; now longer, now shorter; now in quick succession, now few and far between. Nor did they arise, as at first, out of a cloud, but they often emerged at once out of the pure sky, which was more than ordinarily serene and still. Most of these rays ended in a point, and were shaped like erect cones; others resembled the tails of comets so much that they might easily be mistaken for them. Some would continue visible for several minutes, but the greater number just showed themselves and died away. Some had but little or no motion; others moved from east to west under the pole, contrary to the motion of the heavens, by which means they would sometimes seem to rush together, at other times to fly from each other. After this sight had continued about one hour and a half, the rays became less numerous and less elevated; but that diffused light which had illuminated the northern parts of the heavens gradually subsided, and settling on the horizon, formed the representation of a very bright twilight, out of which arose long beams of light, not exactly erect, but declining toward the south; these, ascending by a quick and undulating motion to a considerable height, vanished in a little time, while others, at uncertain intervals, supplied their places. At the same time, an exceedingly black and dismal cloud seemed to hang over that part of the horizon which was situated between the north-west and the east. Yet no cloud was there in reality, but only a serene sky, so remarkably pure and limpid that the stars shone brightly in it, and particularly a star in the tail of the Swan, then very near the horizon; the great blackness being only in appearance, and caused by a contrast with the great light collected above it. But the light had now assumed a new form, that of two streaks lying in a position parallel to the horizon, with ill-defined edges; they were each about a degree in breadth, the lower being eight or nine degrees high, the other four or five degrees above it; these remained immovable for some time, and their light was so great that a man might have read print of an ordinary size. After an interval, the northern end of the upper streak bent downward and joined to the end of the lower, so as to shut up on the north side a space which still continued open to the east. Not long after, there suddenly appeared within this space a great number of small columns, perpendicular to the horizon, and extending from one streak to the other, which disappeared so quickly that the observer could not decide whether they rose from the under, or fell from the upper line; by their sudden changes they caused such an appearance as might well be considered by the superstitious as conflicts in the sky. About this time there suddenly appeared, low under the pole, and very nearly due north, three or four lucid spots like clouds, in the pure black sky. These, as they broke out at once, so, after a few minutes continuance, they disappeared as quick as if a curtain had been drawn over them. Not long after, in the space above the parallel lines of light, there was seen a large pyramid of light, like a spear sharp at the top, which seemed to reach the zenith, or beyond it. This moved, with an equable and not very slow motion, from the north-east, where it arose, to the north-west, where it disappeared, keeping a perpendicular position, and passing successively over all the stars of the Little Bear, and not effacing the smallest in the tail, such was the extreme rarity and transparency of the matter of which it consisted. This was about eleven o'clock at night. Soon after, (the two parallel streaks of light having faded away,) there was formed in the north an arch extending from the north-east to the north-west; it had very much the appearance of a rainbow, except that it was of one uniform color, viz. a flame color, inclining to yellow; beneath this arch the sky was very black, and appeared like a dark cloud to the eye, but with the telescope the small stars were visible, though so near the horizon. Above this arch were visible the rudiments of another and larger arch, with an interval of dark sky between them. The moon rose in the course of the night, but caused no perceptible change in these appearances, neither diminution nor increase of light, but, as before, at intervals the light seemed to undulate and sparkle, not unlike the rising of the vaporous smoke of a great blaze when agitated. The following figure in some faint measure exhibits the appearances that have been described. A B is the lower streak of light, somewhat brighter than the upper, C D. Near its lower edge appeared Vega of the Harp; and the bright star in the Swan's tail was below its northern extremity, (on the left.) All that region of the heavens was unusually black, as if all the light had been abstracted to form those bright parallel lines; only at Q, between the west and north-west, there was the luminous bow, and the conical beams M L N arising out of it. In the mean time luminous spots G, G, G, G broke out from the clear sky. They did not break forth together, but successively; yet two, or even three, might have been seen together. F, F, F, &c. are the small perpendicular columns. Lastly, from above the middle of C D arose the obelisk of light at H, which moved from east to west till it reached K in the north, and there disappeared. In accounting for these phenomena, Dr. Halley broaches a singular notion, which was supposed to have originated with one of our own countrymen,* and which was, a few years since, a subject of universal discussion, and of almost universal ridicule. We shall quote Halley's own words:—"Supposing the earth to be concave, with a lesser globe included, then, in order to make that inner globe habitable, there might not improbably be contained some luminous medium between the balls, so as to make a perpetual day below. And if such a medium is inclosed within, what should hinder us from supposing that some of this lucid substance may, on rare and extraordinary occasions, transude through and penetrate the shell of our globe, and being loose, present us with the phenomena above described. This seems favored by one circumstance, the figure of the earth; for that being a spheroid flattened at the poles, the shell must be thinner at the poles than in any other part, and therefore more likely to give passage to these vapors; whence a reason is derived for the light being always seen in the north."



We have accounts of similar appearances of the northern light, occurring more than one hundred and fifty years previous to the above; viz. in January, 1560, October, 1564, in 1574, and twice in 1575. Probably, too, (as is intimated by Halley,) the descriptions of armies doing battle in the sky may nearly all of them have been the exaggerated accounts of superstitious or excited imaginations, alarmed by the peculiar appearances of the northern lights. Halley was unable to determine the height of this aurora, for want of contemporary observations at other places; although it was visible from the west of Ireland to the confines of Russia, and the east of Poland, extending nearly thirty degrees of longitude, and from about the fiftieth degree of north latitude over almost all the north of Europe; and in all places at the same time it exhibited appearances similar to those above described. Boscovich calculated the height of an aurora in 1737 to have been eight hundred and twenty-five

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* John Cleves Symmes.

miles. Bergman, from a mean of thirty computations, placed the average height at four hundred and sixty-eight miles. Euler supposed the height to be several thousand miles. Dr. Blagden, speaking of the height of some fiery meteors, says that "the northern lights appear to occupy as high, if not a higher region above the surface of the earth, as may be judged from the very distant countries to which they have been visible at the same time." He adds that "the great accumulation of electric matter seems to lie beyond the verge of our atmosphere, as estimated by the cessation of twilight." However, the height of these meteors, none of which appear to have ascended so high as one hundred miles, is trivial compared with the elevations above ascribed to the northern lights; but as it is difficult to make such observations on this phenomenon as are sufficient to afford a just estimate of its altitude, they must be subject to considerable variations and to material error. It is not improbable that the highest regions of the northern lights are the same as those in which fire-balls move; more especially as Dr. Blagden informs us that instances are recorded in which these lights have been seen to join and form luminous balls, darting about with great velocity, and even leaving a train behind like the common fire-balls.

Many attempts have been made to assign a cause for the phenomena. Halley, among other theories, supposed that the watery vapors or effluvia, rarefied exceedingly by subterraneous fires, and tinged with sulphureous streams, which many naturalists have imagined to be the cause of earthquakes, might have been the cause of this appearance also. But this hypothesis was not sufficient to account for the immense extent of these phenomena over the surface of the earth. Abandoning this hypothesis, he conceived that the lights are produced by a subtil matter, or magnetic effluvia, freely pervading the pores of the earth, and which, entering at its southern pole, passes out again with a like force into the ether near the northern pole, the obliquity of its direction being proportionate to its distance from the pole. This subtil matter, by becoming more dense, or having its velocity increased, may be capable of producing a small degree of light, after the manner of effluvia from electric bodies, which, by a strong and quick friction, emit light in the dark; to which sort of light this seems to have a great affinity. If Halley had known that an electrical stroke would give polarity to a needle, and reverse the poles of one already magnetic, he would have probably been led to conclude that the electric and magnetic effluvia were the same, and that the aurora borealis was this fluid, circulating from one pole of the earth to the other; and thus he would have anticipated the theory of Beccaria.

Mairan assigns as the cause of the aurora borealis the zodiacal light, which, according to him, is no other than the atmosphere of the sun. This light, happening on some occasions to meet the upper part of our air, on the side of the limits where universal gravity begins to act more forcibly toward the earth than toward the sun, falls into our atmosphere, to a greater or less depth as its specific gravity is greater or less compared with the air through which it passes. Although the whole atmosphere of the earth be involved in the solar atmosphere, it is thrown off both ways from the equatorial to the polar regions. According to this theory, however, the light should dart from the equator to the poles, and not, as it really does, from the poles toward the equator.

Euler thought the cause of the northern light not owing to the zodiacal light, but to particles of our atmosphere driven beyond its limit by the impulse of the sun's light. He supposes the zodiacal light and the tails of comets to be owing to a similar cause.

Ever since the identity of lightning and of the electric matter has been ascertained, philosophers have been naturally led to seek an explanation of aerial meteors in the principles of electricity; and there is now little doubt that most of them, and particularly the northern lights, are electrical phenomena. Beside the more obvious and known appearances which constitute a resemblance between this meteor and the electric matter whereby lightning is produced, it has been observed that the aurora occasions a very sensible fluctuation in the magnetic needle; that the atmosphere yields, at the time of its occurrence, a quantity of electric fire; and that when it has extended lower than usual into the atmosphere, the flashes have been attended with various sounds of rumbling and hissing already mentioned, and attributed by Dr. Blagden to small streams of electric matter running off to the earth from the great masses or accumulations of electricity by which he supposes both meteors and the northern lights are produced. Besides, the last may be partly imitated by means of artificial electricity.

Hamilton, of Dublin, seems to have been the first person who attempted to discover any positive evidence of the electrical quality of the northern lights, but the only proof he produces is an experiment of Hawksbee by which the electrical fluid is shown to assume appearances resembling those lights, when it passes through a vacuum. When the air was most perfectly exhausted, the streams of electric matter were quite white; but when a small quantity of air was let in, the light assumed more of a purple color. The flashing of this light, therefore, from the dense regions of the atmosphere into such as are more rare, and the transition through media of different density, he considers as the cause of the aurora borealis, and of the different colors it assumes. Mr. Canton, soon after he had obtained electricity from the clouds, offered a conjecture that the northern lights are occasioned by the flashing of electric fire from positive towards negative clouds at a great distance, through the upper part of the atmosphere, where the resistance is least. And he supposes that the aurora which happens at the time when the magnetic needle is disturbed by the heat of the earth, is the electricity of the heated air above it; and this appears chiefly in the northern regions, as the alteration in the heat of the air in those parts will be the greatest. Nor is this hypothesis, he says, improbable, when it is considered that electricity is the known cause of thunder and lightning; that it has been extracted from the air at the time of the appearance of northern lights; that the inhabitants of the northern countries observe it to be remarkably strong when a sudden thaw succeeds severe cold weather; and that the tourmalin is known to emit and absorb the electric fluid only by the increase or diminution of its heat. Positive and negative electricity in the air, with a proper quantity of moisture to serve as a conductor, will, he conceives, account for this and other meteors sometimes seen in a serene sky. Canton afterward contrived to exhibit this meteor by means of a vacuum in a glass tube about three feet long, and hermetically sealed. When one end of the tube is held in the hand, and the other applied to the conductor, the whole tube will be illuminated, and will continue luminous without interruption for a considerable time after it has been removed from the conductor. If after this it be drawn through the hand either way, the light will be uncommonly intense, and without interruption from one end to the other through its whole length. And though a great part of the electricity is discharged by this operation, it will flash at intervals, when held only at one extremity, and kept quite still; but if it be grasped by the other hand at the same time in a different place, strong flashes of light will scarcely ever fail to dart from one end to the other, and will continue to do so twenty-four hours and longer, without any fresh excitation. To Canton's hypothesis it has been objected that the electrical fire would flash in every direction, according to the position of the clouds, as well as from north to south, and that by the illustration of the tourmalin, the northern light ought to be most frequent in summer, whereas the reverse is true. Beccaria conjectured that there is a constant and regular circulation of the electric fluid from north to south, which may be the original course of magnetism in general, and that the northern lights may be this electric matter performing its circulation in such a state of the atmosphere as renders it visible on approaching the earth nearer than usual.

Why the electricity of the atmosphere should be constantly found to direct its course from the poles toward the equator, and not from the equator toward the poles, gives rise to a difficulty that has been answered by a writer in the following manner. Assuming three axioms, viz. that all electric bodies when considerably heated become conductors; that therefore non-electrics, when subjected to violent degrees of cold, ought to become electric; and that cold must increase the electric powers of such substances as are already electric; it is easy (says this writer) to deduce from these principles the cause of the northern lights. The air, all round the globe, at a certain height above its surface, is found to be exceedingly cold, and, as far as experiments have yet determined, exceedingly electrical also. The inferior parts of the atmosphere between the tropics are violently heated during the day by the reflection of the sun's rays from the earth. Such air will therefore be a kind of conductor, and much more readily part with its electricity to the clouds and vapors floating in it, than the colder air toward the north and south poles. Hence the electricity in these regions is exhibited in thunder and tempests of the most terrible kind. Immense quantities of the electric fluid are thus communicated to the earth, and the inferior warm atmosphere, having once exhausted itself, must necessarily be recruited from the upper and colder regions. This is very probable from what the French mathematicians observed on the top of the Andes. They were often involved in clouds, which, sinking down into the warmer air, appeared there to be highly electrified, and discharged themselves in violent tempests of thunder and lightning; while in the mean time, on the top of the mountain, they enjoyed a calm and serene sky. In the temperate and frigid zones, the inferior parts of the atmosphere, never being so strongly heated, do not part with their electricity so easily as in the torrid zone, and therefore do not require such recruits from the upper regions; and though a great difference is observable in different parts of the earth near the surface, it is very probable that at considerable heights the degrees of cold are nearly equal all round it. Were there a like equality in the heat of the under part, there never could be any considerable loss of equilibrium in the electricity of the atmosphere; but as the hot air of the torrid zone is perpetually bringing down vast quantities of electric matter from the cold air that lies directly above it, and as the inferior parts of the atmosphere lying toward the north and south poles do not bring it down in any quantities, it follows that the upper parts of the air lying over the torrid zone will continually require a supply from the northern and southern regions. This shows the necessity of an electric current in the upper parts of the atmosphere from each pole toward the equator. We are thus also furnished with a reason for the northern lights appearing more frequently in winter than in summer, because at the former season the electric power of the inferior atmosphere is greater, owing to cold, and consequently the abundant electricity of the upper regions must go almost wholly off to the equatorial parts, it being impossible for it to get down to the earth; hence also the northern lights appear very frequent and bright in the frigid zones, the degrees of cold in the upper and lower regions of the air being more nearly equal in those parts than in any other. In some parts of Siberia, this meteor appears constantly from October to January, and its corruscations are said to be quite terrifying. Travellers agree that the northern lights appear there in the greatest perfection. From experiments made with the electrical kite, the air appears more electrical in winter than in summer, though the clouds are known to be often most violently electrified in the summer-time; a proof that the electricity naturally belonging to the air is in summer more powerfully drawn off by the clouds than in the winter, owing to the excess of heat in the former season.

Still, according to the above hypothesis the streams of light ought to run from north to south, instead of ascending, as they are generally supposed to do. Dr. Halley answered this difficulty by supposing that the magnetic effluvia pass from pole to pole in arcs of great circles, arising to a very great height above the earth, and consequently darting from the places whence they arose almost like the radii of a circle, in which case, setting off in a direction nearly perpendicular to the surface of the earth, they must necessarily appear erect to those who see them from any part of the surface, as is demonstrated by mathematics. It is also reasonable to think that they will take this direction rather than any other, on account of their meeting with less resistance in the very high regions of the air than in such as are lower. We have supposed the equilibrium of the atmosphere to be broken in the day-time and restored only in the night; whereas, considering the immense velocity with which the electric fluid moves, the equilibrium ought to be restored in all parts almost instantaneously, yet the northern lights appear only in the night, although their brightness is such as must sometimes make them visible to us, did they really exist in the day-time. In answer to this, it may be observed that though the passage of electricity through a good conductor is instantaneous, yet through a bad conductor it takes some time in passing. Now as our atmosphere, unless violently heated, is a bad conductor of electricity, when the equilibrium is once broken it cannot be instantaneously restored. Besides, it is the action of the sun that breaks the equilibrium, and the same action, extending over half the globe, prevents almost any attempt to restore it till night, when flashes arise from various parts of the atmosphere, gradually extending themselves with a variety of undulations towards the equator.

It has been observed that the streams do not always move with rapidity, but sometimes appear quite stationary for a considerable time, and are sometimes carried in different directions with a slow motion. In order to account for these circumstances, we should consider that weak electric lights have been known sometimes to exhibit the same appearance at the surface of the earth; and we may therefore suppose them much more capable of doing so at great heights above, where the conductors are much more imperfect, and fewer in number. We may reasonably conclude, from instances which have taken place, that small portions of our atmosphere may, from various causes, be so much electrified as to shine and be moved from one place to another, without parting with the electricity they have received, for a considerable time. In this way we may account for the *crown* or *circle* which is often formed near the zenith by the northern lights, when any of its parallel streams of light, that shoot upward, and (by the laws of perspective) appear to converge toward a point, are over our heads, and actually come to a point. As this crown is commonly stationary for some time, it would serve as a mark by which to determine the distance of the object; for example, let two persons, one at Washington and one at Boston, observe the bearing of the crown from their respective positions, its true altitude from the surface of the earth might be determined by trigonometry. Although the streams may resemble the passage of electric light through a vacuum, it cannot be hence inferred that the air is in a state similar to the vacuum of an air-pump in those places where the northern lights are produced, because there are instances of similar appearances that are produced in very dense air.

The plate of an electrophorus is often so highly electrified as to throw out flashes from different parts as soon as it is lifted up, and by proper management it may be always made to emit long and broad flashes, which shall scarcely be felt by the finger, instead of small dense and pungent sparks; so that, though long flashes may be produced in rarefied air, it does not follow that the same may not be produced also in denser air. Little, the inventor of one variety of the air-pump, conceived that the northern lights could not appear in air less rarefied than four thousand times, and consequently that its *least* distance from the earth is about forty-five miles; and that in air rarefied more than twenty-six thousand times it would not be visible, and therefore its greatest distance is about fifty miles. He thinks, also, that it is air burnt and exploded in its passage which makes the electric matter visible, and that without air, if it could pass at all, it would not be luminous. Upon the whole, he concludes that the northern lights are within our atmosphere.

Our Franklin supposes that the electrical fire discharged into the polar regions from many leagues of vaporized air raised from the ocean between the tropics, accounts for the northern lights, and that they appear first where it is first in motion, viz. in the most northern part, and the appearance proceeds southward, though the fire really move northward.

His reasoning is this:—Air heated by any means becomes rarefied, and specifically lighter than any other in the same situation not heated; when lighter it rises, and the neighboring cooler and heavier air takes its place. If in the middle of a room you heat the air by a stove or vessel of burning coals near the floor, the heated air will rise to the ceiling, spread over the cooler air till it comes to the cold walls, where, being condensed and made heavier, it descends to supply the place of the heated air which had ascended toward the ceiling. Thus there will be a continual circulation of air in the room, which may be made evident by setting free a little smoke, for that smoke will rise and circulate with the air.

A similar operation is performed by nature on the air of the globe. Above the height of our atmosphere the air is so rare as to be almost a vacuum. The air heated between the tropics is continually rising; its place is supplied by northerly and southerly winds, which come from the cooler regions. The light, heated air, floating above the cooler and denser, must spread northward and southward, and descend near the two poles, to supply the place of the cool air which had moved toward the equator. Thus a circulation of air is kept up in our atmosphere, as in the room above-mentioned.

The great quantity of vapor rising between the tropics forms clouds, which contain much electricity; some of them fall in rain before they come to the polar regions. Every drop brings down some electricity with it; the same is done by snow and hail; the electricity so descending, in temperate climates, is received and imbibed by the earth. If the clouds are not sufficiently discharged by this gradual operation, they sometimes discharge themselves suddenly by striking into the earth where the earth is fit to receive their electricity. The earth in temperate and warm climates is generally fit to receive it, being a good conductor.

The humidity contained in all the equatorial clouds that reach the polar regions, must there be condensed and fall in snow. The great cake of ice that eternally covers those regions may be too hard frozen to permit the electricity descending with that snow to enter the earth; it may therefore be accumulated upon the ice. The atmosphere, being heavier in the polar regions than in the equatorial, will there be lower, as well from that cause, as from the smaller effect of the centrifugal force; consequently the distance of the vacuum above the atmosphere will be less at the poles than elsewhere, and probably much less than the distance from the pole to those latitudes in which the earth is so thawed as to receive and imbibe electricity. May not then the great quantity of electricity brought into the polar regions by the clouds—electricity which would enter the earth, but cannot penetrate the ice—may it not, as in a bottle overcharged, break through that low atmosphere, and run along in the vacuum over the air toward the equator, diverging as the degrees of longitude, strongly visible where densest, and becoming less visible as it diverges more, till it finds a passage to the earth in more temperate climates, or is mingled with the upper air? If such an operation of nature were really performed, would it not give all the appearances of the northern lights? And would not these become more frequent after the approach of winter, not only because more visible in longer nights, but also because in summer the long presence of the sun may soften the surface of the great ice-cake and render it a conductor, by which the accumulation of electricity in the polar regions will be prevented?

The atmosphere of the polar regions being made more dense by the extreme cold, and all the moisture in that air being frozen, may not any great light arising therein and passing through it, render its density in some degree visible during the night-time to those who live in the rarer air of more southern latitudes? And would it not in that case, although in itself a complete and full circle, extending perhaps ten degrees from the pole, appear to spectators (so placed that they could see only a part of it) in the form of a segment, its chord resting on the horizon, and its arch elevated more or less above it, as seen from latitudes more or less distant; darkish in color, but yet sufficiently transparent to permit some stars to be seen through it?

The rays of electric matter issuing out of a body diverge by mutually repelling each other, unless there be some conducting body near to receive them; and if that conducting body be at a great distance, they will diverge, and then converge in order to enter it. May not this account for some of the varieties of figures seen at times in the motions of the luminous matter of the aurora, since it is possible that, in passing over the atmosphere from the north in all directions towards the equator, the rays of that matter may find, in many places, portions of cloudy region or moist atmosphere which may be fit to receive them, and toward which they may therefore converge; and when one of these receiving bodies is saturated, they may again diverge from it toward other surrounding masses of such moist atmosphere, and thus form the crowns or other figures mentioned in the histories of this meteor.

Kirwan supposes that the rarefaction of the atmosphere in the polar regions proceeds from the northern and southern lights, and that these are produced by a combustion of inflammable air caused by electricity. This inflammable air is generated, particularly between the tropics, by many natural operations, such as the putrefaction of animal and vegetable substances, volcanoes, &c., and being lighter than any other air, occupies of course the highest regions of the atmosphere. Kirwan adds, that after the appearance of the northern lights the barometer commonly falls, and that it is generally followed by high winds, proceeding usually from the south; all which facts strongly prove a rarefaction in the northern regions. It has been observed also by another writer, that the appearance of the northern lights is a certain sign of a hard gale of wind from the south or south-west. This occurred without fail in twenty-three instances; and he thinks that the splendor of the meteors will enable the observer to form some judgment concerning the ensuing tempest. If the aurora is bright, the gale will come on in twenty-four hours, but will be of no long duration; if the light is faint and dull, the gale will be less violent, and longer in coming on, but will last longer.

That the northern lights ought to be succeeded by winds, may be easily deduced from the hypothesis above-mentioned. If this phenomenon is occasioned by the vast quantity of electric matter conveyed to the equatorial parts of the earth, it is certain that the earth cannot receive any great quantity of this matter at one place without emitting it at another. The electricity, therefore, which is constantly received at the equator, must be emitted nearer the poles, in order to perform its course; otherwise there would not be a constant supply of it for the common operations of nature. It is to be observed, that electrified bodies are always surrounded by a blast of air, sent forth from them in all directions; hence if the electric matter find a more ready passage through one part of the earth than another, a wind will be found to blow from that quarter. The electric matter which had been received at the equator during an aurora, will be discharged at this part sometime after, and a wind will blow from that quarter. All the matter, however, will not probably be discharged at one spot, and therefore, according to the situation of these electrical vents, winds may blow in different directions.

We shall conclude with certain accounts of recent appearances of northern lights, which have been represented as exceedingly brilliant and beautiful, but, when compared with the general description of these phenomena given above, will be found not to exceed the common appearance.

On August 28th, 1827, the aurora borealis was generally seen in the northern states, in most of which there were no material variations in its appearance. In the city of New York it was first observed at about half past nine in the evening, at which time the light, excepting in color, resembled that produced by a fire at some distance. It however soon became more intense, and its outline more distinctly defined. It gradually assumed a columnar shape, and extended from about north-north-west to the opposite point of the horizon. In ten or fifteen minutes, waves of light in detached masses began to flow from the eastern toward the western part of its course, until the whole were blended, and the heavens adorned with a beautiful arch. The greatest breadth of this arch was nine or ten degrees. The whole arch moved with a gradual and nearly uniform motion toward the south, and passed the zenith at about three quarters past ten, presenting to the eye through its whole length a broad, bright band of wavy light, studded with stars that were distinctly visible through it. The eastern limb became less distinct, but the western more exact in its outline, and as well defined as a pencil of rays passed through a prism into a dark room. The color was a bright white. A great bank of light lay almost permanently in the northern horizon, sometimes surmounted by, and sometimes resting upon, what seemed a black cloud, visible during the whole phenomenon. Occasionally broad flashes of the aurora would illuminate the apparent cloud, presenting an appearance of a black thunder-cloud penetrated by vivid lightnings.

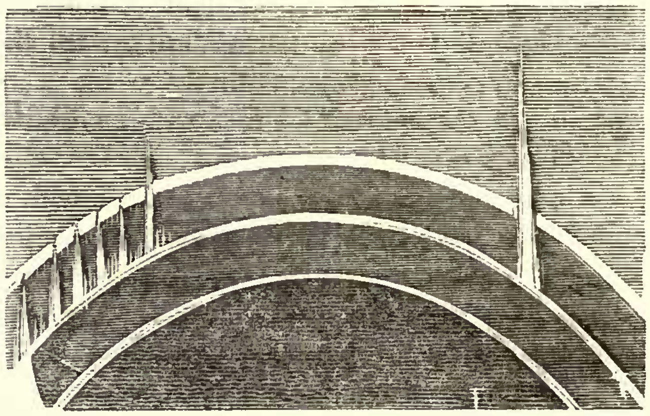
At Gosport, about nine o'clock on the evening of September 25th, 1827, a bright yellow light appeared in the north-west quarter, behind a low stationary *cirrostratus* or *wane-cloud*, and gradually extended from the north toward the west nearly seventy degrees. At ten, it had a brighter appearance than the strongest twilight that appears in this latitude. At half past ten, the aurora had formed a tolerably well defined arch of intense light, and at quarter before eleven, perpendicular lucid columns and vivid corruscations appeared in quick succession. At eleven, the streamers reached eight or nine degrees above the Pole-star, and their apparent base was nearly horizontal with the star Beta in the Great Bear. Soon after eleven, a column of light six degrees in width gradually rose from the position of the fore-mentioned star, and when it had reached an altitude of seventy degrees, it changed its color to a blood-red, which, with the more vivid and elevated flashes, gave the aurora an awfully grand appearance that it would be difficult to paint or express. This wide column increased in brilliancy, and passed through the gradation of colors that is sometimes seen in the clouds near the horizon at sunset, as lake, purple, light crimson, &c. Two other columns of light, similar in color and width, soon sprang up in different directions, and passed the zenith several degrees to the southward. These three large variegated columns presented a very grand appearance. At one o'clock, lofty perpendicular columns emanated from the aurora at the western point, and the northern hemisphere was filled with long and short streamers, varying in width and brilliancy, and often terminating in very pointed forms.

The aurora in high northern latitudes, when at its extreme, is almost dazzling, and the quickness of its motions approaches to that of lightning. In other situations it has been observed to be variously colored.

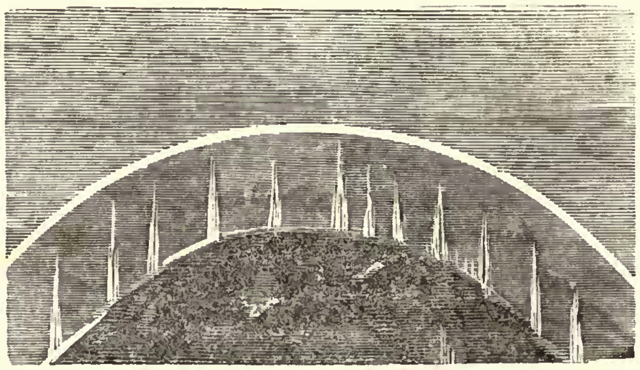
But although all these combined are eminently wonderful, and strike the spectator with profound admiration and awe, yet perhaps regions of lower latitude exhibit, though not so splendid and varied a display of this mystery, one equally or perhaps more interesting to the philosopher. During the winter months, on Lake Ontario, the aurora may be said to be almost a constant companion of the dark and cheerless nights, and it occasionally presents itself at other times of the year. Nor is it in winter a mere display of a glorious phenomenon, the utility of which has not yet been exemplified by science, for it sheds a continued and pleasing light, which resembles the twilight. This light does not, as in Europe, emanate from the vivid streamers which dance over the starry floor of heaven in ever-changing and inexplicable mazes, but proceeds from the horizon, over which a pale luminous and depressed arch, embracing an extent of from sixty to ninety degrees, is commonly thrown. This arch is generally luminous in its whole body, not on the rim or verge only, which fades away into ethereal space, but from its superior circumference to the chord formed by the horizon itself, and varies in its elevation from ten to twenty degrees. Wherever it embraces stars, these are either veiled or dimly seen, being strongly contrasted with their fellow orbs of the southern heavens, which appear to shine out with the greater brilliancy. Within the space comprehended by this arch of light continual changes are operating, if the lights assume a splendid shape. Dark volumes of vapor, not like clouds, but blackening in a moment, rise and fall whenever a ray or an interior arch begins to form, and it is remarkable that this darkness usually accompanies the commencement of every change, thereby increasing the majesty and beauty, as well as the brilliancy of the scene. But it is impossible for any pen adequately to describe a phenomenon which is continually presented in these regions, and it will be more satisfactory to detail the circumstances attending one of the most beautiful of those seen at Kingston, U. C., during the winter of 1835.

On the 11th of December, after the sun had set, the sky was dark and gloomy, and although there were but few clouds visible, and the stars were rapidly brightening, a change of weather was apparent.

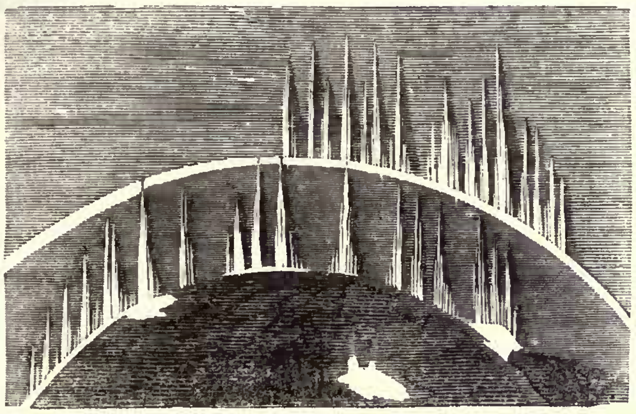
The first appearance of the northern lights, after darkness had completely set in, was by the luminous arch above-mentioned assuming its wonted place. From this arch, in the north, arose, almost incessantly, streamers of bright white light, which shot upward to the zenith, and streaked the dark sky with their silvery lines. Once a mass of light suddenly opened in the zenith, and from it darted out innumerable pencils of bright rays, overspreading the dark vault of heaven with their glories, and seeming for a moment to illuminate the sky with a star which its space seemed scarcely capable of containing. Again rods of white light would dart forth from the horizon, and one in particular spanned the whole arch of heaven. This play of the northern lights continued from seven till nearly nine, and was most brilliant and magnificent about nine, when it assumed another and not less singular attitude, of which the following is a faint delineation.

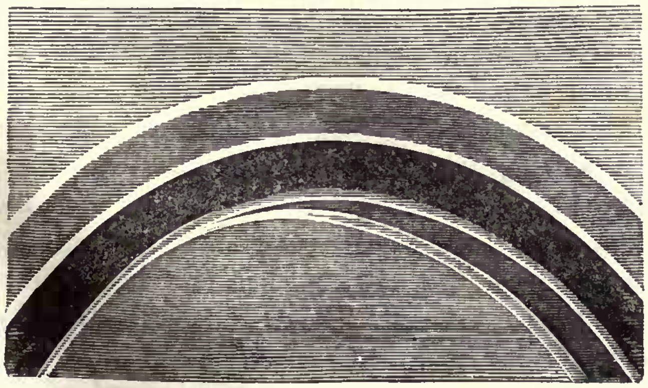


These arches are not so flat as they should be. The lower one was usually the boundary of a very black, changing mass; between the lower and the second arch the space was not so dark; and between the middle and upper arch it was still lighter, excepting where the corruscations shot upward from the middle arch, and there it was very dark. The ray shooting up on the right was extremely brilliant. Stars were partially visible above the upper arch, but the bright ones in the Great Bear had lost all their splendor, and the constellation could just be traced. This obscuration of the heavenly bodies reached nearly to the zenith above the centre of the arch, but was less over the extremities. After a short time the appearance became changed, and the aurora assumed the form shown in the following figure. The lower arch had somewhat heightened and become darker, with here and there spots of light in it, whilst from its circumference shot out brilliant rays and pencils of light. The second arch had altogether disappeared, but the upper held its accustomed place. The upper arch was constantly paler and more indistinct in



its outline than the others. Faint stars now appeared through the vapor, between the two arches, and the lower band became indistinct, excepting to the left of its central space, where it was extremely well defined by a band of bright light cut off, both above and below, by black vapory masses. After another interval the aurora assumed a somewhat different form. Both arches became less distinct; the lower one was almost obliterated, but its place was well marked by the arch of vapor below, which was darker than ever. Three large spots of intense light were now to be seen, one on the horizontal chord, and one on each side of the lower arch; and the lower zone shot out innumerable pencils and floods of light from its dark nucleus, the upper zone also darting forth long lines of brilliant rays; all these rays moved in a stately march from east to west. Toward the southern and western portions of the heavens, all was clear starlight, Orion being particularly brilliant; the north was, as it were, overspread with a thin veil, through which the stars were barely visible. In the fourth change the northern lights resumed their three arches, but they were no longer concentric, the third being broken on the right into a portion of a fourth. Between the second and third there was the darkness of blackness, while the third arch was light itself; but the lower arches were not so bright, and the lower nucleus was only darkish.





The two following descriptions are from the pen of Professor Olmsted, of Yale College. They were given to the public immediately after the occurrence of the phenomena they respectively describe. The first took place on the 17th of November, 1835; the last on the 23d of April, 1836.

On the 17th of November, 1835, our northern hemisphere was adorned with a display of auroral lights remarkably grand and diversified. It was first observed at fifteen minutes before seven o'clock, when an illumination of the whole northern sky, resembling the break of day, was discernible through the openings in the clouds. About eighteen degrees east of north, was a broad column of shining vapor tinged with crimson, which appeared and disappeared at intervals. A westerly wind moved off the clouds, rendering the sky nearly clear by eight o'clock, when two broad, white columns, which had for some time been gathering between the stars Aquila and Lyra on the west, and the Pleiades and Aries on the east, united above, so as to complete a luminous arch, spanning the heavens a little south of the prime vertical. The whole northern hemisphere, being more or less illuminated, and separated from the southern by this zone, was thrown into striking contrast with the latter, which appeared of a dark slate color, as though the stars were shining through a stratum of black clouds. The zone moved slowly to the south until about nine o'clock, when it had reached the bright star in the Eagle in the west, and extended a little south of the constellation Aries in the east. From this time it began to recede northward, at nearly a uniform rate, until twenty minutes before eleven, when a vast number of columns, white and crimson, began to shoot up, simultaneously, from all parts of the northern hemisphere, directing their course towards a point a few degrees south and east of the zenith, around which they arranged themselves as around a common focus. The position of this point was between the Pleiades and Alpha Arietis, and south of the Bee.

Soon after eleven o'clock, commenced a striking display of those undulatory flashes denominated merry dancers. They consisted of thin waves or sheets of light, coursing each other with immense speed. Those undulations which play upon the surface of a field of rye, when gently agitated by the wind, may give to the reader a faint idea of these auroral waves. One of these crimson columns, the most dense and beautiful of all, as it ascended towards the common focus crossed the planet Jupiter, then at an altitude of thirty-six degrees. The appearance was peculiarly interesting, as the planet shone through the crimson clouds with its splendor apparently augmented rather than diminished.

A few shooting stars were seen at intervals, some of which were above the ordinary magnitude and brightness. One that came from between the feet of the Great Bear, at eight minutes after one o'clock, and fell apparently near to the earth, exhibited a very white and dazzling light, and as it exploded, scattered shining fragments very much after the manner of a sky rocket.

As early as seven o'clock, the magnetic needle began to show unusual agitation, and after that it was carefully observed. Near eleven o'clock, when the streamers were rising and the corona forming, the disturbance of the needle was very remarkable, causing a motion of one degree and five minutes in five minutes of time. This disturbance continued until ten o'clock the next morning, the needle having traversed an entire range of one degree and forty minutes, while its ordinary diurnal deflection is not more than four minutes.

Another writer, speaking of the same appearance, says—We can compare the spectacle to nothing but an immense *umbrella* suspended from the heavens, the edges of which embraced more than half the visible horizon; in the south-east its lower edge covered the belt of Orion, and farther to the left the planet Jupiter shone in all its magnificence and glory, as through a transparency of gold and scarlet. The whole scene was indescribably beautiful and solemn. It was a spectacle of which painting and poetry united can give no adequate idea, and which philosophy will fail to account for to the satisfaction of the student of nature or the disciple of revelation. The cause can be known only to Him at whose bidding

> Darkness fled—Light shone,
> And the ethereal quintessence of heaven
> Flew upward, spirited with various forms
> That rolled orbicular, and turned to stars.

The appearance of April 23d, 1836, is thus described by Olmsted:—Last night we were regaled with another exhibition of the auroral lights, in some respects even more remarkable than that of the 17th of November. It announced itself as early as a quarter before eight o'clock, by a peculiar kind of vapor overspreading the northern sky, resembling a thin fog, of the color of dull yellow, slightly tinged with red. From a bank of the auroral vapor that rose a few degrees above the northern horizon, a great number of those luminous columns called streamers ascended towards a common focus, situated, as usual, a little south and east of the zenith, nearly or perhaps exactly at the magnetic pole of the dipping-needle. Faint undulations played on the surface of the streamers, affording sure prognostics of an unusual display of this mysterious phenomenon. The light of the moon, now near its first quarter, impaired the distinctness of the auroral lights, but the firmament throughout exhibited one of its finest aspects. The planet Venus was shining with great brilliancy in the west, followed at small intervals by Jupiter and the moon; while the large constellations, Orion and Leo, with two stars of the first magnitude, Sirius and Procyon, added their attractions. The sky was cloudless, and the air perfectly still.

There are but few examples on record of the auroral lights displaying themselves with peculiar magnificence in moonlight.

Notwithstanding the presence of the moon, by half past ten o'clock, the auroral arches, streamers, and waves began to exhibit the most interesting appearances. No well-defined arch was formed, but broad zones of silvery whiteness, composing greater or less portions of arches, were seen in various parts of the heavens. Two that lay in the south, crossing the meridian at different altitudes, were especially observable. From each proceeded streamers, all directed towards the common focus. At the same time, those peculiar undulations called merry dancers were flowing in broad and silvery sheets towards that point, writhing around it in serpentine curves, and often assuming the most fantastic forms. The swiftness of their motions, which were generally upward, and often with their broadest side foremost, was truly astonishing. Toward the horizon the undulations were comparatively feeble; but from the elevation of about thirty degrees to the zenith, their movement was performed in a time not exceeding one second,—a velocity greater than we have ever noticed before, which was still distinctly progressive.

Five minutes after eleven o'clock, a few large streamers, of the whiteness of burnished silver, radiated from the common focus towards the east and the west. These were soon superseded by a mass of crimson vapor, rising simultaneously a little south of west and north of east, and ascending towards the focus in columns eight or ten degrees broad below, but tapering above. These disappeared in about ten minutes, and the lights were subsequently a pure white, except an occasional tinge of red. During the appearance of the crimson columns a rosy hue was reflected from white houses and other favorable surfaces, imparting to them an aspect peculiarly attractive.

From this time until half past two o'clock, our attention was almost wholly absorbed in contemplating the sublime movements of the auroral waves: they evidently were formations entirely distinct from the columns, which either remained stationary, or shot out a broad stream of white light towards the focus, while the waves apparently occupied a region far below them.

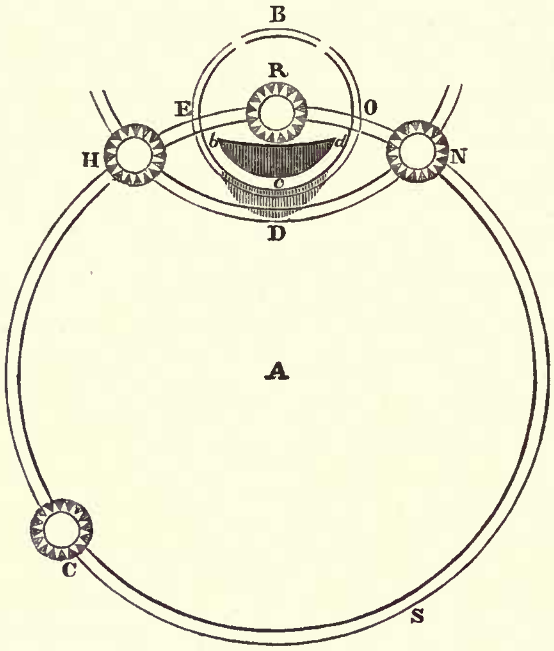
At half past two o'clock, a covering of light clouds was spread over a large portion of the sky, and our observations were discontinued. At this time, although the moon was down, yet its absence produced little change in the general illumination; the landscape appeared still as if enlightened by the moon, and it was easy to discern the time of night by a watch, from the light of the aurora.

The repeated occurrence of late of remarkable auroral exhibitions indicates that we are passing through one of those periods, which recur after long intervals, when this phenomenon presents itself with unusual frequency and magnificence.

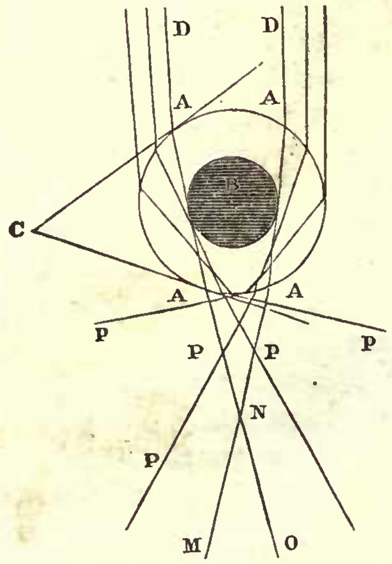
SECTION II.

Remarkable halos and parhelia seen in France in April, 1666—In March, 1667—Huygens' explanation of the causes of such phenomena—Mariotte's explanation of halos—Mock-moon seen by Forster—Extraordinary circles round the moon seen at New Haven in November, 1827—Phenomenon seen at Green Bay in February, 1835—Experiments illustrating the production of halos—Rainbows—Experiments producing colored bows—Cause of rainbows—Remarkable bows observed by Brewster—At Chartres—By Halley—In 1710—In July, 1824—Clouds—Their modifications—Curl-cloud—Stacken-cloud—Fall-cloud—Sonder-cloud—Wane-cloud—Twain-cloud—Rain-cloud—Scud—The color of clouds—Their height—Their structure and buoyancy.

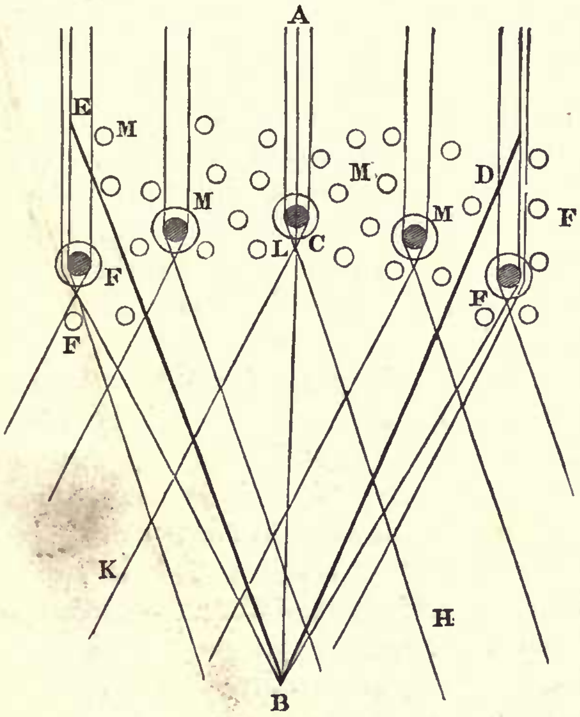
On the ninth of April, 1666, about half past nine, A. M., there were observed (in France) three circles in the sky. One of them S C H N was very large, but little broken, and white everywhere without the least mixture of any other color. It passed through the middle of the sun's disc, and was parallel to the horizon. Its diameter was more than one hundred degrees, and its centre A near the zenith. The second circle D E B O was much less, and deficient in some places, having the colors of the rainbow, particularly in the part within the greatest circle. It had the true sun for its centre. The third H D N was less than the first, but greater than the second; it was not entire, but only an arch of a circle, whose centre was far distant from the sun, and whose circumference about its middle was near that of the least circle,



and intersected the greatest circle near its extremities H, N. In this circle also were visible the colors of the rainbow, but not so strong as those of the second. There was a great brightness of the mixed prismatic colors at the point of nearest approach of this third and the smallest circle. At the points where the third circle intersected the largest there were two mock-suns or sun-dogs, H and N, which were very bright, yet not so bright or well defined as the true sun. Beside these two, there was on the circumference of the first great circle a third mock-sun C, situated to the north, which was less bright than the two first; so that there appeared at the same time four suns in the heaven. There was also a very dark space *b c d* between R and D. This phenomenon was considered very remarkable, both because of the eccentricity of the circle H D N, and the situation of the parhelia or false suns, they not being at the intersection of the circle D E B O with the great circle S C H N, but in that of the semicircle H D N. These are different from the position of the five suns seen at Rome in March, 1629,—two of them appearing in the intersection of a circle passing through the sun's disc with another that was concentric with the sun.

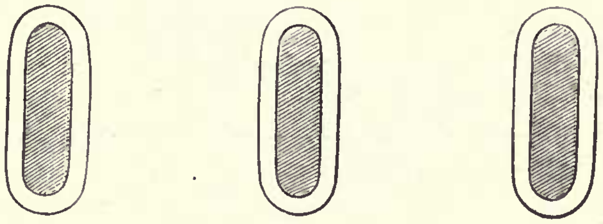


A circle round the sun was seen at Paris on March 12th, 1667, about nine in the morning, the diameter of which was forty-four degrees, and the breadth of its limb about half a degree. The upper and lower parts were of a vivid red and yellow with a little purple, but especially the upper. The other parts appeared whitish and of little clearness. The space within the circle was rather darker than that around it, especially toward the parts that were colored. Besides this circle there was a portion of another and larger circle, which touched the first, with its extremities bent downward. This portion had its colors also, but they were fainter than those of the whole circle. There were small clouds in the air, that somewhat tarnished the blue of the sky, and lessened the brightness of the sun, which seemed as if it were eclipsed. This circle or halo appeared in the same beauty and splendor till about half after ten, when it began to fade gradually, continuing visible till two in the afternoon. Huygens, who was with a large company observing the phenomena, made known his theory concerning the cause, not only of the halos, but of the parhelia, which had before been considered as prodigies, and forerunners of some singular event. As to the halos, they were formed by small round grains, made up of two parts, one transparent and the other opaque, the latter being enclosed in the former as the stone in the cherry; as may be seen in the figure, where A A represents one of these grains, and B the opaque part. He explained how some of these little grains (that swim up and down in the air between us and the sun, being less distant from the axis which extends from the sun to the eye than a certain angle) necessarily hinder the rays that fall on them from reaching our eyes, since the opaque part will cause behind every such grain a space of a conical figure, as M N O, in which the eye of the spectator being situated, cannot see the sun through that grain, though it may see it when situated elsewhere, as at P. The effect of these grains suspended in the air may be better comprehended by reference to the next figure; in which B is the place of the eye;

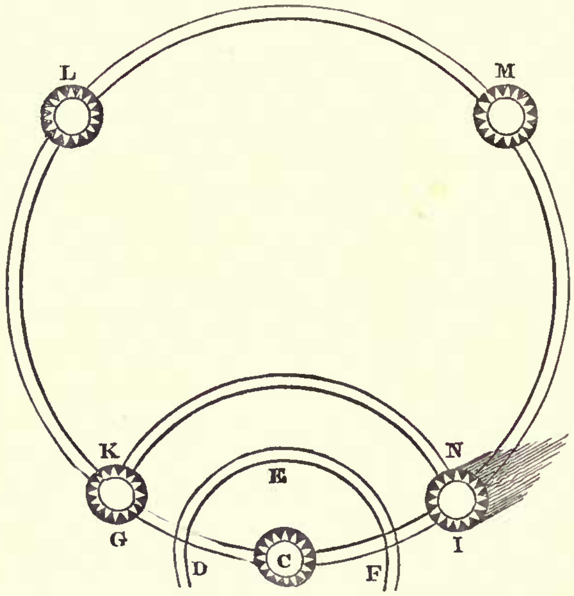


B A the axis drawn from the eye to the sun; C, M, F some of the grains, with their kernels making them semi-opaque. Among these the grain C, being in the axis B A, (the lines C K, L H representing the rays of the sun nearest to the axis, the passage of which is not prevented by the opacity of the kernel,) will not be able to transmit any ray of the sun to B; and if we conceive a cone having its vertex at the eye and its sides B D, B E parallel to the rays C K, L H, all the grains M, M, &c. which this cone may comprise will not suffer any ray to pass to the eye, because the eye must be in the cone of their obscurity; but those grains that are without this cone, as at F, F, &c. will let the rays pass, because the eye is out of the cone of their obscurity; whence it follows, that the angle of this cone D B E determines the diameter of the halo, which depends on the proportion of the opaque to the transparent part of the grain. If this diameter be forty-four degrees, the size of the opaque grain will be to that of the transparent as forty to nineteen. But the proportion varies in different grains of the same assemblage, consequently we sometimes see several halos, one around the other, all having their centre at the sun. The halos are sometimes colored, for the same reason that the spectrum formed by a triangular prism is colored. The space within the halo, and particularly that near the parts most vividly colored, appears obscurer than the space without, because there those grains are the most numerous which transmit no rays of the sun to the eye, and only darken the air, like drops of water when it rains.

As to the arch which touched the halo abovementioned, (seen at Paris on the 12th of March,) and as to the greatest brightness being at the point of contact and at the point opposite, these effects did not proceed from the grains before spoken of, but from another cause, which also produced the mock-suns. On this subject Huygens remarked that, beside the round and semi-opaque grains, there were also formed in the air certain little cylinders. These—being such as are represented in the annexed figure, oblong, and rounding at both ends, with an inner kernel of the same shape—from their different arrangement would produce all the appearances of the mock-suns and their circles.



Some of these cylinders being erect, there must appear in the heavens a large white circle parallel to the horizon, passing through the sun, and of nearly the same breadth as that luminary; as was observed in the phenomenon seen at Rome in 1629, of which Gassendus and Descartes have written, and of which the following figure is a representation. The circle L K N M is caused by the reflection of the rays of the sun on the surface of the cylinders, there being none that can reflect his rays to our eyes except those which are elevated above the horizon at the same angle as the sun; whence it follows that the circle must appear white, of equal altitude with the sun, and consequently parallel to the horizon. Considering the transparency of these perpendicular cylinders and their opaque kernels, it is easily seen that those of the white circle which are distant from the sun at a certain angle begin to give passage to such rays as reach our eyes, in the manner already stated respecting the round, half dark grains. These are the cylinders that, on each side of the sun, cause us to see a parhelion in the large white circle, as in the figure above, where they are marked K and N. These parhelia have commonly luminous tails, because the cylinders following those that form the parhelia, and which are yet farther distant from the sun, also let the rays pass to our eyes; so that these tails may be more than twenty degees in length. The same parhelia are colored, because they are made, like the halo, by refraction. There are two other images of the sun caused by these perpendicular cylinders, and so situated in the large white circle, that the spectator turning his face toward the true sun has them behind him; as the parhelia at L and M in the last figure. These are produced by two refractions and one reflection in the cylinders, in the same manner as the common rainbow in the drops of rain; so that the opaque kernels do nothing toward the production of these two suns, but sometimes even prevent their appearance.

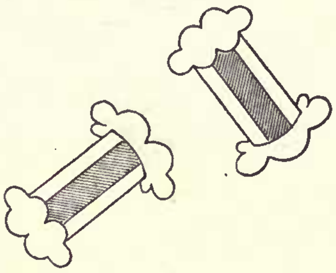


These two parhelia are more or less near each other, according to the greater or less altitude of the sun. They are colored, but when faint they may seem white, as the halos do when they are not very bright. The same perpendicular cylinders can also produce a halo by the rounding of their ends, so that when distant from the sun at a certain angle, they begin from that position to give passage to the rays, transmitting them to the spectator. The halos thus formed are probably those that pass through the two parhelia which are at the side of the true sun, as G K N I in the last figure.

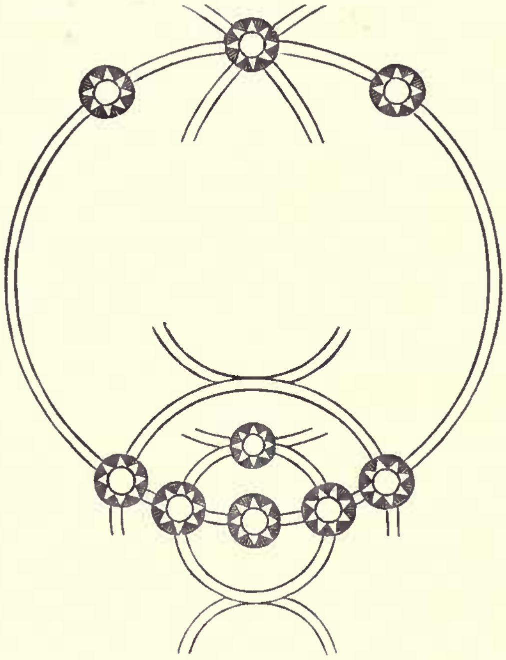
There is yet another situation of these cylinders, such that their axes are parallel to the horizon, yet turned various ways, like needles thrown on the ground confusedly. It is in these cylinders that the arches are formed which touch the halos above or below. The figure of these arches is different, according to the different altitudes of the sun. When the sun is very near the horizon, such an arch, appearing on an ordinary halo of forty-four degrees, must show like two horns; but the sun rising higher, those horns become lower in proportion. The reason why these arches usually touch a parhelion is, that the same horizontal cylinders which produce the arch, produce also that parhelion by means of their two round and transparent ends, in the same manner as has been said of the perpendicular cylinders. In these same cylinders parallel to the horizon, there is also found the cause of the white cross observed with the paraselene or mock-moons by Hevelius, the perpendicular fillet of that cross coming from the reflection of the moon on the surface of these cylinders, as the other fillet, parallel to the horizon, is produced by the reflection of the perpendicular cylinders that make the great white circle of which this fillet is a part. To produce this effect the moon must not be very high.

Besides the perpendicular and the parallel cylinders, there are often a great many that move to and fro in the air in all sorts of positions; these will produce a halo round the sun, and even a more vivid one than that caused by the grains, inasmuch as each cylinder sends many more rays to the eye than each of these little spheres. The little halo D E F in the Roman phenomenon may well have been caused by such cylinders.

As to those mock-suns which sometimes show themselves directly opposite the true sun, Huygens could find nothing that should make these suns necessarily meet in the great white circle parallel to the horizon. For the production of those suns he supposed a number of small cylinders with opaque kernels, like the foregoing, which were carried in the air neither perpendicularly, nor horizontally, but inclined to the plane of the horizon at a certain angle, (being nearly ninety degrees;) among which are to be numbered those cylinders which Descartes saw fall from the heavens having stars at both ends, such as are here shown. In these cylinders was found not only the cause of the *anthelia* made by the intersection of two arches, as in the next figure, but also that of some other extraordinary arches and rods that are sometimes observed near the sun.



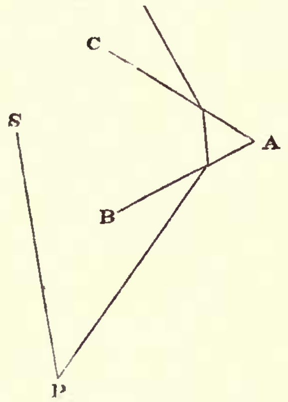
To make all these different effects of the cylinders manifest to the eye, Huygens produced one of glass, a foot long, of the shape first figured in this section; and for the opaque kernel in the middle, a cylinder of wood, the intermediate space being filled with water instead of transparent ice.



This cylinder being exposed to the sun, and the eye properly stationed, there were successively seen all the reflections and refractions above-mentioned.

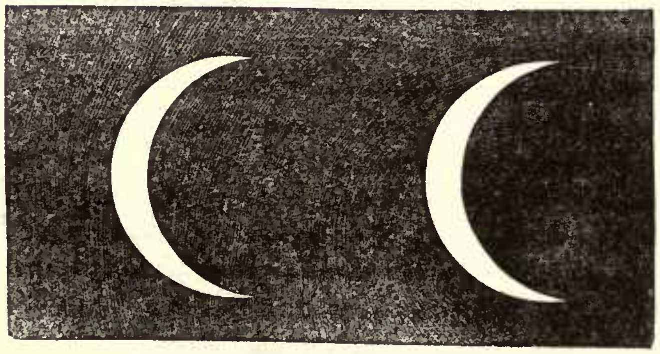
Mariotte finds a cause for halos in the form of those small, transparent, prismatic needles of which snow is composed. In congealing, water assumes very regular crystalline shapes, among which we often meet with those whose faces make angles of sixty degrees, thus constituting prisms of ice whose refracting angle is sixty degrees. These prisms, being turned in the air all possible ways, will receive the solar rays under all possible inclinations. But in certain positions of the prisms, light passing through them experiences the least possible deviation: this position is such that the refracted ray makes an isosceles triangle with the two sides of the prism, or that the angle of refraction is equal to half the refracting angle. As the refracting angle is here sixty degrees, the angle of refraction will be thirty degrees, and the angle of incidence about forty-one degrees. In this case, the angle of deviation is equal to twice the angle of incidence diminished by the refracting angle, which gives twenty-two degrees nearly for half the diameter of the halo.

We may then imagine, (the observer being situated at P,) that when the direct rays arrive in the direction S P, all the small prisms of sixty



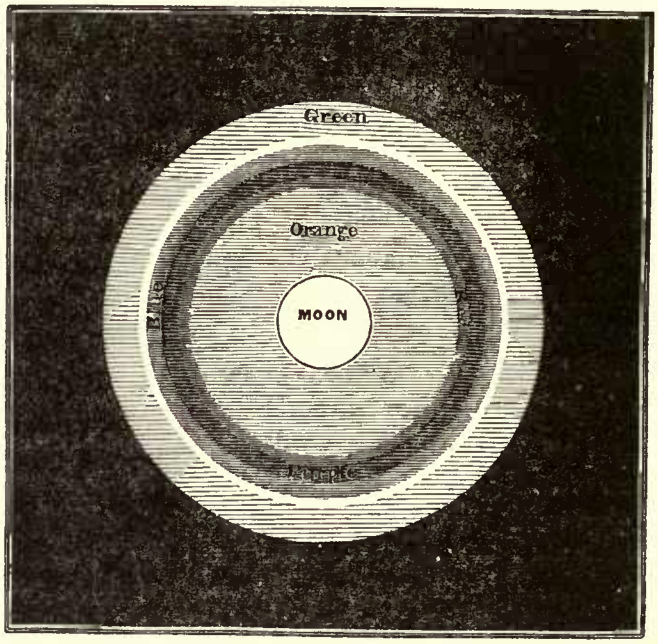
degrees floating in the higher regions of the atmosphere, and turned like the prism A C B, will reflect toward the eye a small, but vèry bright beam, because this will be composed of rays sensibly parallel; and the same phenomenon reproducing itself in a conical surface, and making an angle of twenty-two degrees about the line S P drawn to the sun's centre, a crown of forty-four degrees in diameter will be visible. The refraction of the violet ray being greater than the red, we shall have for this ray a greater crown. The sun's diameter, being thirty minutes, will increase the breadth of the colored bands.

Dr. Forster, in a paper read before the Meteorological Society of London, and published at the time, mentions a curious lunar refraction which he observed some years before. About seven o'clock in the evening, the moon being five days old, he



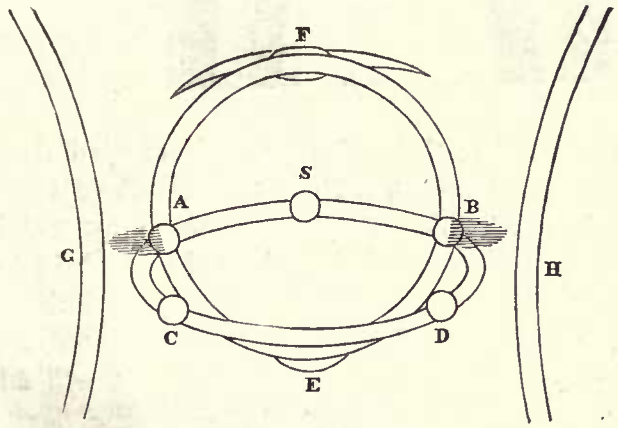
noticed a double refraction of the above form and relative position; that is, two distinct crescents instead of one, and so precisely similar that it could not be distinguished which was the paraselene or mock-moon, and which the true. Forster thought this phenomenon analogous to the double refraction in certain laminated spars, and that it might have indicated the existence of atmospherical laminæ at that time, such a condition of the atmosphere being perhaps connected with the various counter currents of the air which are known to exist at the same time at different altitudes.

Singular Appearance of Circles round the Moon. On the evening of the 2d of November, 1827, between the hours of seven and eight, there appeared around the moon (a little more than its width in diameter) a very luminous saffron-colored light. On the outer edge was a circle of bright red, which was surrounded by a dark purple; around the purple was a circle of bright blue, which faded into a yellowish green, increasing toward the outer edge to a very vivid green. There appeared to be faint white rays passing from the moon across these columns, whose circles formed, around this lunar glory, a larger circle of a dark leaden color, which gave the whole a very beautiful appearance. This was observed by a great number of spectators at New Haven, who all said that they had never seen any thing of the kind



equal to it in the course of their lives; and some of these spectators were aged people. A young lady copied the hues at the moment, and before they had changed or materially faded. The plate is a very correct representation of the appearance as it was seen by the editor of the American Journal of Science, from which the plate and account were taken.

At Fort Howard, Green Bay, Michigan, there was observed, on the 27th of February, 1835, a large and brilliant halo round the sun, with two parhelia, A and B, within the circumference at the extremities of its horizontal diameter, but little inferior in brilliancy to the true sun; they were accompanied by luminous trains opposite the true sun. Immediately above and beneath the sun in the circumference of the same circle, at E and F, there were bright luminous spots of an elliptical form, less intense in brilliancy than the first, but much larger; from the highest point, rays faintly colored and slightly curved appeared to emanate, forming a small arc of a greater circle than the halo. Another circle, the plane of which was horizontal, at right angles to and of greater diameter than the first, with its centre apparently in the zenith, completely surrounded the heavens; its circumference passed through the sun and the mock-suns A and B, and these last were distinctly reflected in the opposite part of the heavens at C and D. Between the zenith and the sun were two faintly luminous arcs, convex toward and nearly tangent to each other. These are not represented in the cut. Two well-defined and quite brilliant rainbows, G and H, situated on the right and left of the halos, and with their convexity toward the mock-suns, completed this interesting appearance.



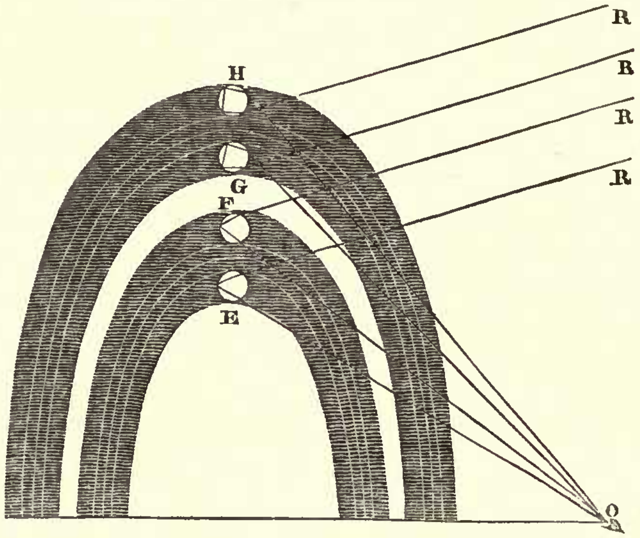
This phenomenon was first observed a little before eight o'clock in the morning, the lower part of the halo being then about two degrees above the horizon, its diameter descending as the sun ascended. It was most brilliant and splendid at fifteen minutes before ten, when it began to fade, and finally disappeared about fifteen minutes before eleven, the total duration having been about three hours.

The production of halos may be illustrated experimentally by crystallizing various salts upon plates of glass, and looking through the plates at the sun or a candle. When the crystals are granular and properly formed, they will produce the finest effects. A few drops of a saturated solution of alum, for example, spread over a plate of glass so as to crystallize quickly, will cover it with an imperfect crust, consisting of flat, octahedral crystals, scarcely visible to the eye. When the observer, with his eye placed close behind the smooth side of the glass plate, looks through it at a luminous body, he will perceive *three fine halos*, at different distances, encircling the source of light. The interior halo, which is the whitest of the three, is formed by the refraction of the rays through the crystals that are least inclined to each other. The second halo, which is *blue* without and *red* within, with all the prismatic colors, is formed by a pair of more inclined faces; and the third halo, which is large and brilliantly colored, from the increased refraction and dispersion, is formed by the most inclined faces. As each crystal has three pairs of each of these included prisms, and as these refracting faces will have every possible direction to the horizon, it may be understood how the halos are completed and equally luminous throughout. When the crystals have the property of double refraction, and when their axis is perpendicular to the plates, more beautiful combinations will be produced.

THE RAINBOW.

This, as every one knows, is a luminous arch extending usually across the region of the sky opposite the sun. Under favorable circumstances, two bows are seen, the inner and the outer, or the *primary* and the *secondary*. Within the primary, in contact with it, and without the secondary, there have been seen supernumerary bows. The primary, or inner bow, which is commonly seen alone, is a part of a circle whose radius is forty-two degrees. It consists of seven differently colored bows, viz. *violet*, which is the innermost, *indigo*, *blue*, *green*, *yellow*, *orange*, and *red*, which is the outermost. These colors have the same proportional breadth as the spaces in the prismatic spectrum. This bow is, therefore, only an infinite number of prismatic spectra, arrayed in the circumference of a circle; and it would be easy by a circular arrangement of prisms, or by covering up all the central part of a large lens, to produce a small arch of exactly the same colors. All that we require, therefore, to form a rainbow, is a great number of transparent bodies capable of forming a great number of prismatic spectra from the light of the sun.

As the rainbow is never seen unless when rain is actually falling between the spectator and the sky opposite to the sun, we are led to conclude that the transparent bodies required are drops of rain, which we know to be small spheres. If we look into a globe of glass, or water, held above the head and opposite to the sun, we shall actually see a prismatic spectrum reflected from the farther side of the globe. In this spectrum the violet ray will be innermost, and the spectrum will be vertical. If we hold the globe horizontal on a level with the eye, so as to see the sun's light reflected in a horizontal plane, we shall see a horizontal spectrum with the violet ray innermost. If we hold a globe in a position intermediate between these two, so as to see the sun's light reflected in a plane inclined forty-five degrees to the horizon, we shall perceive a spectrum inclined forty-five degrees to the horizon, with the violet ray innermost. Since, in a shower of rain, there are drops in all positions relative to the eye, the eye will receive spectra inclined at all angles to the horizon, so that when combined they will form the large circular spectrum which constitutes the rainbow. To explain this more clearly, let E, F be drops of rain exposed to the sun's rays, incident upon them in the direction R E, R F; out of the whole beam of light which falls upon the drop, those rays which pass through or near the axis of the drop will be refracted to a focus behind it; but those which fall on the upper side of the drop will be refracted, the *red* rays least, and the *violet* most, and will fall upon the back of the drop with such an obliquity that many of them will be reflected. These rays will be again refracted, and will meet the eye at O, which will perceive a spectrum, or prismatic image of the sun, with the *red* space uppermost and the *violet* undermost. If the sun, the eye, and the drops E, F are all in the same vertical plane, the spectrum produced by E, F will form the colors at the very summit of the bow. Let us suppose a drop to be near the horizon, so that the eye, the drop, and the sun are in a plane inclined to the horizon; a ray of the sun's light will be reflected in the same manner as at E, F, with this difference only, that the plane of reflection will be inclined to the horizon, and will form part of the bow distant from the summit. Hence it is manifest that the drops of rain above the line joining the eye and the upper part of the rainbow, and in the plane passing



through the eye and the sun, will form the upper part of the bow; and the drops to the right and left of the observer, and without the line joining the eye and the lowest part of the bow, will form the lowest part of the bow on each hand. Not a single drop, therefore, between the eye and the space within the bow is concerned in its production; so that if a shower were to fall regularly from a cloud, the rainbow would appear before a single drop of rain had reached the ground.

If we compute the inclination of the *red* ray and the *violet* ray to the incident rays R E, R F, we shall find it to be forty-two degrees and two minutes for the *red*, and forty degrees and seventeen minutes for the *violet*, so that the breadth of the bow will be the difference of those numbers, or one degree and forty-five minutes—nearly three times and a half the sun's diameter. These results coincide so accurately with observation as to leave no doubt that the primary rainbow is produced by two refractions and one intermediate reflection of the rays that fall on the upper sides of the drops of rain. The *red* and *violet* rays will suffer a second reflection at the points where they are represented as quitting the drop, but these reflected rays will go upward, and cannot possibly reach the eye at O. But though this is the case with rays that enter the upper side of the drop as at E F, or the side farthest from the eye, yet those which enter it on the under side, or the side nearest the eye, may, after two reflections, reach the eye as shown in the drops H, G, where the rays R, R enter the drops below. The *red* and *violet* rays will be refracted in different directions, and after being twice reflected, will be finally refracted to the eye at O, the violet forming the upper, the red the under part of the spectrum. If we compute the inclination of these rays to the incident rays R, R, we shall find them to be fifty degrees and fifty-seven minutes for the *red*, and fifty-four degrees and seven minutes for the *violet* ray; the difference of which, three degrees and ten minutes, will be the breadth of the bow, and the distance between the bows will be eight degrees and fifty-five minutes. Hence it is clear that a secondary bow will be formed exterior to the primary, and with its colors reversed, in consequence of their being produced by two reflections and two refractions. The breadth of the secondary bow is nearly twice as great as that of the primary, but its colors must be much fainter, because it consists of light that has suffered two reflections.

Newton found the semidiameter of the interior bow to be forty-two degrees, its breadth two degrees and ten minutes, and its distance from the outer bow eight and a half degrees—numbers which agree so well with the calculated results as to leave no doubt of the truth of the explanation given above.* The production of artificial bows by the spray of a water-fall, or by the drops scattered from a wet cloth or forced out of a syringe, is another proof of the correctness of the explanation. Lunar bows, and many peculiar solar bows, have been seen and described.

On the 5th of July, 1828, Brewster observed three supernumerary bows within the primary, each consisting of *green* and *red* arches, and in contact with the *violet* arch of the primary bow. On the outside of the secondary bow there was a *red* arch, and beyond it a very faint *green* one, constituting a supernumerary bow analogous to those within the primary.

Two extraordinary rainbows were seen at Chartres on the 10th of August, 1665, about half an hour past six in the evening, crossing each other nearly at right angles as seen in the figure. That opposite the sun in the usual manner was more deeply colored than that which crossed it, though the colors of the first were not indeed so strong as they are seen at other times. The greatest height of the strongest rainbow was about forty-five degrees; the feebler bow lost one of its legs, growing fainter above the stronger bow, but the leg below appeared continued to the horizon. The fainter seemed a portion of a great circle; but the stronger, as usual, a portion of a small circle. The sun at

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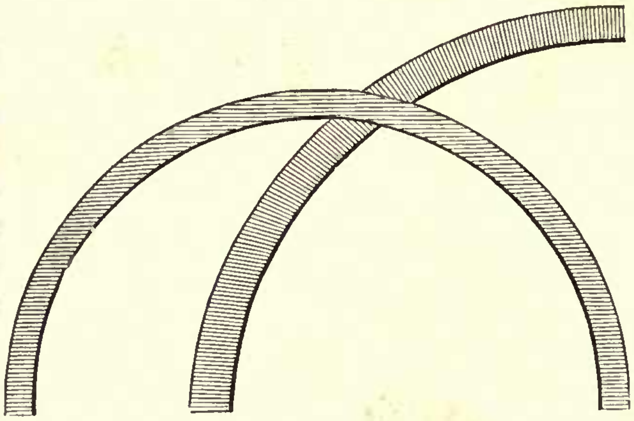
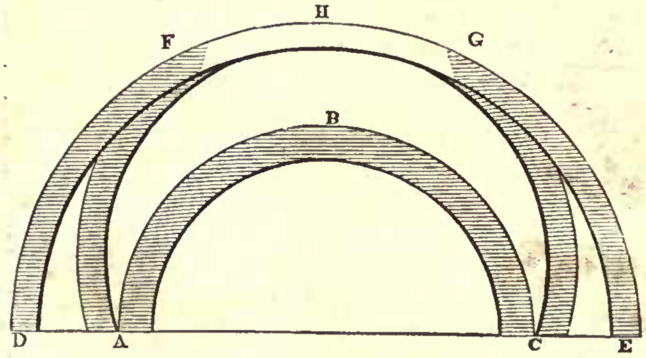
* If any farther evidence were wanted, it might be found in a fact observed in 1812 by Brewster, viz. that the light of both the bows is wholly polarized in planes passing through the eye and the radii of the arch.

their appearance was about six degrees above the horizon, and the river of Chartres, which runs south, was between the observer and the bows; he stood level with the river, one hundred and fifty paces from it.



On the 6th of August, 1698, Dr. Halley observed a remarkable rainbow, shown in the succeeding figure, where A B C is the primary bow, D H E the secondary, and A F H G C the new bow intersecting the secondary D H E, and dividing it nearly into three parts. Halley observed the points F, G to rise, and the arch F G gradually to contract, till at length the two arches F H G and F G coincided, so that the secondary iris for a great space lost its colors, and appeared like a white arch at the top. The new bow A H C had its colors in the same order as the primary A B C, and therefore the two spectra at G F counteracted each other and produced the white arch. The sun at this time shone on the river Dee, which was unruffled, and Halley found that the bow A H C was only that part of the circle of the primary that would have been under the castle, bent upward by reflection from the river.



On Christmas day in the year 1710, a gentleman, walking about eight o'clock in the evening, "to his great delight saw a bow that the moon had fixed in the clouds." The moon was at the time nearly full; the evening had been rainy, but the clouds had broken and the moon shone pretty clear. This iris had all the colors of a solar bow exceedingly distinct and beautiful, though dimmer than those we see by day. It continued about ten minutes, when the interposition of clouds hindered farther observation. Dr. Platt, of Oxford, England, observed a similar phenomenon at that town on the 23d of November, 1675.

The following is from a journal kept on board a ship in the Pacific Ocean, July 13th, 1824. "This afternoon we were gratified with an unusual and beautiful sight, viz. part of four distinct, concentric rainbows all united to each other. The principal or outer bow made the usual angle with the sun, and was the broadest; the others diminished in size and brightness, but the prismatic colors were distinctly seen in each, and were all in the same order. The secondary bow, often seen at a distance from the primary with colors reversed, was not seen. The bow was complete to the horizon, but the compound part was not above twenty degrees in length; this part did not appear to be broader than that which was single. The sun was about twelve degrees above the western horizon, shining through the interstices of a very dense broken cloud, each aperture appearing almost as bright as the sun itself. This was considered by the observer as the cause of the phenomenon.

CLOUDS.

The presence of the ocean of vapor which is constantly ascending from the earth and constituting part of the atmosphere is not always evident to the sight; in its elastic state it is invisible, and therefore it is only in some of its changes that the eye can detect it. By one of the most remarkable of these, those masses of visible aqueous vapor are formed, which, floating in the sky, or drifting through it with the wind, at different elevations, with every variety of color and form, are called *clouds;* or which, recumbent on the surface of the land or of the water, and spread over greater or smaller portions of them, are denominated *fogs*, or *mists*, according to their intensity. In all cases their composition is similar, and consists of the moisture deposited by a body of air in minute globules.

Their formation, in every position, is a consequence of decrease of temperature in some parts of the atmosphere where a certain proportion of aqueous elastic vapor is present; but in those where the latter condition may be wanting, it is evident that the development of clouds will not follow the decrement of temperature. Nothing is more common than the fact of the necessary conditions existing in some of the atmospheric strata, and at the same time being absent in others; and thus we can understand the causes of the alternate beds of clouds and clear air which often diversify the sky in serene weather. We can hence also comprehend how, in stormy weather, a solitary cloud sometimes appears to be stationary over a mountain-top, while myriads of other clouds drift past it on the gale. An observer on the summit feels the dew-drops of the seemingly fixed cloud sweeping by with great velocity, and discovers the stationary aspect which it exhibited below to be altogether an illusion. The fact is, the inferior invisible beds of air are relatively warmer and more moist; they dash against the sloping side of the mountain, and are reflected up to the plane of condensation in the atmosphere, where they give out their excess of water in the form of clouds. Above the cooling influence of the mountain-top the temperature of the air may not be depressed to the same point, and hence it continues clear.

If the globules of water which constitute a cloud descend in consequence of their weight, and come once more within the influence of an elevated temperature, the aqueous vapor necessarily becomes again invisible. In this way the under surface of a stratum of clouds becomes nearly parallel, or rather concentric, with the surface of the sub-adjacent landscape over which it floats. Above this first range of clouds the temperature may still be considerably higher, and hence another large body of air must be passed through before a temperature sufficiently low be arrived at to cause a second deposition of clouds.

Fresnel ingeniously supposes that the air contained between the minute globules of vapor, or the very fine crystals of snow which form a mass of clouds, is always of a higher temperature than the surrounding clear air. He supports this opinion on the well-known facts that the rays of the sun will pass through the air without heating it, unless the air be in contact with water, land, or some other reflecting object. The cloud accordingly forms such a body as will stop the sun's rays, and force them to warm, not only the air in external contact with it, but all the air in its interstices. It follows, therefore, that though the mass of waters in a cloud be heavier than the surrounding air, the warmer air in the interior of the cloud buoys it up and causes it to float.

Gay-Lussac, on the other hand, refers the mounting of clouds in the air to the impulsion of the ascending currents which result from the difference of temperature between the surface of the earth and the air in elevated regions.

The formation of clouds may be observed with most advantage in Alpine countries, as they are there so frequently produced under the eye, upon the sides or the summits of mountains, by the condensation of the vapor in the sheet of air immediately over them. A mountain cloud is at first of but small extent, but it enlarges insensibly, and is swept by the winds into the bosom of the air, where it either meets and unites with others, or various tufts of these are scattered over the sky. These aerial groups appear, while drifting through the sky, to avoid dashing themselves upon the mountain peaks in their course; and, as if endowed with instinctive repulsion, they bound over the crest of a mountain in a concentric curve, and slide down into the valley on the other side. The French naturalists, with much plausibility, ascribe this beautiful phenomenon to electricity. Bory de St. Vincent thinks, that, when small tufts of cloud are carried towards the sides or the summit of a mountain, they move with less rapidity than the force (wind) which moves them, and this force consequently arriving sooner at the obstacle, is reflected, and meets and checks the cloud in its progress.

Clouds are distinguished into seven modifications, the peculiarities of which seem to be caused by the agency of electricity; for example, three primary modifications, the CIRRUS or *Curl-cloud*, the CUMULUS or *Stacken-cloud*, and the STRATUS or *Fall-cloud;* two which may be considered intermediate in their nature, the CIRROCUMULUS or *Sonder-cloud*, and the CIRROSTRATUS or *Wane-cloud;* one which appears to be a compound, the CUMULOSTRATUS or *Twain-cloud;* and lastly the NIMBUS or *Rain-cloud*, a state which immediately precedes and attends the resolution of clouds into water.

By this classification and nomenclature their appearances may be noted down and transmitted to contemporary and future observers, for the purposes of comparison and record. A great advance has consequently been made in the perspicuous description which has succeeded to the vague and unintelligible generalities of preceding ages.

In the engravings are representations of the more usual forms of these genera, and a few remarks on each are subjoined to render their classification still more easy.

CURL-CLOUD. The *curling* and flexuous forms of this cloud constitute its most obvious external character, and from these it derives its name. It may be distinguished from all others by the lightness of its appearance, its fibrous texture, and the great and perpetually changing variety of figures which it presents to the eye. It is generally the most elevated, occupying the highest regions of the atmosphere.

The *comoid curl-cloud*, vulgarly called the *mare's tail*, is the proper cirrus. It has, as represented in the engraving, figure first, somewhat the appearance of a distended lock of white hair, or of a bunch of wool pulled out into fine, pointed ends.

In variable and warm weather in summer, when there are light breezes, long and obliquely descending bands of cirrus are often observed, and seem sometimes to unite distinct masses of clouds together. Frequently, by means of the interposition of these curl-clouds between a stacken-cloud and some other cloud, (as, for example, the wane-cloud,) the twain-cloud, and ultimately the rain-cloud, is formed.

Upon a minute examination of the cirrus, every particle is found to be in motion, while the whole mass scarcely changes its place. Sometimes the fibres which compose it gently wave backwards and forwards to and from each other.

After a continuance of clear, fine weather, the cirrus is often observed as a fine, whitish line of cloud, at a great elevation, like a white thread stretched across the sky, the ends of which seem lost in each horizon.

To this line of cirrus others are frequently added laterally, and sometimes, becoming denser by degrees and descending lower in the atmosphere, inosculate* with others from below and produce rain. To this kind the name of *linear cirrus* (figure fifth) has been given. Sometimes, on the sides of the first line of a cirrus, clouds of the same kind are propagated, and sent off in an oblique or transverse direction, so that the whole phenomenon has the appearance of net-work; this has been denominated *reticular cirrus.*

Figure second represents a cirrus lengthened out to a long, pointed tail; figure third a cirrus beginning to change to a cirrocumulus or sonder-cloud; figure fourth a variety figured like the cyma of architecture.

Though the above-mentioned varieties of the cirrus are all composed of *straight* lines of cloud, either parallel, or crossing each other in different directions, they are ranged under the head of *cirrus*, or *curl-cloud*, from their analogy of texture to the substance from which this cloud is named.

The cirrus is a cloud that appears to have the least density, the greatest variety of extent and direction, and generally the most elevation. It may well be called the Proteus of the sky; for in some kinds of weather its figure is so rapidly changed, that after turning the eye away for a few moments, it may be found so completely altered as scarcely to be identified. But this is not the case universally, for it sometimes remains visible hours, and even days, with very little change. That the varieties are the effect of a variation in the cause of the clouds, cannot be doubted; many of them are attendant upon particular kinds of weather. When the weather is dry the curl-cloud has more of a fibrous texture than when it is damp; and whatever may be its figure, its extremities are always fine points, probably for the easier transmission of the electric fluid. These points are consequently directed toward that part of the sky with which the electric communication is to take place.

In wet weather this cloud, being seen in the intervals of the rain, is ill defined, and often of a sort of plumose figure, (i. e. giving the idea of the folded ends of a plume,) and has less of the fibrous structure; this may be caused by its being surrounded with moister air, which is a conductor, though an imperfect one. There is, therefore, not the same necessity for the cloud's extension into fine points, as the fluid can fly off from all parts of it. The plumose cirrus often appears when the sky is deep blue, and that of fibrous structure when the sky is pale-colored. But the intensity of the blue of the sky does not seem to depend on the dryness of the air; indeed, Sir Isaac Newton remarked that the deepest blue happened just at the change from a dry to a moist atmosphere.

The detached cirri called mares' tails are seldom very much elevated; their presence is well known to be an indication of wind, and when their terminations have a decided direction, the wind that ensues has been often found to blow from the quarter to which they have pointed. This circumstance cannot well be explained.

There is sometimes a kind of motion observable in the cirri which is difficult to describe, and which seems only to take place in that variety that has a plumose extremity, with a long, fibrous body and a fine, pointed tail. The plumose head (which is clear and more fibrous than usual) and the body seem in motion, as if every particle were alive. Can this motion be the effect of an effort on the part of the electrified particles of the cloud to equalize their own electricity with that of the air? or is there some disturbance in the electricity within the cloud, from other causes? or can the motion be occasioned by the evolution of air generated in the cloud?

When the curl-cloud ceases to conduct, it changes its form and becomes some other cloud; thus sometimes a sky-full of cirrous streaks after a while become overspread with a milky whiteness. This is a sort of change to a wane-cloud, which often ends in rain. The curl-clouds, however, frequently change to the sonder-cloud, and in the progress of the change the fibres seem to shoot out laterally into transverse and intersecting streaks. They change first at their points of inter-

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* Inosculation is a union by the conjunction of the extremities.

section, which thicken, approach to the orbicular form, and seem like centres, from which fibres irradiate; thus a sort of stelliform sonder-cloud is formed, which either goes on changing into a more perfect feature of that cloud, or changes again to curl-cloud or to wane-cloud, or evaporates.

STACKEN-CLOUD. This cloud is easily known by its irregular hemispherical or heaped superstructure; hence its name *cumulus, a heap or pile.* It has usually a flattened base. The mode of its formation is by the gathering together of detached clouds, which then appear *stacked* into one large and elevated mass, or *stacken-cloud.* The best time for viewing its progressive formation is in fine, settled weather. About sunrise, small, thinly-scattered specks of clouds may be observed. As the sun rises these enlarge, those near each other coalesce, and at length the cumulus is completed.

It may be called *the cloud of day*, as it usually exists only during that period, dissolving in the evening, in a manner the exact counterpart of its formation in the morning. Those stacken-clouds which are of a more regular hemispherical form, whitish-colored, and which reflect a strong silvery light when opposed to the sun, appear to be connected with electrical phenomena. Those seen in the intervals of showers are more variable in form, and more fleecy, with irregular protuberances. When this kind of cloud increases so as to obscure the sky, its parts generally inosculate, and begin to assume that density of appearance which characterizes the twain-cloud.

Some of the little stacken-clouds are not so fleecy as the rest; they are more compact in form, and flying along rapidly between the showers, are considered as a foreboding of their return, and are hence by some called water-wagons.

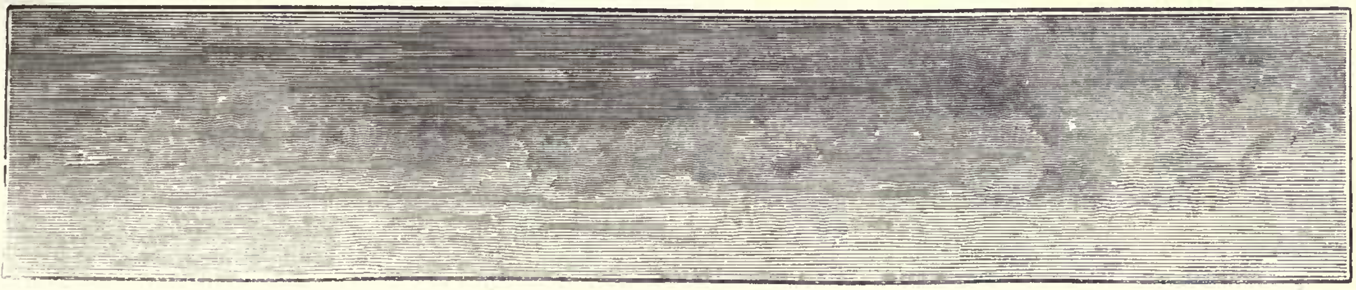
It is curious to watch the formation of stacken-clouds in the morning, and trace them from minute specks that seem to form out of the atmosphere, to those large masses that move majestically along in the wind, and convey water from place to place. In fair weather, soon after sunrise a small cloud appears; as this increases, others form near it and fall into it as if attracted; a large mass is at length upraised, and then all the smaller clouds that form in its neighborhood are soon lost, while the mass augments; and the spectator, though he sees not the process, feels no doubt that the disappearance of the smaller, and increase of the larger cloud, must be owing to the larger mass having attracted the less into itself. But why are the smaller clouds lost to the view before they reach and are quite drawn into the larger one? Possibly, when the small cloud is very near, with most of its vapors drawn away, the rest rush into the larger, as a magnet, when it has approached a larger one within a certain distance, is forcibly and suddenly attracted.

When these ephemeral mountains of electrical vapor have increased much, as they do toward midday, they often unite and form dense, extensive, and irregular masses.

The rapid formation and disappearance of small cumuli is a process constantly going on in particular kinds of weather, especially when the air is clear and dry, with light easterly breezes. These little stacken-clouds seem to form out of the atmosphere, and to be resolved into it again as rapidly.

The cumulus, then, may either evaporate, change into other modifications, or, by uniting with any of those that are differently electrified, may form the sonder-cloud, and ultimately the rain-cloud, hereafter to be described.

Fall-cloud. This kind of cloud rests upon the surface of the globe. It is of variable extent and thickness, and is called *stratus, a bed or covering.* It is generally formed by the subsidence of vapor in the atmosphere, and has, therefore, been denominated *fall-cloud.* This genus includes all fogs, and those creeping mists that in summer evenings fill the valleys, remain during the night, and disappear in the morning. The best time for observing its formation is on a fine evening, after a hot summer's day. As the cumuli that have prevailed through the day decrease, a white mist forms close to the ground, or extends only for a short distance above it. This cloud arrives at its density about midnight, or between that time and morning, and it generally disappears about sunrise. It is for this reason called by some *the cloud of night.* The coming in of autumn is generally marked by a greater prevalence and density of this cloud. In winter it is still denser. It has often been found to be electrified positively. The stratus should not be confounded with that variety of the cirrostratus which is similar in external appearances; the test to distinguish them is, the stratus does not wet objects that it alights upon, the cirrostratus moistens every thing it touches.



As the sun sinks the heat is diminished, and the lower atmosphere becomes cooler than that above; the air, no longer capable of containing so much vapor in solution as when it was warmer in the day, may deposit it in minute particles of water, which may descend in the form of stratus. In the evening, too, the under atmosphere being as cold, or perhaps colder than the upper, the vapor plane is not preserved, and stacken-clouds by degrees may sink down in dew. Under these circumstances they often appear to evaporate. The subsidence at a time when the general dampness of the air would afford a passage for its electricity to the earth, seems to indicate the agency of that fluid in keeping its particles collected into the hemispherical mass in which it usually appears during the day.

The fall-cloud is found to be electrified positively, and in general to be highly charged. It has been proposed to examine the air above to see whether a negative counter-charge can be found. Most persons must have noticed the difference between the white mists that wet nothing, but only leave dew-drops on the herbage, veiling the meadows and valleys through a summer night and ascending in the morning, and those wet fogs that happen at all times of the day, but oftener in the morning, which in some places amount to fine rain, being known as "the pride of the morning." The former are stratus; the latter, probably, twain-clouds. As the temperature decreases in autumn the stratus becomes thicker; the rays of the sun seem hardly able to overcome it, and it sometimes lasts throughout whole days; thus it gave rise in the minds of the ancients, whose organization led them to express facts metaphorically, to the fable of Phœbus and Python.

In the neighborhood of great cities these fogs, impregnated with numerous effluvia and with smoke, have a yellow appearance that is explainable; but even in the country the yellow fogs of November extend over large tracts of land. Dense fogs also happen sometimes, and appear suddenly, in different places; while at other times fogs continue for weeks together.

Sonder-cloud. This consists of extensive beds of a number of little, well-defined, orbicular masses of clouds, or small *cumuli*, in close horizontal opposition, but at the same time lying quite asunder, (*sonder-cloud*,) or separate from one another. It is to be distinguished from some appearances of the cirrostratus which resemble it by the dense and compact form of its component nubeculæ (*little clouds*.) From the intermediate nature of this cloud between the *cirrus* and *cumulus*, it has been called *cirrocumulus*. The word *sonder-cloud* is of Saxon derivation.

Sometimes the nubeculæ are very dense in their structure, very round in their form, and in very close opposition.*

At other times they are of a light, fleecy texture, and of no regular form.

The sonder-cloud of summer is of a middle nature between the two last; its nubeculæ vary in size and in proximity, and its picturesque appearance in this season by moonlight, has been well described by Bloomfield :—

> "For yet above these wafted clouds are seen,
> In a remoter sky still more serene,
> Others detached in ranges through the air,
> Spotless as snow, and numberless as fair,
> Scattered immensely wide from east to west,
> The beauteous semblance of a flock at rest."

The formation of this kind of cloud is either spontaneous, that is, unpreceded by any other, or results from the changes of some other modification. Thus the curl-cloud or wane-cloud often changes into the sonder-cloud, and the reverse. If it does not terminate with this kind of change, it subsides slowly as if by evaporation.

In the change from the curl-cloud to the sonder-cloud some appearances are presented that cannot be referred to either. They generally, however, end in a determinable modification, which may be called the permanent form, for in this it generally remains sometime before it evaporates, or assumes another form. The permanent features of the sonder-cloud vary at different times, and the varieties are connected with particular states of the atmosphere. In fine, warm weather in summer, particularly toward evening, the nubeculæ that compose this cloud are often large, well-defined, and separate from each other: the whole sky is sometimes replete with them. This feature is often the forerunner of fine, after a continuation of wet and variable, weather. It is strikingly contrasted to the variety that is composed of very small nubeculæ, in which the sky seems studded with innumerable round, white specks, sometimes of so light a texture as to be almost transparent. There is a cloud of this sort, which (though its nubeculæ preserve something of the round shape of sonder-clouds) has the light and flimsy appearance, and almost the transparency, of one variety of the wane-cloud, and it is very difficult to decide what name to give it.

In stormy weather previous to thunder a sonder-cloud often appears, whose component nubeculæ

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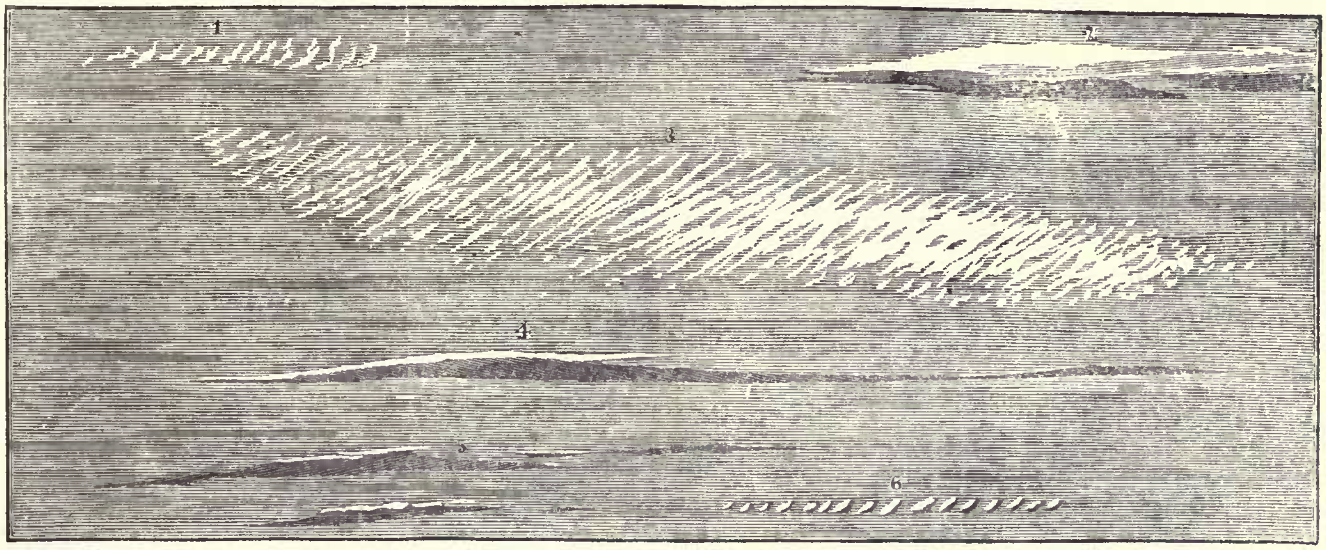
* When this cloud prevails we may, in general, anticipate in summer an increase of temperature; in winter it often precedes the breaking up of a frost, and is an indication of warm and wet weather.

One variety is very striking before, or about the time of, thunder-storms in summer. It is commonly a forerunner of storms, and has been remarked as such by the poets.

are very dense and compact round bodies in close arrangement; the prevalence of this feature, particularly when accompanied by the twain-cloud, is a sure indication of an approaching storm. The sonder-cloud is generally a foreboder of warmth. In Germany these clouds are called little sheep. In certain weather sonder-clouds rapidly form in different places in the sky, and again as rapidly subside.

Wane-cloud. This cloud is distinguishable by its flatness, and great horizontal extension in proportion to its perpendicular height. Under all its various forms it preserves this characteristic. It often results from the fibres of the cirrus, after descending from a higher station in the atmosphere, subsiding into strata of a more regularly horizontal direction, and hence it is called *cirrostratus*. As it is generally changing its figure, and slowly subsiding, it has received the name of *wane-cloud*. It originates more frequently from the curl-cloud than from any other, and less from the twain-cloud than the sonder-cloud. Being once formed, it sometimes reassumes the character of the modification from which it originated; but more frequently it evaporates by degrees, or, by inosculating with some other modification, produces the twain-cloud, and eventually the rain-cloud.



Sometimes this cloud is disposed in wavy bars or streaks, in close horizontal opposition; and these bars vary infinitely in size and color, generally blended in the middle, but distinct towards its edges, (figure third.) A variety not unlike this is the *mackerel-back sky* of summer evenings. It is often very high in the atmosphere. Another common variety appears like a long streak, thickest in the middle, and wasting away at its edges. This, when viewed in the horizon, has the appearance of figure fifth. It often seems to lie on the summit of the cumulostratus; in this case, the density of the latter increases in proportion as the former form and evaporate upon it. The result of this intermixture, and the consequent density, is the formation of the rain-cloud and the fall of rain.

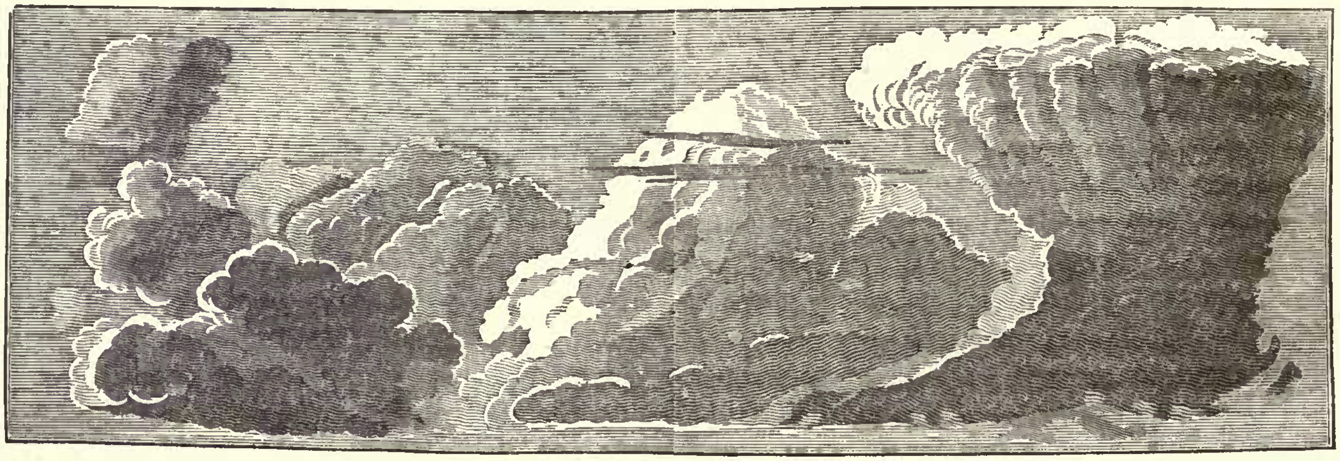
Another principal variety of the cirrostratus is one which consists of small rows of little clouds, curved in a peculiar manner; it is from this curvature called *cymoid*, (figure first.)

Figure sixth is the representation of a wane-cloud changing to a sonder-cloud. Figures second and fourth represent wane-clouds seen in profile.

All clouds are capable of becoming lighter or darker according to their position with respect to the sun; the wane-cloud, however, is remarkable for exhibiting a great variety of beautiful colors, according to its variation in density, to other peculiarities, or to its relative position. These appearances are best seen in the evening or morning, when the sun is near the horizon. They have been well described by the ancient poets, who considered them as precursors of rain and tempestuous weather; and modern meteorologists have confirmed this speculative notion of the ancients, and observed the prevalence of the wane-cloud to be usually followed by bad weather.

The most simple form of this cloud is the plane sheets. When these are not extensive and are seen in the distance, they often look like dense streaks drawn along near the horizon, but distinguishable from streaks of curl-cloud. It is the thin and extensive sheets of the wane-cloud covering the heaven before its condensation, in which the halo appears. It is this cloud, that, under some known circumstances of atmospheric change, first in a diffused form, obscures the sky, (dimming the light of the sun, moon, or stars, and causing such peculiar refractions as mock-suns,) and finally becomes mimbiform, and ends in gentle and continued rain. The sun often sets apparently shrouded in a dense feature of this modification, and this is a sure indication of a wet morning.

TWAIN-CLOUD. The base of this modification is generally flat, and lies on the surface of an atmospheric stratum, the superstructure resembling a bulky stacken-cloud overhanging its base in large fleecy protuberances, or rising into the forms of rocky mountains. Considerable masses of these are frequently grouped upon a common stratum or base, from which it has been named *cumulostratus.* It derives the other appellation, *twain-cloud*, from the frequently visible coalescence of two other modifications, as, for example, the curl-cloud and the stacken-cloud. Its density is always much greater than the stacken-cloud. Cumulostratus sometimes forms spontaneously, but is generally produced by the retardation of the stacken-cloud in its progress with the wind, which then increases in density and lateral dimensions, and finally protrudes over its base in large and irregular projections. Sometimes contiguous stacken-clouds unite at their bases, and at once become cumulostratus. Sometimes the upper currents of air conduct wane-clouds near the summits of stacken-clouds, or pierce them.



Cumulostratus often evaporates, sometimes changes to stacken-cloud, but in general it ends in rain-cloud, and falls in rain. In long ranges of these clouds, it has been observed that part has changed into rain-cloud, and the rest remained unchanged.

The twain-cloud varies in appearance; sometimes it overhangs a perpendicular stem, and looks like a great mushroom; frequently a long range appears together that has the appearance of a chain of mountains with silvery tops. Before thunder-storms it seems frequently reddish, which some have supposed to be caused by its being highly charged with the electric fluid. Whether this cloud is formed by a visible conjunction of different modifications, whether the stacken-cloud spontaneously assumes its form, or whether it appears of itself previously, we must regard it as a stage toward the rain-cloud. The very dense and black appearance of this cloud, coming up with the wind and just ripening into a storm, must be familiar to every body. Where the rain has actually begun to fall, the blackness is changed for a more obscure and gray color. This may be only the effect of the interposed water of the falling rain; but if not, and if the rain-cloud be affected by an intenser union of the watery particles, the blackness of the previous twain-cloud must depend on some other principle.

Rain-cloud. This is not a modification depending upon a distinct change of form, but rather from increase of density and deepening of shade, in the twain-cloud, indicating a change of structure which is always followed by the fall of rain. This has been, therefore, called *nimbus*, (a rainy black cloud.) Any one of the preceding six modifications may increase so much as to obscure the sky, and, without falling in rain, "dissolve," and "leave not a rack behind." But when the twain-cloud has been formed, it sometimes goes on to increase in density and assume a black and portentous darkness. Shortly afterwards the intensity of this blackness yields to a more gray obscurity, which is an evidence that a new arrangement has taken place in the aqueous particles of the cloud; the nimbus is formed, and rain begins to fall. The accompanying plate represents a nimbus pouring rain. The shower continues until another interior change succeeds, when the nimbus is extinct, and more or less of other modifications reappear; the curl-cloud, wane-cloud, or perhaps the sonder-cloud is seen in the higher regions of the atmosphere, and the remaining stacken-cloud, no longer retarded, sails along in a current of wind nearer the earth. These effects may be satisfactorily observed when showers fall at a distance; the nimbus can then be seen in profile, and the process of its formation and destruction followed through all its stages.

Stacken-clouds may be seen rising into mountains and becoming twain-clouds, while long strata of wane-clouds permeate their summits, and the whole phenomenon has the appearance of a range of mountains transfixed by the mighty shafts of a giant. After having existed for some time in this form, they become large and irregular, and get darker by intensity, till all seem concentrated in a dense black mass, with a cirrose crown extending from the top, and ragged stacken-clouds entering from below, and the whole eventually resolves itself into rain.

A division may be made of rain-clouds into three kinds:—Those that result from the visible union of distinct clouds; those that follow the interposition of moisture between distinct clouds; and those that appear to form spontaneously in the air without being preceded by either of the above phenomena. 1st. If a curl-cloud, after it has ceased to conduct electricity, should receive from either mass of air (between which it may have been conducting) an electric charge, it would lose its cirriform figure and take some other, perhaps that of a sonder-cloud, and by degrees sink down toward the earth. Under such circumstances, it may come in contact with a stacken-cloud rising from below. The result would be a sudden mixture of both clouds into a dense mass of rain-cloud, which would resolve itself into a gentle shower, and thus the union of two clouds would effect apparently the destruction of both. Such showers are of short duration, because the rain-cloud thus formed is circumscribed by dry air, and has no source of supply.

2. Previous to rain the stacken-cloud in the lower atmosphere changes its appearance, becomes denser, irregular in shape, and rock-like in superstructure, with fleecy protuberances about its base, and by degrees a complete twain-cloud. While this process is going on, curl-clouds, wane-clouds, or sonder-clouds, that have previously been seen above, are to all appearance lost, as if they had suddenly evaporated. The air will now be found damper, and there is frequently a visible mistiness above. Thus, the surrounding air being damp, the process continues, and affects clouds more and more distant, and the result is nimbus or rain.

3. It appears, then, that the cause of union between two differently electrified strata of clouds, is the moisture of the interposed atmosphere; and this humidity may take place, either in consequence of the dispersion of some cloud from a cessation of the electric actions, or by a more general deposition of haze from the over-saturated air. Either of these might cause a union, and the production of a rain-cloud. This may explain the cause of that rain-cloud which is unpreceded by other clouds. For if the air, from unknown causes, can so deposit watery particles which may be diffused through a large mass of air, if the large tracts of air, before dry and consequently electric, should have a plus and minus state, the watery particles would also receive such a division of electricity. But these electricities, having now (by the general moisture) a communication almost as soon as formed, might unite and cause the moisture to descend as rain.

This process would be comparatively slow and progressive, and thus we may account for what has been called by some "the spontaneous formation of rain-clouds," and by others "the gradual condensation of the air into rain," that lasts whole days, affording an example of the slow and gentle operation of the same causes, which, when effected rapidly, produce the phenomena of violent thunder-storms.

Masses of clouds frequently appear, not referable, for a time, to any of the preceding modifications; but if they last long enough, even these generally break out into some modification ultimately.

It is not always an easy matter for an inexperienced eye to judge how every cloud it sees should be classed. There are intermediate varieties of curl-clouds, wane-clouds, and sonder-clouds, which approach so much to the nature of each other, that the assignation of a name becomes very difficult. A tendency to the orbicular arrangement while the nubeculæ are kept asunder, is the distinguishing trait of the sonder-cloud; but clouds sometimes appear having somewhat of this kind of arrangement, yet so light in their texture as to partake almost of the nature of the wane-cloud. There are many varieties with these indeterminable features. A flimsy cloud of this kind is often seen in the clearer intervals of rainy weather, which gives the idea of the flowers of the cauliflower. The innumerable little round spots of cloud which sometimes cover a great extent of sky are sometimes of this flimsy and almost transparent structure, while at other times they are denser, and therefore more decidedly sonder-clouds. In some kinds of weather, a cloud is seen (covering a great part of the sky) which has the thin and transparent texture of wane-cloud, but the nubeculæ have the large and rounded form of sonder-cloud. It seems to differ from the latter in being shallow and flimsy, and from the former in having a rounded outline. Among the sportive and amusing features exhibited, we have sometimes long, tapering columns, horizontal or inclined, of a cloud composed of sonder-cloud nubeculæ, and sometimes of those of a sort of wane-cloud like little freckles, or like numerous small streaks arranged in rows. These little bunches are generally in a plane, but have sometimes appeared (perhaps an optical illusion) in a roundish column, giving a faint resemblance to the tail of an armadillo. Forster once saw a column of this sort inclined, curved, apparently pendant from a variety of curl-cloud, and colored purple and lake by the setting sun. In the large and long beds of nubeculæ which frequently float gently over us in summer, there are sometimes wane-clouds and sonder-clouds in the same bed. These change by degrees from one to another, and there are intermediate features more or less evident in the same mass of floating waters.

Scud. We may observe after showers, when the rain-cloud seems to be spent, and the separate modifications reappear in their different stations, loose flocky detachments of clouds flying along in the wind, and generally low down. These seem like broken fragments of the rain-cloud, and are called scud by the seaman. They often fly along in a lower current of wind at a time when large mountainous twain-clouds and stacken-clouds appear somewhat higher and more stationary, and when flimsy features of wane-cloud, sonder-cloud, and curl-cloud are visible in regions still more elevated. When this scud is abundant, we may reasonably expect a return of the showers.

The Color of Clouds. Clouds refract and reflect a great variety of beautiful tints, the shades of which vary according to their relative position with respect to the sun, but the color seems also to depend on the kind of cloud and the degree of its density. The wane-cloud exhibits the most beautiful and varied colors. Different shades of purple, crimson, lake and scarlet, are the most common. The haze, with a horizontal sun, refracts different colors at different times, viz. yellow, orange, more or less of a golden hue, red, lake, and sometimes a brownish color. Sometimes several colors are seen at once. Clouds of the same variety at different times show different colors, though they may be in nearly the same situation with respect to the sun. Sometimes they appear richly colored, at other times scarcely colored at all, a circumstance that makes it questionable whether the color is from the cloud itself, or the cloud only reflects light already colored by refraction in its passage through the haze of the atmosphere. The former is probably the case; for different clouds, in nearly the same situation with respect to the sun, show different colors at the same time. Yet the colors refracted by the haze are very various. Sometimes its tints in the twilight come on so suddenly, and are so circumscribed, as to induce a belief that very sudden and partial changes take place in the atmosphere at evening. There is frequently a deep golden orange close to the horizon; a crimson blush above it fading into purple and dark blue; about it, on each side, a whitish transparent appearance, or a lively greenish blue, or the light prismatic blue; and all these vary as the sun descends farther below the horizon.

These and other beautiful appearances of diverging streaks, bars, and spots, may often be seen with the sun near the horizon; we notice them chiefly in the evening, because we do not rise early enough in the morning; but they display nearly the same degree of beauty, with some variety of appearance, when they usher forth the dawn rising from the couch of sable night, as when they throw their painted canopy over the declining sun, or mark the spot where he sank beneath the western hills, till they gradually fade away and are lost in the universal gloom.

The Height of Clouds. The average elevation of the different modifications is different. According to Howard, the curl-cloud is the highest, the sonder-cloud next, then, in succession downward, the wane-cloud, the stacken-cloud, and fall-cloud. The twain-cloud is of vast vertical dimensions; when it forms on a stacken-cloud, the top of it appears to rise higher, and the base is generally lower, than those of the stacken-cloud. The nimbus, which is the resolution of clouds into rain, may be considered as having its base on the earth, and its summit at the end of the fibres of its cirrose crown. The modifications have different elevations at different times, and they are sometimes inverted. Sonder-cloud may at times be seen under a spreading sheet of curl-cloud of a milky appearance, that looks like a bass-relief. The long lines of curl-cloud have been found by geographical observation to be very high. Saussure speaks of the great height of certain clouds, that, from his description, must have been mottled beds of wane-cloud; and Dalton mentions that mackerel-back clouds have appeared from the tops of high mountains almost as high as from the ground. Aeronauts have generally ascended much beyond the stacken-clouds, but it is probable that there are clouds much higher up than any balloon ever ascended.

Those who have been on the tops of mountains, have spoken of having seen clouds pass below them; but, being unacquainted with the peculiarities of clouds, and inattentive in their observations, their accounts have been of little value in ascertaining the general height of the modifications. Indeed, nothing very satisfactory has been decided on this head.

Structure and Buoyancy of Clouds. Do the particles remain afloat in the air, or only gravitate very slowly toward the ground? On what peculiarity of structure does their comparative levity depend? These questions can be answered only with conjecture. De Luc and Saussure have supposed the particles to be hollow vesicles, and if these vesicles contain an aeriform fluid lighter than common air, they would be buoyant, and float in the atmosphere. This, however, is but conjecture, and nothing is certainly known of the structure of clouds. But that the structure of different clouds is very different, is manifest from their different refracting and reflecting powers, producing the various appearances of halos, coronas, mock-suns, &c., on different occasions, as well as from the different appearances of the clouds themselves.

SECTION III.

Division of falling meteors—Phenomenon witnessed at Leeds, England, in 1710—In March, 1719, all over England—In March, 1813, at New Haven, Connecticut—In Vermont, January, 1817, and March, 1822—In various places, November 13th, 1833—Olmsted's theory respecting its cause—Repetition of the meteoric phenomenon in 1834, 1835, 1836—Arago's theory—Ignis fatui, or Will o'-the-wisps.

We have thought best to class under two heads those luminous bodies which occasionally make their appearance in our atmosphere, sometimes startling us with the rapidity of their motion and the brightness of their beams, at others simply exciting our curiosity or our admiration. In the first place we shall treat of those which leave no permanent trace behind them, under the denomination of *shooting stars* and *Will-o'-the-wisps*—leaving for another section those meteors which project stones or metallic substances to the earth under the name of *aerolites*, using meteor as a term common to both.

A strange meteor was seen at Leeds (England) in 1710, on Holy Thursday; the common people called it a flaming sword. It was seen not only in the neighboring towns, but far north, and more than fifty miles south of Leeds. It appeared at Leeds at a quarter after ten at night, and took a northerly course. It was broad at one end, and small at the other, and was by some thought to resemble a trumpet moving with the broad end foremost. Its light was so great as to impart a shadow to objects around. All the persons who saw it (though many miles distant from each other) thought it fell very near them, and that it went off with bright sparklings at the small end. A clergyman asserted that it was the strangest illusion that ever happened to him if that meteor was not extinguished within a few paces of him, and yet others saw it, a few moments after, many miles farther north.

On the 19th of March, 1719, a wonderful meteor was seen all over England. Suddenly a great light, much beyond that of the moon, which shone very bright at the time, was visible in the west to persons in London, at about a quarter after eight in the evening. It seemed at first near the seven stars, whence it moved after the manner of (but more slowly than) a shooting star, in an apparent right line, passing beyond and below the stars in Orion's Belt, thence toward the south-west. The long stream appeared to be branched about the middle, and the meteor as it went on became pear-shaped. It afterward became more spherical and larger, though not so large as the full moon; the color of it was whitish, of a most vivid, dazzling lustre, which seemed in brightness to resemble, if not to surpass that of the sun, beheld by the naked eye, in a clear day. This brightness obliged observers to turn away their eyes several times, as well when it was a stream, as when it was a pear and a globe in form, however great might be their desire to observe it strictly. In the space of half a minute it seemed to move twenty degrees, and to go out as many degrees above the horizon. It left behind it a track of a faint reddish yellow color, that remained visible more than a minute, seemed to sparkle, and kept its place without falling. The sparks issuing from this train appeared like those which come from red-hot iron, when beaten on an anvil. All the observers agreed in this, "that the splendor of the meteor was, at the least, nearly equal to that of the sun," so that the candles within-doors seemed to give no light, and not only all the stars became invisible, but the moon, then nine days old, and near the meridian, was so far dimmed as to be scarcely perceptible, (the sky all the while being perfectly clear,) and wholly incapable of causing any object to cast a shadow. For a few seconds the night in all respects resembled perfect day;—this was about a quarter after eight o'clock. The velocity of the fire-ball was computed by Halley to be at least three hundred miles a minute, a swiftness almost incredible, so great that if a heavy body were projected horizontally with the same, it would not descend by its gravity to the earth, but move round in a perpetual orbit resembling that of the moon.

Of several accidents that were said to have attended its passage, many were the effects of fancy; such as hearing it hiss, as if it had been very near the observer. Some imagined that they felt the warmth of its beams, and others asserted that they were scalded by it. One thing is certain, viz. an extraordinary noise followed the explosion. There was heard a sound like the report of a heavy cannon, or rather of a broadside, at some distance, that was followed by a noise similar to the rattling of small-arms discharged promiscuously. These sounds were attended with an uncommon tremor of the air; the windows and doors of the dwelling-houses were sensibly shaken, and according to some, even the houses themselves, beyond the usual effect of cannon, though near. The phenomenon was attributed by Halley to the unusual and long-continued heat of the preceding summer.

At New Haven, on March 21st, 1813, a little before ten o'clock, a meteor was observed. The sky was overcast, yet the covering was everywhere thin, and in the north, where the meteor appeared, the stars were in full view. The observer was looking eastward when the light first appeared, and he supposed it to be caused by lightning. When the meteor was first seen, it was about thirty-five degrees above the horizon, and the direction of its track was estimated to be about north twenty degrees east. Its figure was nearly that of an ellipse, with the ends slightly pointed. Its longest apparent diameter was about equal to the apparent diameter of the moon on the meridian; its shortest diameter about three-fourths of that quantity. The color of the body was similar to that of the moon, yet of a more decided yellow. A train of light was formed behind it of ten or twelve degrees in length. This was broadest near the body, and decreased in breadth very slowly for two-fifths of its length, after which it was a uniform stripe of light, about as wide as the apparent diameter of Venus. The light was so powerful that all objects around cast distinct shadows. Numerous star-like sparks continually issued from the body, and a short time before its disappearance three larger fragments were thrown from it, two apparently as large as Venus, the third much larger. Each fragment as it moved became less and less distinct, until it disappeared entirely. The last of these continued visible until within twenty degrees of the horizon. The meteor itself disappeared as suddenly as if in one indivisible moment it had passed into a medium absolutely opaque, or as if it (all at once) left the atmosphere; but a few moments afterward there was a distinct and somewhat extensive illumination over that part of the sky for about a second, as if the light of the departing body had been reflected from some unknown surface to the earth. When the meteor disappeared, it was about thirty degrees above the horizon. Within eight or ten minutes after its disappearance there was a very loud and heavy report, accompanied with a sensible jar. The report did not resemble either thunder or the roar of cannon, but was louder, shorter and sharper than either.

On the evening of January 8th, 1817, during a rapid fall of moist snow attended with repeated claps of thunder, lights or luminous appearances were seen in the atmosphere in many places on the Green Mountains. In all these places the lights were described as having the same appearance. They were observed on the tops of bushes, fences, houses, &c. Some persons represented them as appearing like the blaze of candles, but all agreed that they were luminous spaces which appeared to rest on pointed or elevated substances. In some instances, persons who were travelling suddenly observed a light surrounding their heads; in others, they were completely enveloped in a light but little less than the ordinary light of the sun. Several persons found, when they raised their hands, that the light appeared to stream from their fingers. Phenomena like these had seldom been seen in that vicinity. We have no accounts of such since the first settlement of the country. As usual, for want of more satisfactory explanations, these appearances were attributed to electricity.

March 9th, 1822. An observer at Burlington, Vermont, had his attention arrested by what is commonly called a shooting star, no way differing from such as frequently appear in considerable numbers. When he first saw it, he thought it about in the centre of a triangle formed by lines joining Mars, Castor, and Procyon. It moved south-westerly, passing a little south-east of Procyon, and when about one-third of the way from Procyon to Sirius, it suddenly burst out in great splendor, and continued its course flashing and sparkling east of Sirius, and was apparently extinguished near the tops of some trees about twenty rods distant, considerably above the mountains. Its motion seemed perpendicular to the horizon. Its disc was nearly circular, its absolute diameter was estimated at about one-third of a mile, and its velocity as greater than that of the earth in its orbit.

Meteors of November 13, 1833.—New Haven. About daybreak, the sky presented a remarkable exhibition of fire-balls commonly called shooting stars. To form some idea of the phenomenon, the reader may imagine a constant succession of fire-balls resembling rockets, radiating in all directions from a point in the heavens a few degrees south-east of the zenith, and following the arch of the sky toward the horizon. Around this point was a circular space of several degrees, within which no meteors were observable. The balls usually left after them a vivid streak of light, and before they disappeared exploded, or suddenly resolved themselves into smoke. No report, however, was heard.

Beside these, the atmosphere exhibited *phosphoric* lines, following in the train of minute points that shot off in the greatest abundance in a north-westerly direction. The light of these trains was not unlike that produced by writing with a stick of phosphorus on the walls of a dark room. Between these two varieties, the spectator was presented with meteors of various sizes and degrees of splendor; some were mere points, others were larger and brighter than Venus, and one was judged to be nearly as large as the moon. One ball, that shot off in a north-westerly direction, and exploded a little to the north of the star Capella, left, just behind the place of its explosion, a phosphorescent train of peculiar beauty. This line was at first nearly straight, but shortly began to contract in length, dilate in breadth, and to assume the figure of a serpent drawing itself up, until it appeared like a small luminous cloud of vapor.

The light of the meteors was usually white, but was occasionally prismatic, with a preponderance of blue.

Boston. The sky was clear, excepting near the horizon, where, in the east, there were a few streaks of cloud, and in the south-east and south the round heads of a range of dark, heavy clouds were just visible above the horizon. There was, however, a vapor visible round the horizon, which in the south-east assumed a very beautiful appearance during ten minutes, about half an hour before sunrise. The direction in which the meteors moved was almost exactly downward, (and not oblique, as usually seen,) except in two instances, when the course was horizontal, nearly in a straight line, from north-east to south-west, and these two meteors were high and small. All the meteors left luminous white traces, which generally appeared to be about a yard in length.

Similar phenomena, adds the Boston writer, have occasionally occurred elsewhere, and have been called showers of fire, to which indeed this had a perfect resemblance. One instance occurred about eighty years since in South America, at Quito, when so many falling stars were seen above the volcano of Gayambo, as led the people to imagine that the mountains were in flames. A more extensive and remarkable phenomenon of this kind occurred on the night of November 12th, 1799, and was seen at Cumana. It happened near morning, when thousands of meteors succeeded each other during the space of four hours. There was not a place in the firmament equal in extent to three diameters of the moon, that was not filled with burning stars. They were of different sizes, and left luminous traces of from five to fifteen degrees in length. They were seen by almost all the inhabitants of Cumana, the oldest of whom asserted that the great earthquake of 1766 was preceded by similar phenomena. The fishermen said that the *fire-works* began at one o'clock, and some of the meteors were thought to have been seen a quarter of an hour after sunrise.

West Point. The air was very clear, and there was a perceptible and constant light like twilight given out from the numerous luminous bodies. The greater part of these bodies were like stars suddenly lighted up while in a state of rapid motion, shooting a certain distance, and gone in a second. Another class of luminous bodies, larger in diameter, but equally transient in continuance, and less frequent, shot along like falling lamps, followed by a small, short, and pointed flame, so brilliant as to pain the sight. These might be compared to the morning star in sensible magnitude, and to lightning in brilliancy. One larger body fell vertically west of north. It was a deep-red, fiery ball, of perhaps one-fifth the moon's apparent diameter: It descended to the visible horizon, and left a train of a few degrees in extent, luminous, and striped with prismatic colors, one edge being red, and the other greenish blue. Occasionally, in the smaller bodies also, the prismatic colors were developed; and about the time when the morning light was beginning to make the fainter phenomena invisible, many meteors were observed of a faint but decided green.

There was a point a few degrees south and east of the zenith, which was evidently the emanating point of all the apparent motions. *In the vicinity of this point a few star-like bodies were observable*, possessing very little motion, and leaving very little trace, but in their aspect they were such as if a small nebula had softly swelled out from the heavens, gently elongated its figure, and then as gently subsided.

Farther off, the motions were more rapid, and the traces longer; and the most rapid of all, and the longest in their traces, were those that originated but a few degrees above the horizon, and descended to it. In these, the aspect might be compared to that of flaming sparks driven swiftly athwart the sky by a strong wind. The number of shooting bodies that passed in the heavens on the morning of the 13th, though necessarily the subject of conjecture to a considerable extent, was estimated without extravagance at ten thousand in the course of a single hour.

Annapolis. Many persons thought a shower of fire was falling, and became exceedingly alarmed.

The light was so intense that sleeping apartments were strongly illuminated, and some were aroused under the apprehension that their dwellings were in flames. The meteors were most numerous an hour before dawn, but a number of shooting stars were visible as early as two o'clock in the morning. The phenomenon must have therefore continued, more or less vividly, for four or five hours. The statements of observers agree entirely as to the almost infinite number of the meteors, and, in the words of many, "they fell like flakes of snow." Those who saw it to the best advantage agree as nearly as could be expected, making allowance, as we should, for the probable existence of extraordinary excitement. Several of the meteors appeared to burst into numerous small stars as they fell, and it was asserted that some fell to the earth and rebounded into the air. This was probably an optical deception. The accounts differ as to the size of the meteors. One in particular was stated by some observers to be as large as the moon, while to others it appeared considerably smaller. So also the most brilliant of them was said to have been visible for more than a minute, though it probably could not have been visible beyond a few seconds. It was evident that this meteor was of an uncommon size, and that it was seen much longer than is usual for these transitory scintillations. It was certain that one of the trains continued faintly visible about thirty seconds. No audible explosion attended any of the meteors. The whole scene was like a perfectly silent and simultaneous dance of the stars.

Emmittsburg. It would be difficult for one who did not witness the grand exhibition, to conceive the effect of the uninterrupted succession of innumerable meteors, proceeding from a point so nearly vertical toward the whole circumference of the horizon, and this too during the stillness of night, with an atmosphere perfectly transparent. It could be compared only to a continued discharge of fire-works, occupying the whole visible heavens. Their light was similar to what has heretofore been noticed on analogous occasions, white, with a tinge of blue, comparable to the flame of burning zinc.

Worthington, Ohio. As witnessed from that place, the meteors seemed to diverge from a common centre some fifteen degrees south-east of the zenith, but it is probable that this apparent divergence was an illusion, and that their true courses were nearly parallel. A luminous spot or ring would frequently appear for a moment near the point whence they seemed to emanate, which was unquestionably caused by a coincidence of the course of the meteor with the line of observation.

Augusta, Georgia. It seemed at first as if worlds upon worlds were rushing like a whirlwind toward our globe from the infinity of space; then as if the firmament was slowly melting with fervent heat, and the stars descending like snow-flakes to the earth; until again some fiery sphere would start from its orbit, blazing and hissing through the vast expanse, and sweeping worlds from their places, or rather hurling whole systems from existence in its mad career. The light exhibited was different in the different meteors, and even in the same meteor at different times. In some the fire-ball gave out a pale blue or green light, while the train would be orange or intensely white, and soon, by constant changes, exhibiting all the prismatic colors. Occasionally one would dart forward, leaving a brilliant train three or four inches in breadth, that would gradually extend in width to three or four feet, and remain visible nearly fifteen minutes. By far the most brilliant one seen occurred a few minutes after five in the morning, and seemed by its splendor to announce the close of this grand exhibition of heavenly fire-works. It seemed to pass from south-east to north-west, the ball being apparently five or six inches in diameter, with a train from thirty to forty feet long; the latter, immediately on the passage of the meteor, assuming a serpentine form, and diffusing a light upon the earth equal at least to that of the full moon, and remaining intense for forty or fifty seconds.

Bowling Green, Missouri. Around the firmament, thicker than the stars themselves, which were uncommonly bright and beautiful, were beheld innumerable fire-balls of a pale white color, rushing down, and, to appearance, across the sky, drawing after them long, luminous traces, which clothed the whole heaven in awful majesty.

On comparing the accounts that were given of the "falling stars" in various places, it is found that the appearances were everywhere nearly the same, being, with slight variations, as follows:—The meteors began to attract notice by their frequency as early as nine o'clock on the preceding evening, the exhibition became strikingly brilliant about eleven, but most splendid of all about four o'clock, and continued, with but little diminution, until merged in the light of day. A few large fire-balls were seen even after the sun had arisen. The entire extent of the exhibition covered no inconsiderable portion of the earth's surface. It has been traced from the longitude of sixty-one degrees in the Atlantic ocean, to longitude one hundred degrees in central Mexico, and from the North American lakes to the southern side of the island of Jamaica. It was not seen, however, anywhere in Europe, nor in South America. Everywhere within the above-named limits, the first appearance was that of fire-works of the most imposing grandeur, covering the entire vault of heaven with myriads of fire-balls resembling sky-rockets. On more attentive inspection, it was seen that the meteors exhibited three distinct varieties, the first consisting of phosphoric lines, apparently described by a point; the second, of large fire-balls, that at intervals darted along the sky, leaving luminous trains that occasionally remained in view for a number of minutes, and, in some cases, for half an hour or more; the third, of undefined luminous bodies, that remained nearly stationary in the heavens for a long time. Those of the first variety were the most numerous, and resembled a shower of fiery snow driven with inconceivable velocity to the north of west. The second kind appeared more like falling stars, giving to many persons the impression that the stars were actually falling from the sky, a spectacle which was contemplated by the more unenlightened beholders with great amazement and terror. These fire-balls were occasionally of enormous size. Dr. Smith, of North Carolina, describes one that appeared larger than the full moon rising. "I was," says he, "startled by the splendid light in which the surrounding scene was exhibited, rendering even small objects quite visible."

One of the most remarkable circumstances attending this display was, that the meteors all seemed to emanate from one and the same point; that is, if their lines of direction had been continued backward, they would have met in the same point, a little south-east from the zenith. They set out at different distances from this point, and, following the arch of the sky, ran along the vault with immense velocity, describing, in some instances, an arc of thirty or forty degrees in less than four seconds. The trains which they left were commonly white, but were sometimes tinged with various prismatic colors. One ball, that shot off in the north-west direction, and exploded a little northward of the star Capella, left, just behind the place of explosion, a phosphorescent train of peculiar beauty. The line of direction was at first nearly straight; but it soon began to contract in length, to dilate in breadth, and to assume the figure of a serpent drawing himself up, until it appeared like a small luminous cloud of vapor. This cloud was borne eastward, (by the wind, as was supposed, which was blowing gently in that direction,) opposite to the course in which the meteor had proceeded, remaining in sight several minutes.

Of the third variety of meteors, the following are remarkable examples. At Poland, Ohio, a luminous body was distinctly visible in the north-east for more than an hour. It was very brilliant, in the form of a pruning-hook, and apparently twenty feet long, and eighteen inches broad. It gradually settled towards the horizon until it disappeared. At Niagara Falls, a large, luminous body, shaped like a square table, was seen nearly in the zenith, remaining for some time almost stationary, emitting large streams of light. At Charleston, S. C., a meteor of extraordinary size was seen to course the heavens for a great length of time, and then was heard to explode with the noise of a cannon.

The apparent *radiant*, or the point from which the meteors seemed to emanate, was observed, by those who fixed its position among the stars, to be in the constellation Leo. At New Haven it appeared in the bend of the sickle, (a collection of stars in the breast of Leo,) a little to the westward of the star Gamma Leonis. By observers at other places remote from each other, it was seen in the same constellation, although in different parts of it, a change of position supposed to be owing to the effect of parallax. An important observation, confirmed by the concurrent testimony of all the observers who remarked the position of the foregoing radiant point among the fixed stars, is, that this point was stationary among the stars during the whole period of observation; that is, that it did not move along with the earth in its diurnal revolution eastward, but accompanied the stars in their apparent progress westward.

According to the testimony of by far the greater number of observers, the meteors were unaccompanied by any peculiar sound; but, on the other hand, such a sound, supposed to proceed from the meteors, was said to be distinctly heard by a few observers in various places. It is well known, however, that persons unaccustomed to making observations in the stillness of night are apt, when listening at such times, to hear sounds which they associate with any remarkable phenomenon that happens to be present, although wholly unconnected with it. The question, therefore, whether any sound proceeded from the meteors, must rest for its decision on the circumstances of the case, such as the peculiarity of the sounds, and their uniformity as described by different observers. In the present case, the sounds supposed to have been heard by a few observers are represented either as a hissing noise like the rushing of a sky-rocket, or as slight explosions like the bursting of the same bodies. These comparisons are thought to occur too uniformly, and in too many instances, to permit the supposition that they were either imaginary, or were derived from extraneous sources.

It is not held as a fact well established, that any substance reached the ground which can be considered as a residuum or deposit from the meteors, although indications of such a substance were supposed to be discovered by different observers.

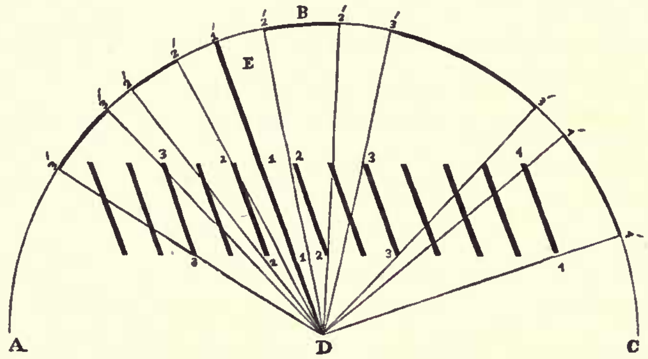
A change of weather from warm to cold accompanied the meteoric shower, or immediately followed it. In all parts of the United States, this change was remarkable for its suddenness and intensity. In many places, the day preceding had been unusually warm for the season; but before morning a severe frost ensued, unparalleled for the time of year. Indeed, the seasons and atmospheric changes exhibited remarkable anomalies long after that period, a fact which it may be well to place on record, to compare with future observations, although it may be impossible to decide, at present, whether or not these irregularities had any connection with the phenomena in question. Thus, at Michilimackinac, so uncommonly mild was the season throughout the latter part of November and the whole of December, that the Indians made maple sugar during this month, and the contiguous lakes remained unfrozen as late as the 3d of January. At the same period, the season in the southwestern states, as far as New Orleans, was unusually cold. In most parts of New England, an uncommonly mild winter was succeeded by a remarkably cold and backward spring, requiring domestic fires to be kindled throughout the month of May, and frequently in the month of June. A succession of gales commenced about the time of the meteoric shower, first in the Atlantic Ocean, and afterwards in various parts of the United States, almost unequalled in this country for their frequency and violence.

In entering on the explanation of these mysterious phenomena, it is argued, in the first place, that the meteors had their origin beyond the limits of our atmosphere; that they, of course, did not belong to this earth, but to the regions of space exterior to it. All bodies near the earth, including the atmosphere itself, have a common motion with the earth round its axis from west to east; but the radiant point that indicated the source from which the meteors emanated followed the course of the stars from east to west; therefore it was independent of the earth's rotation, and consequently at a great distance from it, and beyond the limits of the atmosphere.

Having established this point, the next inquiry is, What is the height of the place whence the meteors proceeded; that is, the height of the meteoric cloud (so to speak) above the surface of the earth? If this cloud were not too distant from the earth to have a parallax, spectators remote from each other would refer it to different points in the heavens. If, for example, an observer at Boston marked the position of the cloud by a certain star, one in South Carolina would refer it to a point farther north, and one in Ohio would see it farther east. The former change of place is called *parallax in declination*, and the latter *parallax in right ascension;* and a parallax either way affords the means of estimating the height of the object above the surface of the earth, in the same manner as we estimate the height of a common cloud.

Now it has been ascertained that observations made in different latitudes indicated a corresponding parallax in declination; and these observations, being collected and carefully compared with each other, give an average distance from the surface of the earth of two thousand two hundred and thirty-eight miles as the height of the meteoric cloud. The anomalies, however, in regard to the corresponding differences of right ascension, are such, that the change of apparent position in the heavens in advancing from north to south might have been owing to some other cause than parallax. We also consider this estimate of the distance of the meteoric cloud as only an approximation, the best that can be derived from data that are imperfect, and sometimes discordant, and regard it as probable that the real source of the meteors was considerably more distant than the limit here assigned.

Material substances comparatively so near the earth as two or three thousand miles would be strongly affected by the earth's gravity, and bodies constituted of exceedingly light materials would be readily attracted down to the earth from such a height. Gravity, therefore, being both a known and an adequate cause, is assigned as the force by which the meteors were drawn or impelled towards the earth; and hence it is inferred that they fell in parallel lines directed to the centre of the earth. This accounts for their apparent radiation from a common centre, as will be readily understood from the annexed representation.



Let A B C represent the vault of the sky, the centre of which D being the place of the spectator. Let 1, 2, 3, &c., represent parallel lines directed towards the earth. A luminous body descending through the line D E, coincident with the axis of vision, would appear stationary all the while at 1′; a body descending the line marked 2, 2 would appear to describe the short arc 2′, 2′; and a body descending the line 3, 3 would appear to describe the longer arc 3′, 3′. By considering thus the manner in which the arcs described on the celestial vault would appear, according as the meteor was nearer the axis of vision or more remote from it, we shall arrive at the following conclusions:—that those meteors which fell nearer to the axis of vision would seem to describe shorter arcs, and move slower, while those which were further from the same axis would appear to describe longer arcs, and to move with greater velocity; that the meteors would all seem to radiate from a common centre, namely, the point where the axis of vision D E met the celestial vault; and that if any meteor chanced to move directly in the line of vision, it would be seen as a luminous body stationary for a few seconds at the centre of radiation. All these conditions are in perfect accordance with the appearances of the meteors as described by various observers.

Although it is doubtful, from the want of the requisite data, whether the source of the meteors, or the height of the meteoric cloud, has been accurately ascertained, yet the limit above estimated is confidently believed not to exceed the actual distance. According to the established laws of falling bodies, the inquiry is next instituted, what velocity the meteors would acquire in falling from a point two thousand two hundred and thirty-eight miles above the earth to within fifty miles of its surface, this being considered as nearly the height of the atmosphere. The calculation gives nearly a velocity of four miles per second as that with which the meteors entered the earth's atmosphere, a velocity more than ten times the maximum velocity of a cannon-ball, and about nineteen times that of sound. It must be recollected that the atmosphere diminishes in density very rapidly as we ascend from the earth, until, at the height of fifty miles, it is so rare as hardly to oppose the least resistance to a body moving in it. It is well known that when air is suddenly compressed, a great quantity of heat is extricated from it. A little instrument is constructed on this principle for lighting tinder, by forcing down a solid piston upon a confined column of air in a small barrel. A spark is elicited, which ignites tinder at the bottom of the barrel. In the same manner the meteors, on entering the atmosphere, produced a sudden and powerful compression of the air before them, thus extricating heat sufficient to produce in them an intense ignition, and, if they were combustible, to set them on fire.

The meteors were constituted of very light, combustible materials. Their combustibility was rendered evident by their exhibiting the actual phenomena of combustion, being consumed, or converted into smoke, with intense light and heat; and the extreme tenuity of the substance composing them is inferred from the fact that they were stopped by the air. Had their quantity of matter been considerable, with so prodigious a velocity they would have had sufficient momentum to enable them to reach the earth, and the most disastrous consequences might have followed. Upon submitting the subject to accurate calculation on established principles, it was ascertained that the quantity of heat extricated from the air by the falling meteors exceeded that of the hottest furnaces, and could be compared only to those immeasurable degrees of heat produced in the laboratory of the chemist, before which the most refractory substances are melted, and even dissipated in vapor; and of course it was abundantly adequate to account for all the effects of ignition and combustion which were actually observed. Mr. Twining, indeed, supposes the meteors to have had a relative velocity, arising from the earth's motion towards them, independent of the motion here supposed to arise from gravity; and that they fell towards the earth with a velocity of fourteen, instead of four miles per second. Should this estimate prove the more correct, it will not set aside the conclusions based upon the idea of the meteor's falling into the atmosphere with very great velocity, but the intensity of the cause, and its adequacy to produce the effects ascribed to it, will be proportionally augmented.

Some of the larger meteors must have been bodies of very large size. If we know the actual distance of a luminous body, and its apparent diameter compared with that of the moon, it is easy to compute its real dimensions. In the present case, we have no means of ascertaining the exact distance of any meteor from the observer, and can only make probable suppositions. Dr. Smith, of North Carolina, and other persons in various places, saw a meteor which appeared as large as the full moon. If this body were at the distance of one hundred and ten miles from the observer, it must have had a diameter of one mile; if at the distance of eleven miles, its diameter was five hundred and twenty-eight feet; and if only one mile off, it must have been forty-eight feet in diameter. These considerations leave no doubt that many of the meteors were bodies of large size, though it may be difficult to say precisely how large. The fact that they were stopped by the resistance of the air, proves that they were constituted of very light materials; still the quantity of smoke or residuum which resulted from their destruction indicates that their quantity of matter was considerable. The momentum of even light bodies of such size, and in such numbers, traversing the atmosphere with such astonishing velocity, must have produced extensive derangements in the atmospheric equilibrium.

These large bodies were stopped in the atmosphere only by transferring their motion to columns of air, large volumes of which would be suddenly and violently displaced. Cold air of the upper regions would be brought down to the earth; the portions of air incumbent over districts of country remote from each other, being mutually displaced, would exchange places, the air of the warm latitudes being transferred to colder, and that of cold latitudes to warmer regions. Remarkable changes of seasons would be the consequence, and numerous and violent gales would prevail for a long time, until the atmosphere should have regained its equilibrium. That the state of the weather, and the condition of the seasons that followed the meteoric shower, corresponded to these consequences of the disturbance of the atmospheric equilibrium, is a remarkable fact, and favors the opinion that such disturbance is a natural effect of the meteoric shower, and it is a consequence from which the most formidable dangers attending phenomena of this kind are to be apprehended.

Although it is doubtful whether the meteors, in any case, reached the ground, yet there is reason to believe that they sometimes descended very low. A credible witness asserted that he saw one explode and leave its train between his eye and an opposite precipice several hundred feet in height. The remarkable meteor before mentioned as having exploded near the star Capella, left a train which exhibited appearances so peculiar, that it was a fit object upon which to build the inquiry whether the same meteor was seen by persons remote from each other. If this were the fact, then the different points in the heavens to which different observers would refer it would furnish data for estimating its height. Mr. Twining rendered it probable that the fact was so, and grounded upon it the estimate that the place where the meteor exploded was twenty-nine and a half miles above the surface of the earth. Circumstances, however, made it somewhat doubtful whether any single meteor could be identified as seen by different and distant observers; and other facts strongly indicated that the place of explosion was much nearer to the earth than the limit assigned by Mr. Twining.

With regard to the nature of the meteors, after establishing the fact that they were combustible, light, and transparent bodies, it was inferred that the cloud which produced the fiery shower consisted of nebulous matter, analogous to that which composes the tails of comets. We do not know, indeed, precisely what is the constitution of the material of which the latter are composed; but we know that it is very light, since it exerts no appreciable force of attraction on the planets, moving even among the satellites of Jupiter without disturbing their motions, although its own motions, in such cases, are greatly disturbed, thus proving its materiality; and we know that it is exceedingly transparent, since the smallest stars are visible through it. Hence, so far as we can gather any knowledge of the material of the nebulous matter of comets, and of the matter composing the meteors of November 13th, they appear to be analogous to each other.

Various hypotheses have been proposed to account for this wonderful phenomenon. The agent which most readily suggests itself in this and in most other unexplained natural appearances, is electricity. But no known properties of electricity are adequate to account for the production of the meteors, for the motions that they exhibited, or for the trains that they, in many instances, left behind them. And if this agent be supposed to have some connection with the light and heat which they exhibited, it may be replied, that the compression of the air which must result from the rapid progress of large bodies through it is a sufficient cause of these. Indeed, electricity itself, according to the most rational view, owes its light and heat to the same cause. Magnetism has also been assigned as the principal agent concerned in producing the meteoric shower. The aurora borealis, and the remarkable auroral arches which occasionally appear in the sky, have been found to have peculiar relations to the magnetism of the earth, arranging themselves in obedience to the laws of magnetic attraction. Something of this kind was supposed by some to appear during the meteoric phenomenon, especially in the position of the apparent radiant, which was, as noticed by many observers, very nearly in the place towards which the dipping-needle is directed. From other observations, however, it is proved that the radiant point was not stationary with respect to the meridian, but accompanied the stars in their westerly progress, and, of course, that such an apparent coincidence with the pole of the dipping-needle was purely accidental. Moreover, were magnetism competent to explain the direction of the meteors, it would still leave their production unaccounted for.

Hydrogen gas, or phosphoretted hydrogen, has been alleged as another cause of the meteoric shower. Collections of this substance, it has been supposed, were exhaled into the higher regions of the atmosphere, according to the hypothesis of the formation of ignes fatui, and, becoming inflamed, exhibited the appearance of falling stars. Electricity has sometimes been called in to aid the entire explanation. It is sufficient to say of this hypothesis, that it is assigning a cause not known to exist, and which, if its existence be granted, is not sufficient to account for the phenomena. According to the view that has been taken of the origin of meteoric stones, namely, by ascribing them to terrestrial comets, the hypothesis has been suggested, that the meteors in question might have a similar origin. But the body which afforded the meteoric shower could not have been of the nature of a satellite to the earth, because it remained so long stationary with respect to the earth. The periodical time of a satellite revolving in a circle at the distance of six thousand one hundred and ninety-four miles from the centre of the earth (the estimated distance of the body in question) would be two hours forty-five minutes and twelve seconds; and consequently its mean motion at the perigee, in a circle, would be nearly four miles per second; and its motion in an eccentric ellipse at the perigee, would be about five and a half miles per second. This result is plainly incompatible with the supposition that the body in question was a satellite to the earth, since it remained stationary with respect to the earth for at least two hours, a period sufficient to have it carried nearly round the earth in a circular orbit, and through many degrees of a parabolic orbit.

Nor can we suppose that the earth in its annual progress came into the vicinity of a nebula, which was either stationary, or wandering lawless through space. Such a collection of matter could not remain stationary within the solar system, in an insulated state; and had it been in motion in any other direction than that in which the earth was moving, it would soon have been separated from the earth, since, during the eight hours while the meteoric shower lasted, (and perhaps it lasted much longer,) the earth moved in its orbit through the space of nearly five hundred and fifty thousand miles.

On projecting a diagram to represent the respective places of the earth in its orbit, and the place of the body which afforded the meteoric shower, on the morning of the 13th of November, there was exhibited the remarkable fact, that the earth, in its annual revolution, was moving almost directly towards the point from which the meteors proceeded, varying from it but two and one-fourth degrees. Now the meteoric cloud remained apparently at rest, and of course nearly in the earth's path, for at least two hours. This it could not have done unless it had been moving nearly in the same direction as the earth, and with nearly the same angular velocity round the sun. For, had it been at rest, the earth, moving at the rate of nineteen miles per second, would have overtaken it in less than two minutes; or had it been moving in the opposite direction, the meeting would have occurred in still less time; or had not the angular velocities of the two bodies been nearly equal, they could not have remained so long stationary with respect to each other. Hence it was inferred that the body which afforded the meteors was pursuing its way along with the earth round the sun.

Two other conclusions are sustained in the Journal of Science. These are, that the body revolves around the sun in an elliptical orbit but little inclined to the plane of the ecliptic, and having its aphelion near the orbit of the earth. That the body has a period of nearly six months, and its perihelion a little below the orbit of Mercury.

A remarkable light was seen in the east at the time of the meteoric phenomenon, and subsequently in the west after twilight, at different times, until the month of May, which light assumed different aspects, corresponding, apparently, to those which the body revolving around the sun in the manner contemplated by the theory would occupy. Hence it was conjectured that this luminous appearance proceeded from the body itself which afforded the meteoric shower. Should future observation establish the truth of this conjecture, the fact would afford a striking confirmation of the theory; but the theory was founded on evidence independent of this last consideration. It was also suggested that this light might have resulted from the same cause as the zodiacal light, and that the latter unexplained phenomenon perhaps results from a nebulous body revolving around the sun interior to the orbit of the earth.

We must advert, for a moment, to the provident care that the Creator displayed in shielding the earth from the direful effects which the "fiery shower" might, without such care, have unquestionably produced. Had the meteors been constituted of materials a little more dense, their momentum would have enabled them to reach the earth; and had they held on their course three seconds longer, it is impossible to conceive of the calamities that would have ensued by the descent to the earth of bodies of such magnitude, glowing with the most intense heat. Half the continent might have been involved in one common destruction.

If the above reasonings and conclusions were correct, there was a chance at least that similar phenomena might be again seen in November, 1834. Such was in reality the case, and the public have been favored with an account of them in the Journal from which we have already drawn so freely, and to which we again turn for information. On the morning of the 13th of November, 1834, there was a slight repetition of the meteoric shower that presented so remarkable a spectacle a year before. The presence of the moon in an advanced stage, until nearly four o'clock in the morning, permitted only the larger and more splendid meteors to be seen; it may fairly be supposed that many of the smaller and fainter meteors, such as constituted last year much the greater part, were invisible from this cause merely. The number of the meteors, however, was evidently above the common average. They began to be visible soon after one o'clock, when a fire-ball of unusual size and splendor blazed forth in the east. From this time they were seen to fall at a pretty uniform rate until the light of day was far advanced. From a quarter past two until quarter past five, there were counted in the eastern view, embracing one-third of the visible heavens, one hundred and fifty-five. Some meanwhile fell in the south-west, and a few in the north-west. To estimate the number that fell during the whole night at one thousand, would not probably be exceeding the truth. The direction of the meteors was more remarkable than their number, and afforded evidence of the identity of the phenomenon with that of 1833. They appeared to radiate from a common centre as before, and that centre was again in the Lion. It was a little to the northward and westward of the place it occupied the year before. Then it was near Gamma Leonis; this time it was near the Lion's eye. This point was not observed to vary in position for three hours, thus corresponding to the conclusions drawn before concerning the radiant. The meteors generally fell in arcs of great circles, but four were observed to ascend. One at quarter before four shot from near Procyon towards the radiant, and three were observed moving with extreme slowness horizontally from west to east, south of Orion and the Little Dog. On the 14th of November, 1835, meteors were again seen in numbers by Herschel at the Cape of Good Hope, by persons in the states of New York, Maryland, North Carolina, and again in 1836 by professor Olmsted, the result of whose observations is as follows:—

"Facts already ascertained leave no doubt of the recurrence of 'the meteoric shower' on the morning of the 13th of November. About half past three o'clock, observing that the meteors began to appear in unusual numbers, I directed my attention towards the eastern part of the heavens, whence they mostly proceeded, and closely watched the stars from the Great Bear on the north to the south, embracing in my field of view about one-third of the firmament.

It was soon discovered that nearly all the meteors shot in directions which, on being traced back, met in one and the same point, near the Lion's Eye. For a quarter of an hour, from half past three o'clock, I counted twenty-two meteors, of which all but three emanated from the above radiant point in Leo. Ten left luminous trains; twelve were without trains; and the three that did not conform to the general direction, moved perceptibly slower than the others. The greatest part shot off to the right and left of the radiant, a majority tending south, towards the heart of Hydra. The next fifteen minutes afforded but seven meteors, and the number gradually declined until daylight.

The exact position of the radiant was near a small star forming the apex of a triangle with the two bright stars in the face of Leo. Its place was therefore very nearly the same as in 1834, differing only half a degree in right ascension, and all the phenomena very much resembled those observed that year, except that they continued for a shorter period.

Although shooting stars occur at various seasons of the year, yet these meteoric showers, whether they occur on a larger or a smaller scale, are marked by several striking peculiarities. The meteors are much more frequent than usual, and sometimes are exceedingly numerous. A larger proportion than common leave luminous trains. They mostly seem to radiate from a common centre, and for several years past the radiant has been in nearly the same part of the heavens, namely, in the constellation Leo. It is also remarkable that the shower is not only repeated on the same day of the year, but arrives at its maximum everywhere, and at every recurrence, at nearly the same hour of the morning, from three to four o'clock.

By a letter from Springvale, Maine, it appears that the display was considerably more splendid at that place, the whole number of meteors counted from three o'clock to fifteen minutes past six being two hundred and fifty-three."

This subject has not escaped the attention of Arago, whose profound knowledge of physics entitles his opinion to great weight. He has adverted to it in a paper, of which there is a translation in the Edinburgh Philosophical Journal. He mentions observations made in France in November, 1835, confirmatory of the periodical occurrence of the meteors; rejects the idea of their originating within the atmosphere; and, alluding to the grand display of them in America in 1833, says—"It is scarcely possible at present to see any other mode of explaining the astonishing appearance of these bodies, than by supposing that, besides the large planets, there move round the sun myriads of small bodies, which are not visible except when they penetrate into our atmosphere, and there become inflamed; that some of these asteroids move in a certain sense in groups, and that others are insulated."

Again he says—"All these facts tend more and more to confirm us in the belief that there exists a zone composed of millions of small bodies, whose orbits meet the plane of the ecliptic towards the point which the earth occupies every year from the 11th to the 13th of November. It is a new planetary world just beginning to be revealed to us." Arago's idea is, that millions of globules, or small parcels of nebulous matter, circulate round the sun in a vortex or whirlpool, which crosses the earth's path about the middle of November; and some of these, drawn from their course by the earth's attraction, take fire when they reach the atmosphere, and assume the form of shooting stars. He suggests that they should be looked for at the opposite point of the ecliptic about the end of April, and alludes to an observation of Messier, who saw, in June, 1777, at mid-day, "*a prodigious number of black globules pass across the sun for about five minutes.*" Might not these be asteroids? This hypothesis explains the facts better than professor Olmsted's; for we may suppose millions of these small nebulous bodies revolving at all distances and angles round the sun, but distributed unequally; some moving singly, some in groups or circular trains, and coming in contact with the earth at any point of its orbit, less or more frequently, less or more abundant, in that part of space through which it is moving at the time. We would thus account for the occasional appearance of falling stars at all seasons of the year. The old notion that they were trains of hydrogen or some other combustible gas existing in the atmosphere, and accidentally inflamed, is found to be untenable.

IGNES FATUI.

Those luminous appearances which are popularly called "Will-o'-the-wisps" and "Jack-a-lanterns" have been alike the object of vulgar superstition and philosophical curiosity; and notwithstanding all attempts to apprehend and subject them to examination, they are not much better understood now than they were centuries ago. They are still but an ignis fatuus to the philosopher, and a mystery to the credulous. Probably this light is oftener visible than we might be led to imagine, in consequence of its not being always distinguishable from the lights in surrounding houses. These mysterious luminaries have been often seen by the fishermen on the Connecticut River while they plied their nets at night. They commonly stated that they saw them a little above the surface of the meadow, dancing up and down, or gliding quietly along in a horizontal line. Sometimes two, or even three, would be seen together, skipping and dancing, or sailing away in concert, as if rejoicing in companionship. A person, returning from abroad late in the evening, had to cross a strip of marsh. As he approached the causeway, he noticed a light toward the opposite end, which he supposed to be a lantern in the hand of some person whom he was about to meet. It proved, however, to be a solitary flame a few inches above the marsh, at a short distance from the edge of the causeway. He stopped some time to look at it. It was evidently a vapor (phosphoretted hydrogen probably) issuing from the mud, and becoming luminous by contact with the air. It exhibited a flickering appearance like that of a candle expiring in its socket; alternately burning with a large flame, and then sinking to a small taper, and occasionally for a moment becoming quite extinct. It remained constantly over the same spot.

These lights have been supposed endowed with a locomotive power. They appear to recede from or advance toward the spectator. This appearance, however, may be explained without attributing to them any change of distance, but by supposing a change in respect to the quantity of flame. When the light dwindled, it would appear as if it receded, and with a velocity proportioned to the rapidity of its diminution. As it became larger, it would seem to be advancing toward the spectator. When it expired, by several flickerings or flashes, it would seem to skip from him; and when it reappeared, he would easily imagine that it had assumed a new position. This reasoning will account for their apparent motion to or from the spectator. Do they ever move in any other direction—in a line perpendicular or oblique to that in which they first appeared? In one instance a close observer thought this was so, and the light, singularly enough, seemed to move directly against a strong wind with great rapidity. After gazing for some time, he reflected that he had not changed the direction of his eye at all, but if the apparent motion had been real, he must have turned half round. The deception was occasioned by the motion of the wind itself—as a stake standing in a rapid stream will appear to be moving against the current.

It is a common notion that the ignis fatuus cannot be approached, but moves off as rapidly as we approach it. This must be an illusion. Persons attempting to approach them have been probably deceived as to their distance, and, finding them farther off than they had imagined, have given over the attempt, under the impression that the pursuit was vain. A man who said that "he actually stole up to one" and thought he had caught it in his hat, was asked, "and what was it?" "It was nothing." On looking in his hat for the shining jelly, it had wholly disappeared. His motions had dissipated the vapor, or his foot had closed the orifice from which it issued. The circumstance of these lights appearing usually over marshy ground, explains the popular notion that they possess the power of beguiling persons into swamps and fens. In a misty night they are easily mistaken for the light of a candle in a neighboring house, and the traveller, directing his steps towards it, meets with fences, ditches, and other obstacles; and, if he perseveres, he soon is quite bewildered in the middle of the swamp itself. By this time he begins to find out that the light is but a "will-o'-the-wisp." A man left his neighbor's house late in the evening, and at daylight had not reached his own, a quarter of a mile distant. Accordingly a number of persons went in search of him. They found him near a swamp, with soiled garments and a thoughtful countenance, reclining by a fence. He stated that he had been led into a swamp by a jack-a-lantern. Yet there was nothing marvellous in this. The night was dark, and the man's senses being a little disordered by a glass of his neighbor's punch, he saw a light, and supposing it was on his own mantel, he made toward it. A bush might have led him to the same place, if he had mistaken it for his chimney top.

SECTION IV.

Aerolites—Their resemblance to each other—A proof of their common origin—Direction in which they appear to move—No theory as to their origin satisfactory—Accounts of various aerolites—Their specific gravity—The substances of which they consist—They could not have been produced in the atmosphere—Do they fall from the moon?—Or, are they fragments of an exploded planet?

Solid bodies composed of mineral substances have been observed to fall from the upper parts of the atmosphere, and they have for this reason been named aerolites, which means stones of the air. The reality of their fall was doubted for a long time, and the general belief in their existence was regarded as a popular delusion. But their existence has been confirmed by such testimony as can no longer be resisted.

Their most remarkable characteristic is that they perfectly resemble each other, being all of them masses glittering with metallic particles. The external surface is black, as if so colored by fire; while the interior is a yellowish white. They all have nearly the same specific gravity. The substance of which they are composed is for the most part *metallic;* but the ore of which they consist is not to be found in the same constituent proportions in any *terrestrial* substances. Their fall is generally preceded by a luminous appearance, a hissing noise, and a loud explosion; and when found immediately after their descent they are always hot. Their size differs, from small fragments of inconsiderable weight to the most ponderous masses. Some of the largest portions of these stones have been found to weigh from three hundred pounds to several tons, and they have often descended to the earth with a force sufficient to bury them many feet under the soil. In some instances they have penetrated through the roof of houses and proved destructive to the inhabitants.

Their common character proves beyond a doubt that these stones have a common origin. We might remark, also, that iron in a metallic state is scarcely to be met with in terrestrial bodies. Volcanic substances do not contain any which is not oxydated. Aerolites also contain nickel, which is very rare, and never found at the surface of the earth. They contain chrome, which is still more rare. These facts make it probable that meteoric stones have an origin foreign to our globe, or at least that they are not the product of any phenomenon hitherto observed.

These masses of matter are discharged upon the earth by a species of meteors which have been named fire-balls. They are in fact burning globes, that appear suddenly in the atmosphere, and move with extreme rapidity. Their velocity is sometimes equal to that of the earth in its orbit, (or one thousand and one hundred miles a minute.) They move in a direction inclined to the horizon. After shining with great splendor for a few moments, they explode with a loud noise, often at a great height above the surface of the earth. They do not appear to affect any particular direction with regard to the earth's motion, but tend toward all the various points of the compass. Philosophers have in vain attempted to account for the origin of the aerolites. No idea has yet been generally adopted on this subject. True, two theories have been started, but they are of so extraordinary a nature as to excite rather our astonishment at the novelty and boldness of their conception, than a persuasion of their truth. These are, 1st, That they originate in the moon, being thrown beyond the sphere of its attractive power by volcanoes; 2d, That they are portions of a planet once existing between Mars and Jupiter. We shall give the reasoning used in support of each of these theories. They will tend, at least, to show how difficult and even hopeless is the settlement of such a question.

The conjecture that these stony masses are from the moon, would hardly originate seriously from any but an astronomer. An ordinary person might at random utter the vague expression of a thing's coming from that luminary; yet none but a philosopher could propose such a conjecture with any hope of proving its possibility. La Place attempted to do this by mathematical calculation. He showed that if a mass were projected by a volcano from the moon with a certain velocity, (about one mile and a half per second,) it would be thrown beyond the sphere of the moon's, and into the confines of the earth's attraction, and consequently fall to the earth. To prepare the way for a comparison of the supposed causes with the phenomena themselves, it may be well to enter into some details of the observed circumstances attending their fall.

Traditions have prevailed in almost all ages, and among all people, of the fall of solid materials from the atmosphere, under the various denominations of thunderbolts, showers of stones, masses of native iron, and so forth, generally believed to have descended from the sky or heavens, and ascribed to the miraculous judgments of the Deity; while they were as generally disbelieved by philosophers, either because they had never seen the fall, or because they found it impossible to account for it. Pliny relates that, in the time of Anaxagoras, the preceptor of Socrates, a stone fell to the earth in the daytime, near the river Ægos, in Thrace, (as large as a wagon load) of a burnt color, and at the same time that a comet was visible at night. There was another stone of the same origin preserved in a public place at Abydos, and held in great reverence; a third at Cassandria, in Macedonia; fourth at Vorantia.

In later ages of the world the fact has been observed so often by respectable evidences, and recorded with circumstances of such accuracy, that there now remains "no loop whereon to hang a doubt." One instance of this kind is given by Gassendi, a celebrated astronomer, who was an eye-witness of what he relates. November 27th, 1627, the sky being quite clear, he saw a burning stone fall on a mountain in the south-eastern extremity of France, near the coast of the Mediterranean. While in the air it seemed to be about four feet in diameter; it was enclosed in a luminous circle of colors like a rainbow, and in its fall produced a sound like the discharge of cannon. It weighed fifty-nine pounds, was very hard, of a dull metallic color, and its specific gravity was considerably more than that of marble.

Prior to this a stone fell at a town in Alsace, in the north-eastern part of France, near the upper Rhine. This was in 1492, November 7th, between eleven and twelve before noon, when a dreadful thunder-clap was heard at that place, and a huge stone seen to fall on a field lately sown with wheat. On the people going to the place, a hole was found, and digging out the stone, they perceived that it had penetrated to the depth of three feet. The stone weighed two hundred and sixty pounds; its size, therefore, was equal to a cube of thirteen inches the side. No doubt was entertained of this fact; cotemporary writers agree in its general belief by the neighborhood, and the natives of the place must have known if such a hole or stone had before existed in that wheat-field. In 1672, two stones fell near Verona, in Italy, the one weighing three hundred, the other two hundred pounds. Soon after, a member of the Abbé Bourdelot's academy presented, at one of their meetings, a specimen of these two stones; stating that the phenomenon had been seen by three or four hundred persons; that the stones fell in a sloping direction, during the night and in calm weather; that they appeared to burn; that they fell with great noise, and ploughed up the ground. It is related by Paul Lucas, the traveller, that when he was at Larissa, in Greece, a stone fell in the neighborhood weighing seventy-two pounds. It was observed to come from the northward with a loud hissing noise, and seemed to be enveloped in a small cloud that exploded when the stone fell. It looked like iron dross, and smelled of sulphur. In September, 1753, several stones fell, accompanied with loud noises, a little west of Geneva, two of them falling within nine miles of each other. The sky was clear and the weather warm. A loud noise and hissing sound were heard for many miles round. The stones appeared exactly similar to each other, of a darkish, dull color, very heavy, and their surface appearing as if they had suffered a violent degree of heat. The largest weighed about twenty pounds, and penetrated about six inches into the ploughed ground. This phenomenon has been described by La Lande, the astronomer, who seems to have carefully examined, on the spot, the truth of the circumstances he describes.

In the year 1768, there were presented to the academy of sciences at Paris three stones which had fallen in different parts of France; one in the Maine, another in Artois, and the third in Cotentin. These were externally of precisely the same appearance. On the first of them a report was made by a select committee, who stated that on the 18th of September, between four and five o'clock, P. M., there was seen, near the village of Lucè in Le Maine, a cloud, in which a short explosion took place, followed by a hissing noise, but without any flame; that some persons about ten miles from Lucè heard the same sound, and looking upward, perceived an opaque body describing a curve line in the air, and fall on a piece of green turf near the high road; that they immediately ran to the spot, and found a stone half buried in the earth, extremely hot, and weighing seven and a half pounds. In his account of a shower of small stones which fell at Guienne, in the south-western part of France, on the 24th of July, 1790, D'Arcet mentions two singular circumstances as coming directly under his own observation: viz. that the stones, when they fell on the houses, had not the sound of hard and compact substances, but of matter in a soft, half-melted state; and that such of them as fell upon straws, adhered to them so as not to be easily separated. December 19th, 1798, at eight o'clock in the evening, a large fire-ball was seen at Benares, in Bengal: it was attended with a loud rumbling noise. The inhabitants of Krakhut, fourteen miles from Benares, saw the light, heard a sound like a loud thunder-clap, and immediately after, a noise as of heavy bodies falling to the earth. The watchman of an English resident brought him, the next morning, a stone that had fallen through the top of his hut and buried itself in the earthen floor. During the explosion of a fire-ball near Bordeaux, in 1789, a stone fell through the roof of a cottage and killed a herdsman.

An aerolite fell at Nobleboro', Maine, on the 7th of August, 1823, between four and five o'clock, P. M. The account was given by a person at work near the spot. His attention was attracted by a noise which at first resembled platoon firing, but soon became more rapid in succession. The air was calm and the sky clear, with the exception of a small white cloud, apparently about forty feet square, nearly in his zenith: from this the sound seemed to proceed. After the explosion this cloud appeared to be in a rapid spiral motion downward, as if about to fall on him, and it made a noise like a whirlwind among the leaves. At this moment a stone fell among some sheep, that were much frightened, and ran off to the woods. This circumstance assisted him in finding the spot where the stone struck, which was about forty paces in front of the place where he was standing. The aerolite penetrated the earth about six inches, and there meeting a stone, it was broken into fragments. When first taken up, which was about an hour after its fall, it exhaled a strong sulphureous odor. The whole mass, previous to its fracture, probably weighed between four and six pounds. Other fragments of the same aerolite are said to have been found several miles from Nobleboro'.

On the 10th of February, 1825, an aerolite fell at Nanjemoy, Maryland. About noon the people were alarmed by an explosion in the air, which was succeeded by a loud whizzing noise, (like that of a current of air through a small aperture,) that seemed advancing nearly parallel with the river Potomac in a south-easterly course. Shortly after, a portion of ground was found that had been recently broken, and on examination a rough stone of an oblong shape, weighing sixteen pounds and seven ounces, was found about eighteen inches under the surface. The stone when taken from the ground, about half an hour after it fell, was sensibly warm, and had a strong sulphureous smell. It had a hard vitreous surface, and when broken appeared to be composed of an earthy matrix containing numerous globules of various sizes, of a brown color and very hard, together with small portions of brownish yellow pyrites, which became dark-colored on being reduced to powder. Various ideas were entertained by the people on finding this stone. Some supposed it propelled from a quarry eight or ten miles distant; while others were so fully convinced that it was thrown by a mortar from a packet lying in the river, that they proposed manning a boat to take vengeance on her captain and crew. Yet all agreed that the noise seemed directly over their heads. One gentleman, living twenty-five miles from the place where the stone fell, said that it caused his whole plantation to shake, and that many supposed there had been an earthquake. There was no fire-ball or light seen in the heavens, and no peculiar smell in the air was noticed. An examination of a fragment of this stone is detailed in "The Journal of Science," from which we extract the following. The fragment weighed four pounds and five ounces. Its dimensions were seven by three or four inches; its form an irregular oval, nearly flat where it was detached from the larger mass, and bounded by irregular curves in the other parts of its surface. It is covered, except where broken, by the usual black vitreous coating, which in this case has more lustre than common. This coating has innumerable cracks running in every direction, and communicating with each other so as to divide the surface into portions resembling honey-comb or madrepore, and no undivided portion exceeds half an inch in diameter. This circumstance seemed to have arisen from the rapid cooling of the external vitreous crust after intense ignition. No one who saw this crust could doubt this to be the cause. It is not quite so thick as the back of a common penknife, and is separated by a well-defined line from the mass of the stone beneath. On the fractured surface the stone is of a light ash gray, or perhaps more properly of a grayish white; it is very uniform in its appearance, not being marked with any strong contrast of dark and light gray spots. The fractured surface of the stone is uneven and granular, harsh and dry to the touch, and it scratches window-glass, though not with much energy. To the naked eye it presents very small glittering metallic points, and a few minute globular bodies scattered here and there through the mass. With a magnifier these appearances are of course much increased. The adhesion is so feeble that it falls to pieces with a slight blow, and exhibits an appearance like grains of sand. The Maryland aerolite is highly magnetic, pieces as large as peas being readily lifted by the magnet. The iron is metallic and perfectly malleable. In the crust the iron is glazed over so that the eye does not perceive its metallic character, but the file instantly exposes the innumerable points, which then break through the varnish of the crust and give it a brilliant metallic lustre at all the parts where the file has uncovered the iron. The specific gravity of the specimen was 3.66. On analysis it was found to contain silica, magnesia, lime, oxide of iron, oxide of nickel, sulphur, alumine.

Several of the preceding accounts notice the material circumstance of damage done to objects above the ground by these stones. It seems impossible to deny very great weight to all these testimonies, and many others that might have been detailed, all concurring in the descriptions as nearly as different persons can be expected to do even in describing one and the same occurrence. We shall notice the main points that seem to be substantiated by all witnesses. In various parts of the world luminous meteors have been seen moving through the air with a noise like the whizzing of large shot, followed by explosion, and the fall of hard, stony or semimetallic masses in a heated state. The constant whizzing sound; the fact of stones being found similar to each other, but unlike all others in the neighborhood, at the spots toward which the luminous body or its fragments were seen to move; the scattering or ploughing up of the soil at those spots, always in proportion to the size of the stones; the concussion of the neighboring ground at the time, and especially the striking of the stones on bodies above the earth, or lying loosely on its surface, are circumstances perfectly well authenticated, proving that such meteors are usually inflamed, hard masses, descending through the air.

The reports of all those persons who have seen and observed such meteors and found the stones, uniformly agree in describing those substances as different from all the neighboring bodies, and as presenting the external appearance of semimetallic matter, coated with a thin black crust, and bearing strong marks of recent fusion. Besides this general resemblance, obvious to the most careless inspection, many of these substances have been carefully examined by the first chemists and naturalists, and their investigations have put us in possession of information sufficient to convince the most sceptical that the bodies in question have a common origin, and that we are unacquainted with any natural process by which they could have been formed on our globe. The specific gravities of all these aerolites are nearly the same, being between three and four, that of water being represented by one. In this respect they exceed all the ordinary stones of our globe, and approach to those of the metallic ores. All these stones that have been examined consist of four distinct substances, viz. small metallic particles, a peculiar pyrites, a number of globular and elliptical bodies of a peculiar nature, and an earthy cement surrounding the other component parts. The nature of the metallic particles is the same in all, being an alloy of iron and nickel. The globules contain silica, magnesia, and oxides of nickel and iron. The earthy cement consisted of the same substances, very nearly in the same proportions. We may conclude, then, that the substances that have at different times fallen to the earth in Europe, India, and America, are exactly of the same nature, consisting of the same simple substances in nearly the same proportions, and forming a heterogeneous compound whose general resemblance is complete. The examination of native masses of iron found in South America, in Siberia, in Bohemia, and indeed in all parts of the earth, lead to the conclusion that they are of the same origin as those that we denominate aerolites. Concerning the Siberian iron there exists a tradition among the Tartars that it formerly fell from heaven. The fall of a similar body in India is supported by the testimony of the emperor Tchangine in his memoirs of his own reign. He relates that, in the year 1620 of our era, a violent explosion was heard at a village in the Punjab, and a luminous body fell through the air to the earth. The officer of the district immediately repaired to the spot where it was said the body had fallen, and finding the place hot, he caused it to be dug, on which the heat was found to increase till they reached a lump of iron violently hot. The emperor ordered the mass to be forged into a sabre, a knife, and a dagger. The workmen, after trial, reported that it was not malleable, but that it shivered under the hammer. The mass, however, made excellent blades after mixing with it a third part of common iron. The exact resemblance of this occurrence in its essential circumstances to other accounts of fallen stones, and the remark on the want of malleability in the iron, give a high degree of credibility to the whole narrative, and throw additional weight on the inference before drawn from internal evidence, that the masses of native iron found in different parts of the world have the same origin as the meteoric stones. From the facts and evidence of which a summary has been given, may we not safely conclude that the bodies in question have fallen to the surface of the earth, that they were not projected by any terrestrial volcano, and that we have no reason, from the known laws of nature, to suppose that they were formed in the upper regions of the atmosphere? Such a negative conclusion, in the present state of our knowledge, seems to be all we are entitled to draw. In this embarrassing predicament, some persons have come to the conclusion that they must have dropped from the moon. As the attraction of gravitation extends through the whole planetary system, a body placed at the surface of the moon is affected chiefly by two forces, one drawing it toward the centre of the earth, and the other drawing it toward the centre of the moon. The latter, near the moon's surface, is incomparably the greater. But as we recede from the moon, and approach toward the earth, this force decreases, while the other augments, till at length a point is found between the two planets where these forces are exactly equal, so that a body placed there must remain at rest; but if removed still nearer to the earth, this planet would have the superior attraction, and the body must fall towards it. If, therefore, a body be projected from the moon toward the earth with a force sufficient to carry it beyond this point of equal attraction, it must necessarily fall to the earth. Now, supposing a mass to be projected from the moon by a volcano, or by the production of steam, owing to the internal heat of that satellite, in a direct line toward the earth; and supposing the two planets to remain at rest; it has been demonstrated on the Newtonian estimation of the moon's mass, that a force projecting the body with a velocity of twelve thousand feet per second, would be sufficient to carry it beyond the point of equal attraction. This estimate of the moon's mass is now allowed to be much above the truth; and on the calculation of La Place, it appears that a force of little more than half the above power would be sufficient to produce the effect, that is, a force capable of projecting a body with a velocity of less than a mile and a half per second. A force equal to this is exerted by terrestrial volcanoes; and we may suppose such a cause of motion to exist in the moon, and even in a superior degree, from the volcanoes thought to have been discovered by Dr. Herschel, especially if we consider the moon's atmosphere to be very rare or limited in extent.

All the phenomena of aerolites, say the advocates of their lunar origin, agree well with the circumstances of a substance projected from the moon. With respect to the bright spark, first seen at an immense distance, and gradually increasing with the diminution of its distance;—the body, being projected from a lunar volcano, may be supposed in an ignited state, and, passing through the comparative vacuum between the earth's and moon's atmospheres, would enter the upper part of our atmosphere with but little diminution of its original heat; from which circumstance, united with its rapid motion, the body may become suddenly inflamed.

Next, to trace the body through the earth's atmosphere;—we may observe that it enters the top of it with a great velocity, that acquired by descending from the point of equal attraction, which is such as would carry it to the earth's surface in a few seconds if it meet with no obstruction. But as it enters deeper into our atmosphere, it meets with increasing resistance from the density of the air, by which its great velocity must be diminished. This remaining velocity will be different, according to the size and specific gravity of the body; but, for a particular instance, if the body were a globe of twelve inches diameter, and of the same gravity as the aerolites, the motion would be decreased from six miles per second to a little more than a quarter of a mile per second of perpendicular descent. Now while the body is thus descending, the earth is affected by a twofold motion, the diurnal and the annual, with both of which the descent of the body is to be compounded. The daily motion at the equator is about two-sevenths of a mile per second, but in middle latitudes a little more than half a quarter of a mile per second. This may cause the body to appear to descend somewhat, though not very, obliquely. But the earth's annual motion is about nineteen miles per second; and if this be compounded with the descending motion of the body, it will necessarily have the appearance of a rapid motion but little declining from the horizontal.

Again, with regard to the apparent direction of the body, this will be various, for the motion of the earth in its orbit is various at different seasons of the year. Usually, however, from the great excess of the earth's motion above that of the falling body, the direction of the latter must appear nearly opposite to that of the former.

In the flight of these aerolites, they commonly make a loud whizzing sound. And if such a sound be given by the smooth round cannon-ball, how exceedingly great should be that of a body so much larger, and whose form and surface is so irregular.

These substances commonly burst and fly in pieces in their rapid flight—a circumstance that might be expected, both on account of the violent state of fusion on their surfaces, and from the extreme rapidity of their motion. That the stones, striking the ground with great force, should penetrate to some depth, is not unnatural, since even a cannon-ball or a mortar-shell will often bury itself in the soil.

That the stones are hot when found, and exhibit signs of recent fusion, is not strange, after the extreme degree of inflammation to which they are subjected in their flight through the air.

These masses have all the same external appearance and texture, as well as internally the same nature and composition. These are circumstances which strongly point to an identity of origin; and their entire want of similarity to any terrestrial composition leads the mind to conclude that they did not originate on our globe. These are the arguments that are used to prove the descent of aerolites from the moon. But they prove any other origin (apart from a terrestrial one) just as well.

The existence of four planets between the orbits of Mars and Jupiter, revolving round the sun at nearly the same distances, and differing from all the other planets in their diminutive size, and in the form and position of their orbits, is one of the most singular phenomena in the history of astronomy.

The incompatibility of these phenomena with the regularity of the planetary distances, and with the general harmony of the system, naturally suggests the opinion that the inequalities in this part of the system were produced by some great convulsion, and that the four planets are the fragments of a large celestial body which once existed between Mars and Jupiter. If we suppose these bodies to be independent planets, as they must be if they did not originally form one, their diminutive size, the great eccentricity and inclination to their orbits, and their numerous intersections when projected on the plane of the ecliptic, are phenomena absolutely inexplicable on every principle of science, and completely subversive of that harmony and order which, before the discovery of these bodies, pervaded the planetary system. But if we admit the hypothesis that these planets are the remains of a larger body, which circulated round the sun nearly in the orbit of the greatest fragment, the system returns to order, and we discover a regular progression in the distances of the planets, and a general harmony in the form and position of their orbits. To a mind capable of feeling the force of analogy, this argument must have no small degree of weight, and might be reckoned a sufficient foundation for a philosophical theory. We are fortunately, however, not left to the guidance merely of analogical reasoning. The elements of the new planets furnish us with several direct arguments, drawn from the eccentricity and inclination of their orbits, and from the position of their perihelia and nodes, and all concurring to show that the four new planets have diverged from one point of space, and have, therefore, been originally combined in a larger body.

To those who are acquainted with physical astronomy, it is needless to state the difficulty of ascertaining the paths of four bodies whose masses are known, and which have diverged from one common node, with velocities given, in quantity and direction. This problem is much more perplexing than the celebrated problem of "the three round bodies," and is therefore beyond the grasp of the most refined analysis. It is not difficult, however, to ascertain in general the consequences that would arise from the bursting of a planet, and to determine, within certain limits, the form and position of the orbits in which the larger fragments would revolve round the sun.

When the planet is rent asunder by some internal force capable of overcoming the mutual attraction of the fragments, it is obvious that the larger fragments will receive the least impetus from the explosive force, and will, therefore, circulate in an orbit deviating less than any other of the fragments from the original path of the large planet; while the lesser fragments, being thrown off with greater velocity, will revolve in orbits more eccentric, and more inclined to the ecliptic. Now the eccentricity of Ceres and Vesta is nearly one-twelfth of their mean distances, that of Ceres being rather the greatest; and the eccentricity of Pallas and Juno is one-fourth of their mean distances, the eccentricity of Pallas being a little greater than that of Juno. We should therefore expect, from the theory, that Pallas and Juno would be considerably smaller than Ceres and Vesta, and that Ceres should be the larger fragment, and have an orbit more analogous in eccentricity and inclination than that of any of the smaller fragments to the other planets of the system. In so far as the diameters of the new planets have been measured, the theory is most strikingly confirmed by observation. The observations of Schroeter make Juno considerably less than Ceres; and though the diameter of Vesta has not been accurately ascertained, yet the intensity of its light, and the circumstance of its being distinctly visible to the naked eye, are strong proofs that it exceeds in magnitude both Pallas and Juno. The striking resemblance between the two lesser fragments, Pallas and Juno, in their magnitudes, and in the extreme eccentricity of their orbits, would lead us to anticipate similar resemblances in the position of their nodes, in the place of their perihelia, and in the inclination of their orbits; while the elements of Ceres and Vesta should exhibit similar coincidences. Now the inclination of Ceres is ten degrees, and that of Vesta seven degrees, while the inclination of Juno is twenty-one degrees, and that of Pallas thirty-four degrees; and the two greater fragments having nearly the same inclination, and keeping near the ecliptic, while the lesser fragments diverge from the original path, and rise to a great height above the ecliptic, and far above the orbits of all the other planets in the system. If it shall be found from observation that Vesta is one of the smaller fragments, we may then account for its position with regard to Ceres, and for the small inclination and eccentricity of its orbit, by supposing the planets Ceres, Pallas, and Juno to have diverged in the same plane, and nearly at right angles to the ecliptic, while Vesta diverged from the direction of the original planet in a plane parallel with the ecliptic. This opinion is strongly confirmed by the fact that the orbit of Vesta is nearer to the sun than any of the orbits of the other three fragments.

In the position of the nodes we perceive the same coincidence. The orbits of Pallas and Juno cut the ecliptic in the same point, and the nodes of Ceres and Vesta are not far distant.

If all the fragments of the original planet had, after the explosion, been attracted to the larger fragment, it is obvious that they would all move in the same orbit, and consequently have the same perihelion. If the fragments received a slight degree of divergency from the explosive force, and moved in separate orbits, the points of their perihelion would not coincide, and their separation would increase with the divergency of the fragments. But since all the fragments partook of the motion of the primitive planet, the angle of divergency could never be very great; and therefore we should expect that all the perihelia of the new planets would be in the same quarter of the heavens. This theoretic deduction is most wonderfully confirmed by observation. All the perihelia are in the same semicircle, and all the aphelia in the opposite semicircle; the perihelia of the two larger fragments, Ceres and Vesta, being near each other, as might have been expected, while there is the same proximity between the perihelia of the lesser fragments, Pallas and Juno.

These singular resemblances in the motions of the greater fragments, and in those of the lesser fragments, and the striking coincidences between theory and observation in the eccentricity of their orbits, in their inclination to the ecliptic, in the position of their nodes, and in the places of their perihelia, are phenomena which could not possibly result from chance, and which concur to prove, with an evidence amounting almost to demonstration, that the four new planets have diverged from one common node, and have therefore composed a single planet.

Let us now proceed to consider the other phenomena which might be supposed to accompany this great convulsion. When the cohesion of the planet was overcome by the action of the explosive force, a number of little fragments, detached along with the greater masses, would, on account of their smallness, be projected with very great velocity; and being thrown beyond the attraction of the larger fragments, might fall towards the earth when Mars happened to be in the remote part of his orbit. The central parts of the original planet being kept in a state of high compression by the superincumbent weight, and this compressing force being removed by the destruction of the body, a number of lesser fragments might be detached from the larger masses by a force similar to the first. These fragments will evidently be thrown off with the greatest velocity, and will always be separated from those parts which formed the central portions of the primitive planet. The detached fragments, therefore, which are projected beyond the attraction of the larger masses, must always have been torn from the central parts of the original body; and it is capable of demonstration that the superficial or stratified parts of the planet could never be projected from the fragments which they accompany.

When the portions which are thus detached arrive within the sphere of the earth's attraction, they may revolve round that body at different distances, and may fall on its surface in consequence of a diminution of their centrifugal force; or, being struck by the electric fluid, they may be precipitated on the earth, and exhibit all those phenomena which usually accompany the descent of meteoric stones. Hence we perceive the reason why the fall of these bodies is sometimes attended with explosions, and sometimes not; and why they generally fall obliquely, and sometimes horizontally, a direction which they never could assume if they descended from a state of rest in the atmosphere, or had been projected from volcanoes on the surface of the earth.

If we compare the specific gravity of meteoric stones with the density of the new planets, we shall obtain another argument in support of the theory. It appears from the observations of Maskelyne on the attraction of Shehallien, and particularly from the experiments of Cavendish on the attraction of leaden balls, that the density of the earth increases towards its centre; and therefore the density of the central parts must exceed the average density of the whole globe. This increase of density no doubt arises from the weight of the superincumbent mass; and hence we are entitled to conclude that the density of the central parts of every other planet is greater than the average density of the body. As it is demonstrable, therefore, that the fragments of the large planet, which are supposed to be meteoric stones, must have been detached from the central parts of the primitive planet, the specific gravity of meteoric stones ought to exceed the average density of the planet. According to the observations of Playfair, the density of Shehallien is only 2.7, while that of the earth is 4.8; so that the density of the central parts of our globe cannot be less than seven or eight, in order to make up the mean density. Now the density of the new planets, estimated from their position in the system, by the method of La Grange, is nearly two; and reasoning from analogy, and following the proportion already stated in the case of the earth, we should expect that the average density of meteoric stones should be between three and four; within which limit we may in fact express the specific gravity of all of these bodies. This coincidence, when taken in connection with the evidence arising from the form and position of the orbits of the new planets, gives a probability to the theory which no other hypothesis can claim.

It is objected that if meteoric stones are the fragments of a planet, why are they all of the same kind? If our earth were to be burst in pieces, we should find among its fragments stones of every description. This objection is founded on the supposition that the earth is everywhere stratified, and that there exists at its centre the same diversity of minerals as occur at its surface. This opinion is purely hypothetical; men have scarcely penetrated beyond the surface of the globe, and we have every reason to believe that the stratification is completely superficial. The density of the internal mass is known to be extremely great, and the magnetism of the earth demonstrates that this mass must be either iron-stone, or melted metals, which have the magnetic virtue. Now if we suppose the earth to be burst in pieces by some internal force, it is demonstrable that the smaller fragments which would be projected beyond its sphere of attraction must come from the central parts, and that none of the superficial or stratified parts would be detached from the fragment to which they belong. The only way in which we can conceive the superficial parts of the planets to be affected, is by the shock given to the fragment on which they rest. But this shock cannot produce a velocity greater than the velocity of the fragment itself; and since that fragment is supposed by the hypothesis to continue in an orbit not far from the orbit of the original planet, its superficial parts must also remain in the same region of the heavens. The portions of our globe, consequently, which would be thrown beyond the reach of its attraction, would be the dense parts towards its centre, which probably would be either iron-stone, or melted metals, that had the magnetic virtue. Reasoning from analogy, therefore, we should draw the same conclusion respecting the imaginary planet between Mars and Jupiter; and it is a singular circumstance, that meteoric stones contain a great proportion of iron, that they are endowed with the magnetic virtue, and that the large meteoric stones which have been found in Siberia and in South America are masses of melted iron.

It would not be difficult to anticipate several objections that might be urged against the preceding theory; but, however formidable these may be, we ought to remember that such difficulties do not belong to the hypothesis itself, but arise from our ignorance of the changes induced upon the fragments during their passage through the earth's atmosphere, and that they belong equally to every hypothesis which has yet been suggested. It is not fair, therefore, to demand from one theory an explanation of difficulties which belong to all. It is sufficient to give a plausible explanation of the phenomena, and to combine under a general principle the scattered facts that cannot otherwise be generalized consistently with the established laws and analogies of nature.