# COSMOGRAPHY

# PREFACE

The following pages, whatever be their merit, are printed at the request of several young friends of the writer. To them, therefore, he dedicates the work.

The title announces the subject; but the size of the book warns the reader that he must take the term *Cosmography* in a very limited sense, and hence can expect but a miniature description of the World. But even a miniature copy of a master-piece, if faithful, suffices to make one appreciate the skill of the original artist. Hence we have endeavored to give a faithful sketch of the subject, but we dare not assert that success in every instance has attended our efforts. Yet so magnificent and beautiful is the original that even though imperfectly reproduced it cannot fail to excite feelings of admiration, love and gratitude towards its Author, and the desire of one day seeing Him face to face.

B. S., *S. J.*

# COSMOGRAPHY.

## PRELIMINARIES.

*Object of Cosmography*—Cosmography has for its object, besides the description of celestial bodies, the exposition and explanation of their relative positions, of their movements, and, generally, of the phenomena connected with them. The object of Cosmography is, therefore, the same as that of Astronomy ; but Astronomy treats the subject more copiously and with scientific rigor, while Cosmography is chiefly descriptive.

*Celestial Bodies*— Celestial bodies may be divided into two classes : *fixed* and *erratic* bodies. The first of these two classes, to which belong the stars, is so called because of the apparent permanency of the stars in the same part of space. Planets and comets, which apparently and really change their positions in space, belong to the second class.

*Different parts of Astronomy*—To obtain an accurate knowledge of the arrangement and motions apparent or real of the celestial bodies, means of observation and numerical calculations are required. The use of the instruments, and the labor of calculations constitute *Practical Astronomy*. From the already abundant observations, and from corresponding calculations the real condition and arrangement of the celestial bodies are inferred, and when possible, their magnitudes, their relative distances, the rate and character of their motions are also known. All this forms one of the parts of *Theoretical Astronomy;* the object of the second part is the study of the laws which govern the motions of the same bodies; the third part, which is called *Physical Astronomy*, investigates the physical qualities of the celestial bodies.

*Its Applications*—To appreciate the utility of astronomy it is sufficient to mention its application to *Geography*, *Chronology*, *Navigation* and *Gnomonics*.

Every body is familiar with the object of Geography, but not many are apt to value the difficulty inherent in the construction of geographical maps with those means which astronomy alone confers.

Navigation derives a still greater benefit from astronomy, which affords it a sure and easy guide.

Chronology, the object of which is the accurate measure and order of time, depends totally on Astronomy, and consequently on it depend all the benefits which history derives from chronology, and the many advantages arising from the right distribution and order of time.

The measurement of time, considered under a less general point of view and depending on the motion of the sun, is obtained by dials, the construction of which forms the object of Gnomonics, or, the art of dialling.

# ARTICLE I.

## INTRODUCTION TO THE STUDY OF THE CELESTIAL SPHERE.

1. *Elementary Principles*—It is well known from geometry that the intersection of a sphere by a plane forms a circle, and this circle is called *great* or *small* according as the plane of intersection passes through the centre of the sphere or out of it. It is known also that a diameter, perpendicular to the plane of a great circle, is called the *axis* of that circle, and the extremities of this axis are called *poles*. Now, if we conceive a sphere cut by an indefinite number of parallel planes, it follows that: 1st. Only one of these planes produces a great circle. 2nd. The axis of this circle is perpendicular to all the planes of the other circles and passes through their centres. 3rd. Each pole of the axis is equidistant from every point of the parallel circles.

Suppose now the same sphere to be turned about the axis, each point of the spherical surface will produce a circle, and all these circles will be parallel; and consequently the inferences just mentioned are applicable to them.

2. *Apparent aspect of the Firmament*—The apparent aspect of the heavens is that of the concave surface of a sphere, the centre of which is the spot occupied by the observer, to whom the sphere appears to turn continually and uniformly about an immovable axis. The planes of the circles described by the different points of the sphere are mutually parallel and perpendicular to the axis of revolution.

3. *Three different cases of the Sphere*—The celestial

sphere is not altogether visible to the spectator on the surface of the earth, but that part only which is above, the other being concealed by the earth, which presents itself to the spectator like the plane of a great circle. Now, three cases may occur with regard to the relative position of the sphere and of this apparent plane. The plane is either normal to the axis of rotation of the sphere, or it coincides with this axis, or finally it is neither normal to, nor coincides with this axis.

In the first case the apparent plane coincides with the plane of the great circle, among the parallel circles described by the points of the sphere, and consequently the planes of the remaining circles described by the other points are parallel to the apparent plane; hence this position of the sphere is called *parallel.* In the second case the same circles are all normals to the apparent plane, and the position of the sphere is consequently called *normal.* In the last, the circles are inclined to the apparent plane, and the position of the sphere is accordingly called *oblique.*

4. *Definitions*—The great circle among the parallels described by the various points of the sphere is called the *Equator*, and the great circle formed by the intersection of the apparent plane with the sphere is called the *Horizon.* The extremities of the axis of the equator retain the name of *poles*, but the upper pole of the horizon is called *Zenith*, and the opposite one *Nadir.* It is to be observed that on account of the rotation of the sphere about the axis of the equator, the zenith and nadir points correspond successively to different points of the sphere, while the poles of the equator remain immovable in the same points, just as the corresponding axis of rotation remains immovable

in space. This axis is called *axis of the world*, and occasionally also the corresponding poles are called *poles of the world*.

5. *The Meridian and its Qualities*—Besides the equator and the horizon, another great circle called *Meridian* is much used in astronomy. The plane of this circle is determined by the axes of the two preceding; hence the plane of the meridian is perpendicular to the planes of the other two circles; it divides into two equal parts all the parallel circles, and divides also into two equal parts the portions of those parallels that are cut by the horizon. The upper point of intersection of the equator or of any parallel circle with the meridian is called the *culminating point* or *point of culmination*.

6. *Analogies between the axes of coordinates on a plane, and the circles on a sphere*—The object of astronomers in conceiving the above mentioned circles, and others to be mentioned hereafter, traced, as it were, on the celestial sphere, is to determine the position of the various points on the same spherical surface in as much as they are referred to them. Hence the analogy between these circles and the rectilinear axes of coordinates; and as rectilinear coordinates determine the position of points on a plane relatively to the axes on the same plane, so circular coordinates determine the position of points on a sphere relatively to circles on the same sphere. Now as two axes on a plane are sufficient to determine the position of any point on that plane; so two circles on the sphere, the meridian, for example, and the equator, or the meridian and the horizon, are sufficient to determine the position of the different points of the celestial sphere. It is, however,

customary and convenient to refer the same points to different systems of circles.

7. *Figure of the Earth*—The different position and apparent motion of the firmament depend on the form and motion of the earth. Hence the knowledge of the figure of the earth and of its motion are indispensable elements for the astronomer. For the present we must confine ourselves to show how the form of the earth is nearly spherical. It is a well known fact, constantly observed by all navigators on every part of the earth, that ships seen at a sufficient distance are only partly visible, the lower part of them being more or less depressed below the plane of the horizon, and the greater the distance becomes, the less the upper part of the ship is visible, until finally the tops of the masts totally disappear. This fact alone is sufficient to prove that the surface of the ocean and, in general, of extensive sheets of water is a curved surface; we might infer that the lesser portion of the earth, which is dry land, must likewise be curved, but the same test can, partially at least, be applied to dry land. A traveller on an extensive plane sees constantly, new objects coming in view, and rising, as it were, from the ground in the same manner as navigators upon approaching the shore, see successively the tops of light-houses and then other heights, natural or artificial, the lower parts of which become visible according as the ship approaches the shore. Other analogous observations confirm the same fact, that the earth's surface is neither plane nor polyhedral, but curved and uniformly curved, i. e. it has the curvature of a sphere. To this direct observation another indirect and equally demonstrative may be added. It has been already said that the

firmament has the appearance of a sphere the centre of which is occupied by the observer, whatever be his position on the surface of the earth ; hence in the supposition that the earth has a globular form, its centre must be considered as common both to its own convex surface and to the concave surface of the firmament. Representing (Fig. 1) by $pmp'$ the terrestrial globe, and by $PnP'$ the celestial sphere, let $C$ be their common centre ; a plane passing through this centre and coinciding with $PP'$ the axis of the world, will trace on both spheres a great circle and pass through the poles $PP'$ of the heavens, and through the corresponding poles $pp'$ of the earth. Conceive now a traveller moving on the circle traced by the plane on the terrestrial surface, from $m$, ex. gr., towards $p$; the zenith point of the traveller will change constantly and approach to the celestial pole $P$, because the zenith point is determined by the extremity $n$ or $n'$ of the radius $cn$ or $cn'$ which passes through the place of observation $m$ or $m'$. Again in the supposition of the earth being a sphere, the approaching of the zenith point to the celestial pole must correspond exactly with the approach of the observer to the terrestrial pole ; if, for example, by travelling sixty miles towards the pole of the earth we find that the zenith point approaches one degree to the celestial pole ; by travelling one hundred and twenty miles, it must approach two degrees ; and by travelling one hundred and eighty miles it must approach three degrees, and so on. Now observation shows that this is the case ; hence the spherical form of the earth is demonstrated.

8. *How the Radius of the Earth can be determined*— If the earth is a sphere, it may be asked, how can the

length of its radius be determined? We answer that, when the length of one degree of a great circle of the terrestrial globe is known, we know likewise the length of the great circle rectified, and from the known ratio between the radius and the circumference, we may at once infer the length of the radius.

The radius of the earth can be approximately determined in another way. Let $C$, Fig. 2, be the centre of the earth and $n$ the top of a mountain; let $no$ be a visual ray tangent to the surface of the earth in $m'$, where some immovable object (as a rock, for example, projecting for the sea) is situated. Theoretical and practical Trigonometry supplies the means to determine the length of the visual ray from $n$ to $m'$, and from observation we may determine the angle which the same visual ray forms with the direction $Cmn$, or plumb line. The angle which $nm'$ forms with the radius $m'C$ is a right angle, because $nm'$ is tangent. Therefore in the triangle $nm'C$ we know the side $m'n$ and the two adjacent angles, and consequently the side $m'C$ can be determined.

## ARTICLE II.

### APPARENT MOTION OF THE SUN.

9. *Annual Motion of the Sun*—We have observed that among the celestial bodies some possess a real motion, i. e., they do not permanently keep the same place in the celestial sphere. One of these bodies is the sun. To be convinced of it no apparatus is needed; it being sufficient to observe that while the stars preserve unvaried their relative distances, the sun at various periods of the year is near certain clusters of

stars and successively passes into the vicinity of others.

Again, each fixed star is found to rise and set invariably at the same points of the horizon; but the rising and setting points of the sun vary from day to day. This motion of the sun is called annual, because at the end of one year the sun is found to be in the position in which it was at the end of the preceding year, and resumes again the same period of changes, with the same order as during the year just finished.

10. *How the Motion of the Sun is explained.*—The apparent motion of the sun is explained by supposing it to describe during one year a great circle of the celestial sphere, the plane of which is inclined to that of the equator. Let $PEHP'Q$ (Fig. 3) represent the celestial sphere, and $HR$ the horizon, which separates the visible from that part of the firmament that is invisible to the spectator in $O$, the centre of the sphere. Let $PP'$ be the axis of the world and $E$ $Q$ the equator: finally let $ec$ be the plane of the great circle which we suppose to be described by the sun. It is plain, first, that each one of the points of this circle, on account of the rotary motion of the sphere about its axis, describes one of the parallel circles, and it is equally plain that the two points of the intersection of the same circle with the equator describes the same equator in the diurnal rotation of the sphere. The remaining parallels thus described are divided into two equal sections on each side of the equator. Let us remark, moreover, that each of the parallels, except the two extreme ones on either side of the equator, is described by the two different points. In fact, the plane of the parallel $ab$, for example, evidently cuts the great circle $ec$ in two points, each

of which, with its motion, reproduces the parallel; but the last parallels *ec*, *cf*, are each produced by one point only, which is the point of contact of the same parallels with the great circle *ec*. It is not difficult now to see how an observer in the centre of the sphere with *HR* for his horizon will be spectator of the phenomena mentioned above concerning the annual motion of the sun. Thus, let us suppose the sun to move from one of the points of intersection of the great circle *ec* with the equator, towards *e*, and to continue to move around the whole circle until it returns again to the first point at the end of one year. It is plain, first, that since the stars constantly retain the same position, the sun, with the motion just mentioned, will recede from some of them and approach towards others and then towards others, and so on; which is exactly what takes place. While the sun describes slowly the annual circle, the whole sphere turns about its axis with diurnal revolutions; hence the sun also, like any other body referred to the sphere, describes daily its own circle; with this difference, however, that while the fixed stars describe every day the same parallel, the sun describes every day a circle different from that of the preceding day, because of its constant approaching to, or receding from, the equator. It is more correct to say that the sun describes successive threads or steps of a spiral from the equator to the parallel *ed*, for example, and then from this parallel to the equator, and from the equator to the other parallel *fc*, and from this to the equator again. The two extreme parallels within which the annual motion of the sun is confined are called *Tropics*, because when the sun touches these circles, it turns back. But when the sun touches the tropics its rising and setting points must be the same as those of any other point of the tropic itself, and when it recedes from the tropics towards the equator, its rising and setting points will gradually approach the points of intersection of the equator with the horizon, which points will become the rising and setting points of the sun, as it crosses the equator in its annual motion. All these and other facts are verified by the phenomena which take place during the annual motion of the sun.

11. *Artificial Spheres*—The advantage derived from representing with an apparatus the solar motion, suggested to Archimedes (if he is the inventor), the idea of constructing an artificial sphere, composed of circular wires and belts, and movable about one of its diameters. The motion of the stars and their apparent position is represented by a similar construction, but it has a solid sphere, called the sphere of Aratus, who is supposed to have been the first to make use of it. The solid sphere, in common with the other, has the horizon represented by a great circle, and the meridian represented by another great circle, both immovable. Inside of these circles, the globes of the solid, and the system of rings of the other sphere, revolve about a diameter, which represents the axis of the world, on one plane of the meridian.

12. *The Ecliptic*—The great circle described by the sun in its annual motion is called the *ecliptic* for this reason, that the phenomena of solar and lunar eclipses take place on the planes of this circle. The ecliptic is also taken as a circle of reference, like the equator and the horizon, and together with another great circle perpendicular to it, forms another system

to which to refer the different points of the celestial sphere. The inclination of the plane of the ecliptic to that of the equator is nearly 23° 28′.

13. *Colures*—The plane determined by the axis of the world and the diameter or line of intersection between the equator and the ecliptic, will, when produced, form with the sphere a section representing a great circle. This circle passes through the poles of the sphere and the points where the ecliptical and the equatorial lines intersect each other, and is called *colure of the equinoxes.* The name of colure given to this and another great circle passing also through the axis of the world, the plane of which is perpendicular to that of the first, is derived from κολοι την ουραν, because when the sphere is oblique, a portion of them is cut off by the horizon. The first mentioned is called the *equinoctial colure* because when the sun passes through the same points of intersection, it describes the equator with its diurnal revolution, and consequently during one half of this revolution it remains above, and during the other half, below the horizon, thus making the day equal to the night. The other colure is called the *Solstitial colure*, because when the sun approaches the points of intersection of this circle with the ecliptic, it seems to be stationary, relatively to its distance from the equator.

14. *The Zodiac, and its signs*—In the artificial sphere of Archimedes, the ecliptic is described on a belt or zone of 30° which is bisected by the ecliptical line. This zone is the *Zodiac* or belt of animals. The starry heavens, artificially represented on the globe, is divided into sections, in each of which representations of animals or other figures were originally placed,

and have not only been retained, but others have been added since. The clusters of stars of each section have been denominated after the animal or other object represented by the figure, and are generally called *Constellations*. Now, the zodiac crosses twelve of these constellations, and the zone is divided by them into twelve sections called *signs*. But since the spaces occupied in the firmament by the different constellations differ from each other, and their arrangement follows no regular order; these constellations cannot devide the zodiac and the ecliptic into equal sections. The actual division, however, of the ecliptic into twelve sections, or signs, is made by giving to each of them 30° of extent, retaining still for each one the original name, according to the order of the constellations which begin at the point of the equinox crossed by the sun when it passes into the hemisphere, the pole of which is visible to us. But the position of this point varies with a slow but constant motion, hence the original position of the twelve constellations relatively to this point is liable to constant change. This difference is likewise disregarded and the division of the ecliptic commences with the first of the original twelve signs, as if the corresponding constellations were actually in the same position relatively to the equinox.

It was, and still is the custom to call the constellations (into which the firmament is divided), by their Latin names. The Latin names of the signs also are commonly retained; as in the following distich:

> Sunt Aries, Taurus, Gemini, Cancer, Leo, Virgo,
> Libraque, Scorpius, Arcitenens, Caper, Anphora, Pisces.

In almanacs and calendars, the same signs are indicated by symbols, which, together with the English names, are given in the annexed table:

| | | |
|---|---|---|
| Aries | Ram | ♈ |
| Taurus | Bull | ♉ |
| Gemini | Twins | ♊ |
| Cancer | Crab | ♋ |
| Leo | Lion | ♌ |
| Virgo | Virgin | ♍ |
| Libra | Balance | ♎ |
| Scorpius | Scorpion | ♏ |
| Sagittarius | Archer | ♐ |
| Capricornus | Goat | ♑ |
| Aquarius | Waterman | ♒ |
| Pisces | Fishes | ♓ |

And in rhyme as follows:

"The Ram, the Bull, the Heavenly Twins,
And next the Crab, the Lion shines,
The Virgin and the Scales,
The Scorpion, Archer and He-goat,
The Man that bears the watering-pot,
And Fish with glittering tails."

15. *Division of the circles*—The division of the ecliptic by signs is not the only division of this circle; the ordinary division of degrees, minutes and seconds is applied to it as well as to the other circles of the sphere, but not in the same manner. Thus the numeration of this division for the ecliptic and for the equator commences from 0° and continues uninterruptedly to 360°; the beginning of numeration commencing in the same equinoctial point where the

signs commence and following the same direction of the signs. Hence a point of the ecliptic distant, for example, 63° from the beginning of numeration is said to be distant two signs and three degrees : another at the distance of 95° 7′ is said to be distant three signs, five degrees and seven minutes. The signs, also, are represented by numbers with the letter *s* added to them ; thus in the first case the position of the point would be indicated by $2^s\ 3°$ ; in the second by $3^s\ 5°\ 7'$.

The equator, also, besides the common division into degrees, minutes and seconds, is divided into larger sections, in a manner similar to that of the ecliptic ; but the number of these sections is double that of the signs ; so that each one of these sections contains in the equator 15°. The same sections are called hours.

The horizon and the meridian are each divided into four principal and equal sections, which consequently contain an arc of 90°. Two of these sections of the meridian are between the equator and one of the poles, and the other two between the equator and the other pole ; each one of the four parts has its own subdivision by degrees, minutes and seconds, and for each of them the numeration commences at the equator and ends at the pole. The four divisions of the horizon are the arcs contained between the intersections of this circle with the meridian and with the equator, which intersections are called the cardinal points : North, South, East and West : the two made by the meridian are the North and South, those of the equator, the East and the West. The subdivision of the four quadrants of the horizon from 0° to 90° commences from the South and North as well as from the East and West. In the first case, however, the degrees and their fractions are called *degrees of azimuth*, or, simply *azimuth* ; in the second *degrees of amplitude*. Hence the azimuth is the complement of the amplitude and vice versa.

## ARTICLE III.

### DIFFERENT APPEARANCES OF THE ANNUAL MOTION OF THE SUN.

16. *Corresponding circles of the terrestrial and celestial spheres*—The circles which are conceived to be traced on the celestial, are likewise applied to the terrestrial sphere. Now, the two spheres are concentric; hence the same plane of the equator $EQ$ (Fig. 4), for example, as well as of any other great circle, passing through the common circle $O$ of the two spheres will, with its intersection, trace on the terrestrial sphere, the terrestrial equator The same is not the case with regard to a parallel circle, for instance $MN$, the plane of which escapes the terrestrial globe ; but, if we conceive a radius $OM$ describing that circle with its extremity $M$, the same radius with another point $m$ will describe the corresponding parallel on the surface of the earth ; nay, even in the case of a great circle like $EQ$, if the radius $OE$ be supposed to describe with its extremity $E$ the celestial equator ; the point $e$ of the same radius will describe at the same time the terrestrial equator. Now, suppose the celestial sphere to revolve about the axis $PP'$ and the terrestrial to remain immovable ; all the points of the equator $EQ$ will successively pass through the ex-

tremity $E$ of the radius $OE$, which also we will suppose immovable. Hence, during one revolution of the celestial sphere all the points of the celestial equator pass through the zenith of any point of the terrestrial equator. In like manner, all the points of any parallel $MN$ during one revolution of the sphere will pass successively through the extremity $M$ of an immovable radius $OM$; hence all the points of the celestial parallel will, during one revolution pass through the zenith of any point of the corresponding terrestrial parallel.

17. *Apparent annual motion of the sun for the normal sphere*—For a spectator situated on the equator of the earth, the axis of the world coincides with the plane of the horizon, and the sphere in this case is consequently normal; i. e. the equator $EQ$ (Fig. 5) and all the parallels have their planes perpendicular to the plane $HR$ of the horizon. Hence, since the ecliptic $ec$ cuts the equator in two points diametrically opposite to each other, twice in the year the sun will pass through the zenith of any point of the terrestrial equator; and during one half of the year, it will remain between the equator and the tropic $et$; during the other half, between the equator and the tropic $t'c$; i. e. it will deviate on either side of the zenith towards the poles $P$, $P'$ gradually from $E$ to $e$ to come back to $E$ again and then from $E$ to $t'$ to return once more to $E$, thus describing twice, each of the arcs $Ee$, $Et'$ of about 23° 28′.—Since the axis $PP'$ of the world coincides with the plane $HR$ of the horizon and all the centres of the parallel circles are on this axis, it follows that all the parallel circles are bisected by the horizon; hence, for the inhabitant of the equator

all the diurnal circles described by the sun are bisected by the horizon, and therefore the sun remains every day of the year above the horizon as long as it remains below. This fact is expressed by saying that on the equator the days are all equal to the nights.

18. *Apparent annual motion of the sun for the parallel sphere*—Let us suppose now the spectator to be not on the equator but on one of the terrestrial poles, which are on the axis of the world. In this case the equator $EQ$ (Fig. 6) coincides with the plane $HR$ of the horizon and the sphere is consequently parallel. Since the points of the lower hemisphere $P'QP$ describe circles parallel to the equator none of them can ever appear above the horizon; and for the same reason none of the points of the upper hemisphere can ever descend below the horizon. Now, in this position of the sphere one half of the ecliptic is above and the other half below the horizon. Therefore, in this case the sun, for one half of the year is always invisible and during the other half constantly visible. When the sun, passing from the lower to the upper hemisphere, crosses the equinoctial point, it describes the horizon with its diurnal revolution; then gradually ascending, it describes in the succeeding days, circles parallel to the horizon, until it reaches the tropic $ct'$, about 23° 28′ above the same horizon; then it begins to descend until it reaches and describes the horizon again, when it crosses the equator passing from the upper to the lower hemisphere, where it gradually descends and disappears.

19. *Polar Altitude*—The third case is that of the oblique sphere; this, however, may occur in many ways, each of which is to be considered separately.

The spectator may be somewhere on one or the other of the terrestrial tropics, or between the tropics and the equator, or between the tropics and two parallels, 23° 28′ from the poles called the *polar circles*, or he may be somewhere on the polar circles themselves, or, finally, between the polar circles and the poles. Be-before we examine each of these different cases of the oblique sphere, we must recall to mind an observation made in proof of the sphericity of the terrestrial globe; viz., if a spectator proceed on a terrestrial meridian (i. e., on a circle traced on the surface of the earth by a plane passing through the axis of the world) from the equator towards the pole, for every degree he advances, the celestial pole will ascend one degree above the horizon. Thus, let $HR$ (Fig. 7) be supposed again to coincide with the axis $PP'$ of the world, which is the case when the spectator is on the equatorial line of the earth: suppose the same spectator to advance towards the pole a certain number of degrees, and to have consequently his zenith point no more on the celestial equator but for instance in $Z$. The arc $EZ$ taken on a plane passing through $PP'$ is the measure of the progress of the spectator towards the pole; but, for a spectator having $Z$ for zenith point, the horizon must be a plane $hr$ perpendicular to $OZ$, hence $Zr = EP'$ and consequently $EZ = P'r$. Now, the arc $P'r$ of a *celestial meridian* (celestial and terrestrial meridians correspond to each other, and lie on the same plane) between the point $P'$ and the horizon is called *the altitude* of that point; hence the altitude of the pole is equal to the arc on the terrestrial meridian, between the place of the spectator and the equator. If, therefore, the altitude of the pole is less than 23° 28′, the spectator is between the equator and the tropic; if it is exactly 23° 28′, the spectator is on the tropic; if it is between 23° 28′ and 66° 32′, the position of the spectator is between the tropic and the polar circle; if it is 66° 32′, the spectator is then on the polar circle; finally, if it becomes greater than 66° 32′, the spectator is somewhere between the polar circles and the poles. Now, the position of the celestial pole can be determined, and, in our hemisphere, the close vicinity of a conspicuous star renders its approximate determination an easy task. These remarks show that the spectator is always able to determine the position of the parallel on which he stands, and to determine what is the obliquity of the sphere with regard to him; so that every one of the five cases of the oblique sphere mentioned above, can be, and has been, verified, and found to correspond exactly with the theory which rests on the supposition of the sphericity of the terrestrial globe and concentricity of it, with the celestial sphere.

20. *Parallels on the side of the visible pole, and parallels on the side of the invisible pole*—To the observations made with respect to the altitude of the pole, some others must be added before we examine the various cases of the oblique sphere, with regard to parallel circles. Let $PP'$ (Fig. 8) be the position of the axis of the world inclined to the plane $HR$ of the horizon; $EQ$ is the equator; *mn*, *rs*, parallels on the side of the pole visible above the horizon; and *m′n′*, *r′s*, parallels equidistant from the equator, on the side of the invisible pole.

The plane of the celestial meridian, which passes through the points of intersection between the equator and the horizon and the corresponding circle, may be represented in the figure by the same line $PP'$ which represents the axis of revolution. Now, this plane bisects all the parallels, and consequently more than one half of those that are on the side of the upper pole $P$, and less than one half of those that are on the side of the other pole $P'$ can be seen above the horizon. It follows, therefore, that each point of any of the parallels on the side of the upper pole, remains above the horizon a longer time than below it, during the uniform diurnal revolution of the sphere; and, vice versa, each point of the parallel on the side of the lower pole, remains a shorter time above than below the horizon during the same revolution; nay, more, some parallels on the side of the upper pole, have their points perpetually visible above the horizon; and a corresponding number of parallels on the opposite side have their points remaining permanently invisible below the horizon. In fact, all the points of a parallel are equally distant from the poles; hence all the parallels, whose distance from the pole is equal to, or less than, the altitude of the pole will always remain with all their points visible above the horizon, and a corresponding number on the other side will always remain below it. The parallel $aa'$, the distance of whose points from the pole is equal to the polar altitude, will, evidently, during one revolution, touch the horizon with all its points, and will immediately ascend again. The corresponding parallel $bb'$ will touch the plane of the horizon with all its points during one revolution; but will immediately descend below it again. The points of the other parallels, which are called parallels of perpetual apparition, or of perpetual occultation, stand either totally above or totally below the plane of the horizon. The stars which are situated on these circles are called *circum-polar stars.* Let us now come to the apparent annual motion of the sun for the different cases of the oblique sphere.

21. *Apparent annual motion of the sun: First, for the inhabitants of the tropics*—Let us first suppose the spectator on a tropic; for him the zenith coincides with one of the points of the corresponding celestial tropic. Hence, since the sun, during its annual motion, touches once, and only once, each one of the tropics; our spectator will once a year have the sun passing through his zenith point during its diurnal revolution. During the remainder of the year, the sun will always appear on the side of the equator, and, as long as it remains in the hemisphere of the visible pole, the days will be longer than the nights; when it passes to the other hemisphere, the days will be shorter than the nights.

*Second: For the inhabitants of the polar circles*—Let the spectator be on the terrestrial polar circle. His zenith point coincides with all the points of the corresponding celestial parallels. In regard to the same spectator, one of the celestial tropics is the first parallel of perpetual apparition, and the other, the first of perpetual occultation. For the inhabitants, therefore, of the terrestrial polar circles, the sun, once in the year, remains, during one diurnal revolution, above the horizon, describing the parallel which touches the same horizon: and once in the year the sun, during one diurnal revolution, remains below the horizon. During the rest of the year the days are longer than the nights, as long as the sun remains in the hemisphere of the upper pole, and the days are shorter than the nights when the sun passes to the other hemisphere. The reason of it, mentioned above, is applicable to all the cases of the oblique sphere.

*Third: For the inhabitants of the zone between the equator and either tropic*—The parallel of the celestial sphere, which, during each diurnal revolution, passes with all its points successively through the zenith of a spectator situated between the equator and the tropic, necessarily cuts the ecliptic in two points; hence twice, during its annual motion, the sun passes through the zenith of such a spectator. During the rest of the year, between the successive transitions through the zenith point, the sun will daily intersect the meridian between the zenith and the upper pole, or between the zenith and the opposite side. The time, however, during which the crossing of the meridian takes place on the side of the pole contains a less number of diurnal revolutions than that during which the *transit*, through the meridian, takes place on the other side.

*Fourth: For the inhabitants between the tropics and the polar circles*—It is now easy to see that the inhabitants between the tropics and the polar circles can never see the sun passing through the zenith, which is necessarily between the same circles of the celestial sphere; and for them, the sun, during the whole year, crosses the meridian between the zenith and the horizon, on the side opposite to the visible pole.

*Fifth: For the inhabitants between the polar circles and the poles*—The last case is that of the inhabitants of the extreme zones between the polar circles and the poles. For such, the first circle of permanent appearance is nearer to the equator than the tropic; hence the sun, during an interval embracing a greater or less number of diurnal revolutions, will appear permanently above the horizon; and for an equal number of revolutions will not appear at all.

22. *Division of the terrestrial surface according to the different appearances of the annual motion of the sun*.—The different apparent motion of the sun from different points of the terrestrial surface, has very naturally suggested the idea of dividing the same surface into a number of zones. One contained between the tropics, which on account of the high temperature prevailing on it, is called the *Torrid Zone;* two, from each pole to the corresponding polar circle, which on account of their intense cold are called *Glacial*, or *Frigid Zones;* the two remaining sections between the tropics and the polar circles are the *Temperate Zones*.

To this general and obvious division has been added a secondary division of smaller zones from the equator to the polar circles, and another subdivision has been adopted, of parallel zones from the polar circles to the poles. The zones of the first of these two series are called *climates of half an hour;* those of the latter, *climates of a month*. The reason of this appellation is found in the fact that the longest and shortest days of the year for any of the zones of the first subdivision differ half an hour from the longest and shortest day of the preceding, and of the succeeding zone; and with regard to the latter subdivision, the zones are called climates of a month, because the interval of time in which the sun remains permanently above and permanently below the horizon for any of them, differs one month from that of the preceding, and of the following zone. It follows, therefore, that the climates of half an hour are twenty-four, and those of a month six in number.

## ARTICLE IV.

### DIURNAL ROTATION AND ANNUAL MOTION OF THE EARTH.

23. *The apparent diurnal rotation of the celestial sphere is a consequence of the real rotation of the earth*—

The rotary motion of the celestial sphere about one of the diameters may be explained by the reality of this motion, or by the rotation of the terrestrial globe about the same axis, but in a direction opposite to the apparent rotation of the firmament, or also by the rotation of both spheres, so combined as to present to us the apparent motion of the celestial sphere. To decide this point, it is enough to ascertain whether and how the terrestrial globe turns about one of its diameters.

The simple argument of congruity based on the immense disproportion of the two spheres, and on the circumstance of the innumerable bodies scattered in the immensity of the space below the firmament, compels us to admit the stationary condition of the celestial sphere and the rotation of the earth about the axis of the world. But there is, moreover, the analogy of the solar and lunar globes, and of the planets, whose revolution about their respective axes, induces us to admit the same fact with regard to the earth. The congruity however, and the analogy do not demonstrate rigorously the rotation of the earth; but that which is not done by congruity and analogy, is inferred from direct observation in various ways. One of these modes is by the fall of bodies from a considerable height, for example, from the summit of the Tower of Pisa, which is the well known experiment of Galileo, directed, however, by him, to a different purpose. In fact, let $s$ (Fig. 9), represent the summit of a high tower, and $g$ the point where the plumb line from $s$ reaches the ground. If the globe turns about one of its diameters, the motion of $s$ at a greater distance than $g$ from the centre must be greater than that of $g$ and greater in a measurable ratio. So that, if while a body falls from $s$, the point $g$ describes the space $gf$, the point $s$ or a body at $s$ would describe a space $sh > gf$. Hence the body falling from $s$ is acted upon by two forces, one in the direction of the vertical $sg$, the other in that of $sh$, by which it is made to describe an arc having $sk$ for its chord and reaching $k$ when $g$ has arrived at $f$. But $f$ is still the point met by the plumb line let fall from the summit of the tower to the ground. Hence, if the earth has a rotary motion, the two points $f$ and $h$ cannot coincide. Now this is the case, and the measure of the distance of these two points shows, moreover, that the rotary motion of the earth is exactly that which corresponds to the opposite apparent rotation of the celestial sphere; the celestial sphere, therefore, is stationary, and the earth alone turns about the axis.

Another proof of the rotation of the earth is given by the diminution of the force of gravity from the poles to the equator. This diminution results from a force acting in opposition to the force of gravity, and is nothing but the centrifugal force. It is of such a nature as to correspond with the same rate of rotary motion which the earth must have, if the celestial sphere be stationary.

Another ingenious illustration has been recently found by Focault, in the apparent motion of the pendulum's plane of oscillation; it proves very satisfactorily the rotation of the earth. To these we may add the proof deduced from the spheroidal shape of our globe. A liquid sphere, when turned about one of its diameters, takes the spheroidal form; and that the original condition of our globe was that of a liquid mass is rendered manifest by geological evidence. *

24. *Annual motion of the earth*—As the phenomenon of the apparent rotation of the celestial sphere is the effect of the real rotary motion of the earth about the axis of the world, so the apparent annual motion of the sun is the effect of the real annual motion of the earth about the sun. To conceive how this exchange of motion does not change the apparent effect, it is enough to call to mind any of the numerous and familiar examples in which either the unconsciousness of our own motion causes us to attribute it to objects around us, or the conviction of bodies at rest, which are actually in motion, induces us to admit our own motion, although we are at rest. Let $S$ (Fig. 10) be a luminous point placed in the centre of a vast sphere, and conceive a spectator unconscious of his motion moving along the arcs $aa'a''$, etc. of a great circle belonging to a smaller sphere concentric to the first, such a spectator will refer the luminous point $S$ to the points $b\ b'\ b''$, etc. of the large sphere on the same plane on which he travels, and since his own motion proceeds gradually from $a$ to $a'$, $a''$, and so on, so will

* Some modern scientists hesitate to admit the original liquid state of the earth, but we adhere to the evidence of facts.

the luminous points referred to the opposite side, gradually pass from $b$ to $b'$, $b''$, etc. The condition, therefore, of the moving spectator referring the point $S$ to the outer sphere is the same as that of another spectator, who, being placed in the centre of the sphere, would see a luminous point moving really from $b$ to $b'$, $b''$, etc. This illustration explains how the annual motion of the sun may be only apparent, whilst the real motion on which the apparent depends, is that of the earth. But the phenomenon alone of the apparent annual motion of the sun decides neither for the motion of the one, nor for that of the other. The arguments of congruity and analogy decide for the the motion of the earth, incomparably smaller than the sun, and much smaller also than several planets, which, with periodical motions, circulate about the sun, as about a centre. The main argument, however, is taken from the law of universal gravitation, from which the annual motion of the earth about the sun is inferred as a necessary corollary, The aberration of the stars is also another invincible proof of the same fact, but it is enough for the present to have mentioned this source of proof. Admitting, therefore, the well demonstrated fact of the annual motion of the earth about the sun, we know that while, during one year, it describes an *orbit* around the sun, it revolves daily about an axis which constantly preserves the same inclination. Fig. 11 may give some idea of this combined motion. Let the centre of the small globe, by which the earth is represented, describe the circle in the direction of the arrows, and while this centre passes from 1 to 2, to 3 etc., let the globe itself turn about the axis $PP'$, which forms an invariable angle with the plane of the orbit. By the revolution of the globe about its axis, the celestial sphere will, to a spectator on the surface of the globe, appear to revolve in an opposite direction. Owing to the immense magnitude of the celestial sphere, and the corresponding distance of the stars, the change of place of the globe has no perceptible effect on any apparent change of the celestial sphere, nor on the relative distances of the stars. Everything consequently concerning the apparent rotation of the stellar universe about the axis of the world, will be the same as if the globe $E$ of the earth would remain permanently in the centre of the celestial sphere. The same is not the case with regard to the sun, which on account of its being in the centre of the circle described by the earth, must necessarily change its apparent position relatively to the different points of the celestial sphere, but this motion as we have seen already, is the same as that which would be observed by the spectator on the surface of the earth, if the earth was in the centre $S$ and the sun would describe the orbit. Whether, therefore, we suppose the earth in the centre of the sphere, revolving about its immovable axis, and the sun describing the orbit, or the sun in the centre of the celestial sphere and the earth revolving about its axis, which moves with a motion parallel to itself, while the centre of the earth describes the orbit; all the phenomena mentioned in the preceding article will take place exactly in the same manner,

25. *Elliptical form of the terrestrial orbit*—The plane of the orbit of the earth, which is the plane of the ecliptic, produces, by its intersection with the celestial sphere, a great circle of the same sphere; hence

the apparent motion of the sun on a great circle. The orbit of the earth, however, may be different from the circular line. Suppose the orbit of the earth to have the form represented in (Fig. 12) by the curved line $EE'E''$... The sun, being in the central part of this orbit, will be referred to different points of the firmament, moving apparently on a great circle from $m$ to $m'$, to $m''$, etc; as the earth moves from $E$ to $E'$, to $E''$, etc., describing an angular orbit on the plane of the great circle $mm'm''$... The apparent circular motion of the sun, therefore, is not an indication of a similar form of the terrestrial orbit. An optical principle affords us the means of determining the character of the orbit.

In Fig. 13 let the straight lines $DD$, $D'D'$, be of equal length, parallel to each other, and so situated that the perpendicular $Ot$, let fall from $O$ on $D'D'$, bisects both parallels. Suppose that from the same point $O$ the visual rays $OD$, $OD$ pass through the extreme points of $DD$, and that two more visual rays from the same point $O$ pass through the extreme points of $D'D'$. These two latter visual rays intersect the parallel $DD$ at the points $d$, $d$; and the angle under which $D'D'$ is seen from $O$ is the same as that under which the segments $dd$ of the nearest parallel to $O$ is seen. To a person at $O$, then, the apparent magnitude of $D'D'$ compared with that of $DD$, is the same as $dd$ to $DD$. Now, $dd : DD :: Ot : Ot'$. For from the similar triangles $otd$, $ot'D'$, we have, $td : t'D' :: Ot : Ot'$; hence also $dd : D'D' :: Ot : Ot'$ in which $D'D'$ can be changed into its equal $DD$; the apparent magnitude therefore of $DD$ varies inversely as the distance from the point of vision.

Now, the sun has a visible diameter, and its apparent magnitude can be accurately measured. Were the orbit of the earth a circle having the centre of the sun for its own centre, the apparent magnitude of the solar diameter would be always the same, but, since the distance of the earth from the sun is variable, the apparent magnitude of the diameter is also variable, and from the increase and diminution of this apparent magnitude, we may at once infer the diminution and increase of the distance of the earth from the sun. Let $E$ (Fig. 14), be the position of the earth when a series of diurnal observations is commenced in order to measure the apparent diameter of the sun; and suppose that in the succeeding days the apparent diameter increases in magnitude until the earth reaches the point $E'$, beyond which the diameter begins to diminish. It will be observed to diminish in the same, but an inverted order, until it reaches $E''$, equally distant as $E$ from $E'$. If the earth continue to move, the sun's diameter will appear smaller and smaller, until the earth reaches the point $E'''$ diametrically opposite to $E'$ and from that point it will begin to increase in an inverted order. Taking for the unity of measure the distance $E'S$ of the sun, when the apparent diameter reaches the maximum of its magnitude, we may trace an orbit similar to that described by the earth. Thus, let (Fig.15), the straight line $ES$ represent the unity of measure and the distance of the earth from the sun when the diameter has the greatest apparent magnitude. Let $\sigma$ be the point of the celestial sphere to which the sun observed from $E$ is referred; the points $\sigma'$, $\sigma''$, etc., will be those points of the celestial sphere to which the sun's centre will be successively referred, when the earth passes from $E$ to $E'$ to $E''$ and so on. Now, the arcs $\sigma\sigma'$, $\sigma'\sigma''$, which are known from observation, give the measure of the angles $E'SE$, $E'$, $SE''$, etc. Suppose each of these angles to be of one degree, and calling $D$ the diameter of the sun observed from $E$, let the same diameter, observed from $E'$, $E''$, etc. be $D-\delta$, $D-\delta'$, etc, we will obtain the length of $SE'$, of $SE''$, and so on, from the proportions $E'S : 1 :: D : D-\delta$, $E''S : 1 :: D : D-\delta'$, i. e.

$$E'S = \frac{D}{D-\delta}; \quad E''S = \frac{D}{D-\delta'}, etc.$$

The curve which passes through the points $E$, $E'$, $E''$, thus determined, is of the same form as the terrestrial orbit. Now, this curve is found to be an ellipse; for, supposing $\sigma\sigma'\sigma'$ to be a continuation of this curve, taking the point $S'$ in the straight line $ES\sigma$, equally distant from $\sigma$ as $S$ is from $E$, and from $S$ and $S'$ drawing straight lines to any point of the curve, the sum of these lines will be found to be always equal to $E\sigma$. Hence the terrestrial orbit is an ellipse, one of whose foci lies in the centre of the sun.

## ARTICLE V.

### ROTATION AND DIMENSIONS OF THE SUN.

26. *Spherical form of the sun*—From the fact that the solar disk always retains a circular form, we infer the spherical shape of the solar globe. It may indeed happen that a disk or a cylinder or any body, of which one of the sections of the outer surface is circular, appears invariably circular to a spectator who moves around it at a proportionate distance, provided the vis-

ual ray always falls perpendicular on the plane of that circular section. Rigorously speaking, therefore, the fact of the solar disk retaining invariably the circular form is not a certain proof of the rotundity of the sun. The difficulty, however, of giving to the sun (in the supposition of its shape being other than spherical) a motion so regulated as always to present to us the appearance of a circularly terminated body, compels us to prefer the simpler inference of the sphericity of the sun.

Fortunately, the surface of the sun is not uniformly illuminated, but frequently presents some points more brilliant than the rest, called *faculæ*, and others dark, called *spots*. Now, by observing these points, especially the spots, the sphericity of the sun may be rigorously demonstrated. Nay, more, it may be found whether the sun has no motion about any of the diameters, or is movable about one of them as about an axis; and how this axis is inclined to the plane of the ecliptic; and what is the period of the sun's revolution about it. To show, in a speedy and elementary way, how from the observations of the solar spots the rotation of the sun is inferred. Let (Fig. 16) $EC$ represent the terrestrial orbit and $S$ the centre of the sun on the plane of the same orbit. Any section of the solar body made by a plane, in the supposition of its being spherical, is a circular section, and seen from any point of the terrestrial orbit must appear either like an ellipse, more or less oblong, or like a straight line, or, finally, like a circle. In the last case it either coincides with the solar limb or is concentric to it; suppose, besides, that the sun revolves with uniform rotary motion about the axis $AA'$ inclined to the plane of the ecliptic, each one of its points will describe a circle, which, from any point of the terrestrial orbit, will have the appearance of some of the circular sections just mentioned. But the planes of these circles will all be parallel, and the circles will, from some point of the orbit appear elliptical of a form more or less oblongated, from others, rectilinear, but from none, circular; because for this, it is necessary that the visual ray should fall perpendicularly on the planes of these circles, which cannot happen except when the visual ray coincides with the axis of revolution. Now, supposing this axis $AA'$ inclined to the plane of the ecliptic, evidently none of the points of the terrestrial orbit can be met by it, and consequently there is no point of the orbit from which the motion of the various points of the solar surface may, in our supposition, appear circular. We have said, that from some points of the terrestrial orbit, the track of the various points of the solar surface will appear rectilinear. In proof of this it is to be remarked that the planes of the circles described by these points intersecting the plane of the ecliptic, intersect likewise the orbit of the earth. Now, the points of the terrestrial orbit, where these intersections take place, coincide with the planes of the circles, and consequently a spectator situated on them can see them only as straight lines. We may here observe that the dimensions of the sun, taken comparatively to those of the terrestrial orbit, being small, the portions of the terrestrial orbit from which the circles will appear rectilinear are very limited and, in the vicinity of two points diametrically opposite to each other, corresponding to the intersections of the same orbit with the solar *equator*. At a certain distance on either side of these two intersections, the appearance of the same circle will be elliptical; but the planes of the circles being seen on opposite sides from the points lateral to the intersections, the curvature of the ellipse, seen from one side, will be inverted when compared to that seen from the other.

Although the solar spots are variable in magnitude, number and shape, and remain on the surface only temporarily, still they preserve the same place on the regions where they are formed; hence they may be taken as points of the surface of the sun, and must, with their motion, present the phases just described, if the sun has a spherical form and actually revolves about one of its diameters, inclined to the plane of the ecliptic. Now, this is precisely the fact which has been constantly and uniformly observed from the time of Fr. Scheiner 1627 (who was the first to observe the phenomenon with a telescope, and to classify numerous observations in regard to it), and of Galileo, to the present day. Hence it is demonstrated that the solar mass has a globular form revolving about one of its diameters, and this diameter is inclined to the plane of the ecliptic.

It is a somewhat more complicated task to determine the position of the axis relatively to the plane of the ecliptic and the period during which the solar globe accomplishes one revolution; because, although when the orbit of the spots on the disk of the sun appears rectilinear, the position of the axis is at right angles to that rectilinear orbit, yet, since the plane of the ecliptic is invisible in the firmament, the position of this axis cannot be immediately referred to it. And the period of revolution is modified by the earth's own motion. These difficulties, however, are easily overcome, and from the numerous observations and calculations made on the subject, it is found that the plane of the solar equator has an inclination of about 7° 45′ to the plane of the ecliptic, and consequently the inclination of the axis to the same plane is an angle of about 82° 15′; it has been found, likewise, that the period of the rotation of the sun about its axis is of nearly twenty-seven days and six hours.

*The solar spots*—The solar spots which have offered an easy method of determining the rotation of the globe to which they seem to be inherent, have, since the discovery of the telescope, and the improvements in modern instruments, presented such qualities as to excite the curiosity and stimulate the investigations of scientists. We may first observe that besides being periodical, and variable in regard to the duration of this period, the spots are generally confined to two zones on both sides of the solar equator, which extend from this circle between thirty and forty degrees. Some occasionally, but very rarely, appear beyond these limits. The number and magnitude of these spots and their form are extremely various; there have been occasions in which twenty and thirty clusters of them have been numbered; at other times, on the contrary, even for years, scarcely any prominent one has made its appearance, and not many of the less perceptible ones. It seems that this succession of multiplicity and absence of spots takes place regularly in the interval of ten years. When the spot is in the beginning of its formation, it frequently appears like a hole of uniform darkness; this gradually becomes larger and the central part, which preserves the same darkness, begins to appear encircled by a luminous border or *Penumbra*, whose contour resembles that of the dark part or *nucleus*. But while the spot is progressing in its phases, the form of its nucleus and penumbra undergoes rapid and remarkable changes. The nucleus frequently is, or seems to be, broken into fragments, which gradually diminish in size; the penumbra, on the contrary, expands its dimensions, but it increases in brilliancy and its limits become undefined until the fragments of the nucleus and the penumbra totally disappear.

With telescopes of great power the penumbra, which with ordinary instruments presents a light of uniform intensity, appears radiated and as if formed by streams converging towards the centre, and it has been found that an apparent fracture of the nucleus is produced by the crossing of these streams over it. Occasionally, when several streams intersect each other, the light acquires great brilliancy; frequently, too, the nucleus is not of uniform darkness, but some traces of light are visible on it. These changes manifest the fluid condition of the photosphere in a state of agitation. This opinion of the light of the sun being that of an ocean of fire which covers the solid globe, is, we may say, generally admitted by ancient and modern astronomers, from the time in which telescopic observations commenced; they do not equally agree in their explanation of the mode in which solar spots are formed. The opinion most commonly adopted is that the spots are cavities formed by a vortical motion of the liquid photosphere, which allow us to see either the nucleus of the sun or some other less luminous substance, which occupies the deeper and ordinarily central portion of the vortex. Many facts favor this opinion; among others, the observation of a remarkable spot, made on the 6th of May, 1857, by F. Secchi, in Rome. The spot, which was observed also in Christiania, by Prof. Fearnley, under the same circumstances, presented all the characters of a huge whirlpool or vortex. The filaments or streams of light which formed the penumbra, were spirally arranged, and the whole luminous mass about the opening of the vortex was manifestly moving with great rapidity. Fr. Secchi, in his voluminous and learned work on the sun, has treated this subject at great length, showing, with numerous facts, how the so-called protuberances, which seem to be jets of gaseous incandescent matter, are connected with the formation of these spots. We shall see later on that these jets are frequently of great magnitude as also are the spots which give rise to them.

We may here add that observations on the luminous surface of the sun have convinced astronomers that the sun, besides this luminous envelope, is covered also by a transparent atmosphere. The ordinary facts which prove the existence of this atmosphere are the absorption of luminous rays, as also those of calorific rays, towards the borders of the solar sphere; but the existence of this atmosphere is rendered clearly manifest on the occurrence of total eclipses.

*Dimensions of the sun*—Let us now see how astronomical observations may lead us to find the dimensions of the sun. Let $S$ (Fig. 17), represent the centre of the sun, and $T$ the earth. Suppose two visual rays, $mS$, $nS$, drawn from two different points of the terrestrial surface to $S$. If we know the angles which these two rays form with $mn$,—the chord which unites these two points,—and the length of the chord, the length of $Sm$, $Sn$, and the distance of the sun from the earth will be known. Now, the dimensions of space between us and the sun, considered relatively to the radius of the earth, are such that this latter may be neglected without significant error. Thus $Sm$ and $Sn$ may be taken as equal to one another and for the resolution of the triangle, it will be enough to know the length of the chord $mn$, and the angle at $S$ called *angle of parallax*, or simply the *parallax*. Suppose the chord to be determined, the parallax is obtained by taking on the celestial sphere the arc of a great circle, intervening between the points to which the centre of the sun is referred by the observers at $m$ and at $n$; for, owing to the infinite distance of the celestial sphere from us, this arc measured from the earth is the same one which measures the angle $tSt'$ formed by the visual rays at the sun. Practical astronomy supplies the means to determine with precision the points of the celestial sphere to which the centre of the sun is referred when observed, as also the precise distance of two observers on different parts of the globe; and it supplies, besides, the means to have the observations made at the same time. One observer alone, however, can obtain the same result, by referring the centre of the sun to the celestial sphere, i. e. by observing the apparent position of the solar centre at different times of the day. In fact by the rotation of the earth the observer successively directs his visual rays to the sun from different places, just as different observers situated on the same parallel would do. In this case it is easy to determine the length of the chord of the arc described. But while the observer passes from *m* to *n*, the whole terrestrial globe is advancing in its orbit, so that the second position results from the rotary motion and from the motion of translation: the effect of the latter, however, can be separated from that of the former, and the observations are thus reduced to the case of those of two observers at a distance from each other, and simultaneously directing their visual rays to the sun.

From similar observations, the mean distance of the sun from us has been determined and found to be 92 millions of miles. Knowing the distance of the sun from the earth, the resolution of another triangle gives us the length of the diameter of the sun. Thus let *ac* (Fig. 18.), be this diameter and *E* any point of the surface of the earth; the sides *aE*, *cE*, of the triangle *acE*, are each 92 millions of miles; the angle *aEc* included by them, when measured is for the mean distance of the sun 0° 32′. Resolving the triangles we find the diameter of the sun one hundred and eight times that of the earth, or, in round numbers, 860,000 geographical miles in length. Taking for the mean diameter of the earth 7,900 miles, the volume of the sun compared to that of the earth is numerically given by the cube of 860,000 compared to that of 7,900; in other words, the volume of the sun is about 1,300,000 times that of the earth.

# THE MOON.

The moon is the other celestial body which presents to the naked eye a disk with a measurable diameter. Apparently the diameter of the moon does not differ much from that of the sun, although their real magnitudes differ immensely. But on account of the apparent magnitude of this body and of the close connection between it and the earth, the attention of the observer is naturally directed to the moon after the observations of the sun.

29. *Diurnal revolution of the moon and its periodical motion about the earth*—The moon, like every other celestial body, partakes of the apparent diurnal revolution of the celestial sphere. But like the sun she has besides her own motion eastward, more rapid than that of the sun, because while the sun describes the ecliptic during one year, the moon describes over twelve times another great circle of the sphere. A second remarkable difference between the annual motion of the sun and the similar periodical motion of the moon is, that the annual motion of the sun is only apparent, the monthly motion of the moon is real. Suppose $S$ (Fig. 19), to be the centre of the sun about which the earth circulates, describing the orbit $EE'E''\ldots$, and let the moon be at $m$ on the same side of the celestial sphere on which the sun is visible when the earth is at $E$, about two weeks after passing gradually from $m$ to $p$, $p'$, etc., and while the earth describes the portion $EE'$ of her orbit, she will appear

at $m'$ on the side of the firmament opposite to that of the sun, which evidently can be the result only of the moon's proper motion about the earth. The almost invariable apparent magnitude of the lunar diameter shows besides that the orbit of the moon about the earth is nearly circular, the earth being in its centre. The distance of the moon from the centre of the earth and hér real dimensions are found in the same manner as the distance and dimensions of the sun. It has been found that the distance of the moon from the centre of our globe is about sixty times the radius of the earth, or 237.000 miles; and her diameter about one-fourth that of the earth, or 1900 geographical miles; therefore her volume is the sixty-fourth part of that of the earth.

30. *Phases of the moon*—The spherical shape of the moon, her motion about the earth, her opacity and the light which she receives from the sun and transmits to us, explain the well known phenomenon of her phases. The sphericity of the moon allows but one half of it to receive the solar rays and thus to become illuminated, a great circle of the globe dividing the luminous from the dark part. Now, the hemisphere of the moon on the side of the earth commonly embraces more or less of the illuminated part; when the moon is directly between us and the sun, the hemisphere turned towards us is the one opposite to that illuminated, and it is then only when the moon passes to the opposite side of her orbit (and when, consequently, the earth is between the moon and the sun) that the whole hemisphere which is illuminated by the sun is visible from the earth. Let (Fig. 20), 1, 2, 3, etc., represent different positions of the moon rela-

tively to the earth at *E* during her periodical revolution about the terrestrial globe. The sun is supposed to be far above, in the direction of the arrow, so that when the moon is at 1, both the sun and the moon are in a straight line on the same side of the earth; the plane *ab* perpendicular to the visual ray from the earth divides not only the hemisphere turned towards the earth from the other, but also the illuminated part of the lunar globe from the dark portion which is turned to the earth. In position 3, 90° from 1, the plane *ab* is perpendicular to that of the circle which divides the dark from the luminous section of the moon, and therefore the visual ray from the earth coincides with the plane of this circle, which, from the earth, appears like a straight line, or a diameter of the lunar disk separating the illuminated from the dark part, as represented in $\alpha$. In position 2 the plane *ab* bisects obliquely the circle which divides the luminous from the dark portion of the lunar globe, and accordingly the visual ray from the earth falls obliquely on its plane. The boundary, therefore, between the illuminated and dark part of the moon has in this case the appearance of an elliptical form, which, together with the circular limit of the lunar disk, gives to the luminous part of the moon the well known form of a crescent, as represented in $\beta$. In position 4, in the second quadrant of the orbit, between 90° and 180° from 1, the circular limit assumes the form of a semi-ellipse; but in this case the greater part of the lunar hemisphere which is turned towards the earth is illuminated, as represented in $\gamma$. When the moon passes to position 5, in direct opposition to that of the sun, then, the same hemisphere being turned to the sun and to the earth, the whole disk appears illuminated. In position 6, of the third quadrant, the illuminated part of the lunar disk assumes again the *gibbous* form of position 4, and in position 7, where the last quadrant commences, a diameter of the disk separates the dark from the illuminated part of the globe as in position 3. Finally, in position 8 the luminous section is similar to that of position 2. In all these positions the semi-circular edge of the luminous part of the moon is invariably turned towards the sun. In position 1, the moon is said to be in *conjunction* with the sun ; the phase corresponding to position 3 marks the end of the *first quarter ;* the phase corresponding to position 5, marks the end of the *second quarter*, and is vulgarly called full moon ; the phase of position 7 marks the end of the *third quarter*, and position 1 corresponds to the end of the *last quarter* and to the begining of a new lunation. The period which elapses from one conjunction to any position of the moon in her orbit until it reaches the next conjunction is generally called the *age of the moon.*

31. *Plane of the lunar orbit.—Its nodes.—Eclipses*—If the plane of the lunar orbit coincided with that of the ecliptic, at every conjunction the disk of the moon would pass over that of the sun, and at every opposition, or full moon, the earth would be between the sun and the moon, so that the centres of the three bodies would be found in the same straight line. In this case the moon would hide the sun from the earth in every conjunction and consequently every conjunction would be attended by an *eclipse* of the sun ; and in every opposition the moon would be eclipsed. Now we know well that this is not the case ; therefore the plane of the orbit of the moon does not coincide

with the plane of the ecliptic. But since we see also that at every full moon the lunar disk presents to us a complete circular form we must infer that the inclination of the plane of the lunar orbit to that of the ecliptic approaches to coincidence. In fact, it is found by observations that the angle which the plane of the lunar orbit forms with that of the ecliptic is an angle of 5° 9′. The orbit of the moon referred to the firmament is, as we have said, a great circle of the celestial sphere which may be represented (Fig. 21), by $lnl'n'$, as $encn'$, another great circle of the same sphere (the plane of which forms with that of $ll'$ an angle of 5° 9′), may represent the ecliptic. The points of intersection $n$ and $n'$ of these two circles are called the *nodes*, and the diameter $nn'$ the *line of the nodes*; the point through which the moon passes when entering the hemisphere to the north of the ecliptic is called the *ascending*, and the other the *descending node*. It has been observed that the line of the nodes does not remain in the same position, but moves gradually until it describes an entire circle in the space of about eighteen years and six months; i. e., while the moon describes her own orbit, in the direction of the arrows, the plane of the orbit also moves with a retrograde motion and consequently the nodes also are changed. This movement of the lunar orbit and consequently of the lines of the nodes, can be conceived by supposing the axis $Ep$ of the lunar orbit to describe a conical surface about the axis $EP$ of the ecliptic. The precession of the equinoxes, which is the analogous phenomenon observable between the terrestrial orbit and the equator, can be conceived in the same manner.

The period, or age of the moon, in which she crosses the nodes is variable, as may be easily inferred from the fact that the line of the nodes changes constantly the angle which it forms with the radius of the terrestrial orbit. For suppose *EEE* (Fig. 22), to represent a segment of the terrestrial orbit. and *nn'* the line of the nodes. Although this line is movable about the centre of the earth *E*, the angular motion of the radius vector *SE* of the terrestrial orbit is much more rapid than that of *nn'*. Now the conjunctions and oppositions of the moon, or, as they are called, the *Syzygies*, take place on planes passing through the radius *SE* and perpendicular to the plane of the ecliptic; hence the age at which the moon crosses the nodes will be greater or less according as the angle which the line *nn'* of the nodes forms with the radius vector of the terrestrial orbit, is greater or smaller. When the line of the nodes coincides with, or is in the vicinity of the radius, the centre of the sun, the earth and the moon will be in the same or about the same straight line, when the last body crosses the nodes, and then consequently an eclipse will take place; viz., when the moon is in conjunction, a solar, and when in opposition, a lunar eclipse. Let us examine the case of the solar eclipse.

The disks of the sun and moon, though nearly equal are not exactly so, each being subject to variations in magnitude on account of their variable distances from the earth, but these variations are confined within narrow limits. It happens, however, that the disk of the moon is apparently sometimes greater and sometimes less than that of the sun. Let *R* be the apparent radius of the sun and *r* that of the moon, and let *nc* (Fig. 23), be a portion of the ecliptic, *nl* a portion of the lunar orbit, $En$ the line of the nodes and $mSE$ the plane in which the conjunction takes place. Now the distance $mS$ is either equal to or greater or less than the sum of the radii $R$, $r$. In the first of these suppositions, one disk will be altogether outside of the other as represented in No. I annexed to the figure. If the distance between the centres be equal to the sum of the two semi-diameters, then the two disks will touch each other, neither hiding a part of the other; this position, shown in No. II, is called *external contact.* If the distance between the centres be less than the sum of two semi-diameters, then one of the disks will necessarily encroach upon the other and a partial eclipse will take place; this case is shown in No. III, and the breadth of the part of the solar disk $S$ obscured by $m$ is equal to the difference between the sum of the semi-diameters and the distance between the centres. If the distance between the centres of the two disks be equal to the difference of the semi-diameters, then one disk will be within the other, just touching it, as shown in No. IV. This position of the disks is called that of *internal contact;* and the case as represented by the figure manifestly supposes that the diameter of the interposed disk of the moon is less than that of the sun. In the same supposition, if the distance between the centres of the disks be less than the difference between their semi-diameters, the interposed disk will be within the other, leaving a ring of illuminated surface, as shown in No. V. This phenomenon is called *annular eclipse.* Finally, if the interposed disk $m$ of the moon be greater than the disk $S$ of the sun, and at the same time the distance between the centres less than the difference of the semi-diameters, the interposed disk will completely cover the other, as shown in No. VI. and a total eclipse will take place. If in this case the centres of the two disks coincide, the eclipse is said to be total and central. The magnitude of the eclipse in all cases is expressed by the so called *digits*, each digit being the twelfth part of the diameter of the body eclipsed.

These are all the different appearances of solar eclipses, of which, whenever eclipses take place, one or more are visible from different parts of the surface of our globe. To see how this happens it is necessary for us to resume the subject from a different point of view. The form of the shadow produced by the moon as well as that produced by the earth is conical, and consequently diminishes continually the further it recedes from the globe. For let *ab* (Fig. 24), represent the diameter of the sun and *no* the diameter of the moon, both perpendicular to and on the same plane with the line *Smv* which unites the centres of the globes. Join *a* with *n* and *b* with *o*, which produced will meet somewhere in *v* along the line *Sm*: conceive now the triangle *avb* to be turned around the line *Sv* as about an axis; the surface produced by this revolution is that of a cone having for base the solar disk, for axis the line which joins the centres of the moon and of the sun, and for vertex the point *v* where the luminous rays of the extreme solar limb meet after having grazed the extreme limb of the moon. None of the points therefore of the cone *nov* receive light from the sun, and it is consequently a cone of shadow and for any point in it the interposed disk of the moon is apparently larger than that of the sun and covers it totally. Draw now from the extremities *a* and *b* of the diameter *ab*, *bnp*, *aoq*, passing through the opposite extremities of the diameter *no* of the moon; the two lines will meet in *f* somewhere along the axis *Sm*, and conceiving the plane *abfpq* revolved about this axis, a double cone will be produced, the common vertex being in *f*. It is manifest from this construction that the sun from any point of the surface of the truncated cone *nopq* would be seen at contact with that of the moon, if the latter were visible, and from any point inside of the truncated cone a greater or less portion of the solar disk will appear covered by that of the moon. Observe that the same truncated cone contains three parts, the cone *nvo* of total shadow, another cone *rvs* opposite to the first and the geometrical solid generated by *nprvn* revolved about the common axis *mt*. From each one of these three sections the sun appears differently covered by the moon, and as for a spectator in the cone of shadow the sun is totally covered, for another in the opposite cone *rvs*, the disk of the moon covers only the central part of the sun, leaving a ring of light around it, because the whole limb of the sun is necessarilly visible from any point inside of that cone; but from the surface of this cone, the limb of the lunar disk will appear at contact with that of the sun, the lunar disk itself remaining totally projected over that of the sun. From any point of the last part of the truncated cone a section only of the disk of the moon laps over that of the sun. We have seen how the combined motion of the moon and sun causes, at times, the lunar disk to cover partly or totally the disk of the sun; in such cases the globe of the earth enters into the truncated cone. If the distance of the surface of the earth or of a portion of the surface of the earth from the moon is less than the length of the axis of the cone of shadow, and the same portion happens to pass through that cone in the various points of that portion, the sun will successively appear totally eclipsed ; and no portion of the surface of the earth can be in the cone of shadow without a larger portion of it being immersed in the rest of the truncated cone or, as it is called, in the *penumbra ;* hence while for one section of the surface of our globe the sun is totally eclipsed, for the larger portion it is only partially eclipsed. It is to be observed, besides, that the portion over which the total eclipse takes place is very small compared with the dimensions of the terrestrial hemisphere, the latter being even considerably larger than the section of the truncated cone of the penumbra in the regions crossed by the earth ; so that when the centre of the earth happens to pass through the axis of the cone, the zone of the earth, which terminates the hemisphere towards the sun, is altogether out of the same cone.

If the distance of the surface of the earth be greater than the length of the conical shadow and a portion of this surface happens to cross the opposite cone *rrs* for the part of the earth in that section, there will be an annular eclipse. When the surface of the earth, either at a greater or less distance from the moon than the length of the cone of shadow, crosses the truncated cone without reaching this shadow or the opposite cone, there is neither a total nor an annular eclipse visible at any part of the surface of the globe. It follows then, from what has been observed, that that line on the surface of the earth which coincides with the surface of the truncated cone, is the line for each point of which the external contact takes place; and the line on the surface of the earth, which coincides with the surface of the cone *rvs* opposite to the cone of shadow is the line for each point of which the internal contact takes place.

The spectacle presented during a total eclipse is always most imposing. Mr. Forbes, who observed in Turin a total eclipse of the sun in 1842, says that those who are ignorant of the true cause of this phenomenon are excusable if they are terrified, as if nature itself were about to be destroyed. It is said that Columbus availed himself of his acquaintance with practical astronomy to predict a solar eclipse; and used the prediction as a means of establishing his authority over the crews of his vessels, who showed indications of mutiny. The darkness attending a total eclipse of the sun renders the brighter stars and planets visible. A sudden fall of temperature is sensible in the air. Vegetables and animals comport themselves as they are wont to do after sunset. Nevertheless, the darkness is different from nocturnal darkness and is attended with a certain indescribable light, which throws upon surrounding objects a faint hue, sometimes reddish and sometimes cadaverously green. Our impressions during the total eclipse which we observed in Denver, July 29th, 1878, were not so surprising. Perhaps because we expected to witness a greater darkness, or because our attention was chiefly given to the beautiful corona surrounding the solar disk, of which we give a drawing at the end of the book.

On the same occasion the absence, we may say, almost total, of prominences confirmed Secchi's opinion that these enormous red jets are connected with the formation of spots on the photosphere, for no spot was discerned on the solar disk.

Total eclipses of the sun have offered to modern astronomers the most favorable opportunities of ascertaining the presence of atmosphere on the solar globe, and something of the physical structure of its surface. The corona, or bright ray of glory, surrounding the dark disk of the moon is observed to be concentric with the moon only at the moment when the latter is concentric with the sun. In other positions of the moon's disk it appears to be concentric with the sun. This would be taken for the effect produced by a solar non-luminous atmosphere extending to a vast height above the luminous coating of the sun and faintly reflecting the sun's light; but the vivid light, especially near the disk, and other phenomena show that this light is an effect of incandescence. Another very remarkable phenomenon, visible during total eclipses of the sun, is the irregular reddish prominences which seem to emanate from the surface of the sun. The attention of astronomers was particularly directed to this fact on the occasion of the eclipse which took place on the 28th of July, 1851. It appears to be generally conceded that these emanations from the sun are gaseous or cloudy masses of extreme tenuity. This inference is established by the fact of their enormous magnitude, as they have been observed even as high as 40,000 miles above the surface of the solar sphere, by their faint degree of illumination and by the circumstance of their being sometimes detached from the limb of the sun.

Eclipses of the sun are frequently attended by those of the moon. The line of the nodes, in the vicinity of which solar and lunar eclipses take place, move only slightly during one revolution of the moon about the earth; when the conjunction of the moon takes place near or on the line of the nodes, the opposition also takes place near the same line, and consequently in or near the conical shadow projected by the earth. The distance of the moon from the earth is nearly one third of the length of the terrestrial conical shadow and consequently the diameter of the section of this shadow at a distance from the earth equal to that of the moon is in the ratio of about 2-3 to 1-4 or the diameter of the shadow is nearly 2 and 2-3 times that of the moon. It is easy to conceive how it happens that when it is about to enter the conical shadow, the surface of the moon is partially and more and more deprived of light; the penumbra, through which it must necessarily pass before it touches the shadow, produces this effect. The observations concerning the shadow and the penumbra which affect the surface of our globe during solar eclipses are manifestly applicable to the surface of the moon when the sun is eclipsed at its surface by the interposition of the earth. It might be expected that the gradual obscuration of the moon would render it impossible to perceive the limits of the shadow and of the penumbra; nevertheless, such is the splendor of the solar light that the narrowed crescent of the sun, to which the part of the moon's surface near the edge of the shadow of the earth is exposed, produces a degree of illumination which contrasts so strongly with the shadow as to render the boundary perfectly distinct. The form of the shadow presents one of the most striking evidences of the rotundity of the earth, being exactly that which one globe would project upon another. When the lunar globe totally enters into the conical shadow it does not disappear but continues to be visible to us by reflecting a faint reddish light. This is the effect of the terrestrial atmosphere which, extending to a considerable height all around the terrestrial globe, presents to the moon a halo of light when the opaque disk of the earth covers that of the sun.

32. *Revolution of the moon about her own axis*—The moon, besides describing an elliptical orbit about the earth in the period of nearly a month, revolves, like the earth, about one of her diameters; but her revolution about this axis is performed in the same time in which she describes her orbit about the earth. This is very well demonstrated by the fact that the lunar globe always presents to us the same hemisphere. Let $E$ (Fig. 25), be the centre of the orbit $mm'm''$ . . ., and suppose the lunar globe to pass from $m$ to $m'$, etc., without revolving about any axis, the same hemisphere would be constantly turned towards the same absolute side of space, and consequently when the moon has passed from $m$ to $m^{iv}$, diametrically opposite to $m$, the hemisphere invisible from $E$ in the first position would be totally visible from the same centre when the moon is at $m^{iv}$; this hemisphere having gradually come in sight by the progress of the moon in her orbit from $m$ to $m^{iv}$, and gradually disappearing when the moon passes from $m^{iv}$ to $m^{v}$, $m^{vi}$, etc. In this supposition the visible hemisphere of the moon would be constantly changed for us. But the fact is that the moon always

presents to us the same disk; hence the moon has a rotatory motion, and such that one revolution is performed during the same time as her periodical revolution about the earth. The same rotatory motion is, moreover, about a diameter perpendicular to the plane of the lunar orbit.

33. *Aspect of the firmament from the moon*—As the rotation of the earth about the axis of the world produces upon us the effect of the opposite rotation of the firmament about the same axis with the same uniform motion and during the same time; so the rotation of the moon about her own axis produces a similar effect, and if the moon were inhabited, observers placed upon it would see the celestial sphere revolving about a diameter coinciding with the axis of revolution of the lunar globe in the period of about a month; and as the motion of translation of the earth about the sun does not change the aspect of the firmament, on account of the immense distance, so also the corresponding motion of the moon, which follows the earth, and the additional motion of the same globe about the earth, can have no effect whatever towards changing the aspect of the firmament and the relative position of the stars. To a spectator, therefore, on the lunar globe the moon would appear to occupy the centre of the universe, as the earth appears to us to do. The inhabitants of one hemisphere of the moon would never see the earth; while those of the other would have it constantly in their firmament and always in the the same position. To those who inhabit the central part of the hemisphere towards us, the earth would appear stationary in the zenith; to those who inhabit places intermediate between the central part and

the edge of the moon's disk, the earth would appear at a fixed and invariable distance from the zenith; to an observer at any of the places which lie at the edge of the lunar disk the earth would appear perpetually in a fixed direction on the horizon. The earth illuminated by the sun would appear to them as the moon does to us; but with a disk having an apparent diameter greater than that of the moon in the ratio of 79 to 21 and an apparent superficial magnitude about fourteen times greater, and it would consequently have a proportionally greater illuminating power. The earth would go through the same phases, and complete the series of them in the same period as that which the succession of the lunar phases embraces; but the corresponding phases would be separated by the interval of half a month. The solar day of the moon corresponding to her period of revolution from conjunction to conjunction, is about 29 and 1-2 days, i. e., the length of days and that of nights on the surface of the moon is of about two weeks duration.

34. *Conformation of the visible hemisphere of the moon*—The structure of the surface of the moon has been a subject of investigation from the time of the discovery of the telescope, and Galileo was the first to find that the surface of the lunar globe is not even or smooth, but quite irregular. The vicinity of this globe to the earth and the highly improved condition of telescopes have enabled modern astronomers to devise Selenographical maps of great perfection. Their discoveries, however, and their maps are necessarily limited to that hemisphere of the moon which is turned towards us, or rather to the four-sevenths of the lunar surface; for the moon is subject to certain

apparent oscillations called *librations*, which, now on one side now on another, present to us a narrow zone of the opposite hemisphere.

The best time, even with a telescope of moderate power, to observe the inequalities of the lunar surface is when it has the form of a crescent; the curve which forms the boundary between the illuminated and the dark hemisphere is found to be rugged and serrated, and brilliantly illuminated points are seen in the dark parts at some distance from it, while dark shadows of considerable length appear to break into the illuminated surface; a clear indication of inequalities similar to those which mountains produce on the surface of the terrestrial globe. More accurate and continued observations show, with the same evidence, that the surface of the visible hemisphere is thickly covered with mountain ranges and masses of various forms, magnitudes and heights in which, however, the prevalence of a circular or crater-like form is conspicuous. There are circular areas varying from 40 to 120 miles in diameter, enclosed by a ring of mountain ridges, mostly continuous, but in some cases intersected at one or more points by vast ravines. The enclosed area is generally a plane on which mountains of less height are often scattered.

35. *Force connecting the moon with the earth, and discovery of universal gravitation*—It is a well known principle of mechanics that curvilinear motion supposes the action of a continual force, or an action equivalent to it. Newton, admitting this principle, undertook to calculate the intensity of such a force with regard to the moon and the cause of its rotation about the earth. To form some idea of the process

of his reasoning and of the happy consequence which has been its result, let us suppose the orbit of the moon to be perfectly circular having the centre of the earth for its own centre, and to be described with perfectly uniform velocity. Since we know the length of the radius of the lunar orbit and the time required by the moon to describe the whole of it, we know, also, what is the portion of this orbit which will be described in one hour, in one minute, or in one second. Now let E (Fig. 26), be the centre of the earth and $mm'$ the portion of the orbit which the moon describes in one minute. On account of its smallness the element $mm'$ may be considered as rectilinear and coinciding with the tangent to the point $m$ of the orbit. If the moon were not acted upon by a force impelling it towards the centre of the earth, the same rectilinear direction would be continued and in the following minute the moon would describe $m'l = mm'$ in the same rectilinear direction. But she describes $m'm''$ deviating from $m'l$ so as to be, at the end of the second minute, at $m''$, at a distance from $E$ equal to the distance of the points $m$ and $m'$ from the same centre; hence a force impels the moon towards the earth; and according to the well known law of the parallelogram of forces, the impulse will be measured by $m'd$, if we measure by $m'l$ the action of the tangential force. $m'm''$ is then the diagonal of the parallelogram $dl$. Hence the moon by the action of the impulse towards the earth during one minute would describe the space $m'd$. If we compare this space $m'd$, with that described by a falling body near the surface of the earth by the free action of the force of gravity we find the latter to be 3600 times $m'd$.

Newton however thought, notwithstanding this difference of effect, that the agent impelling the moon towards the earth is the very same force of gravitation which moves a stone towards the centre of our globe when falling from a distance not far from its own surface. To reconcile the difference of the effect with the identity of the cause it is only necessary to add a circumstance attending the force of gravitation, i. e., the more the body recedes from the centre of attraction, the less is the energy of the same action. For, the principle of action remaining the same and acting equally in every direction the action must diminish in intensity as it increases in extensiveness. Thus, two points of two concentric spheres attracted by the same centre (the power of which reaches both spheres) must be differently influenced by the centre, as the surface over which the same power is applied is different for the two spheres; now the surfaces of the two concentric spheres are as the squares of their radii; hence the point of the remotest sphere shares a less influence from the centre than that of the inner sphere, in a ratio which is inversely as the square of the distance of the two points from the centre. This inference, applied to the case of the moon compared with a stone near the surface of the earth, corresponds perfectly to the fact. We have seen that the space which the moon would describe by the action of the force towards the earth is 1-3600 of that which a body freely acted upon by gravitation near the surface of the earth would describe during the same time; hence the tendency towards the centre of the earth is to the force impelling the body near the surface towards the same centre, in the ratio of 1 to 3600; i. e. in the ratio of 1 : $60^2$. Now the distance of the moon from the centre of the earth is 60 times the terrestrial radius, the distance, therefore, of the moon from the centre of the earth, is 60 times that of a body at the surface of our globe; hence, according to the preceding inference, the force of gravitation at the moon must be to that at the surface of the earth, as $1^2 : 60^2$; i. e., as $1 : 60^2$; which corresponds to the fact.

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# SOLAR SYSTEM.

## ARTICLE I.

### GENERAL AND HISTORICAL VIEW.

A process similar to the preceding led Sir Isaac Newton to the great discovery of universal gravitation, one of the principal physical laws which govern the universe. It was not difficult to pass from the moon, attracted by the terrestrial mass, to the earth attracted by the sun, and from the earth to all the other bodies describing about the sun orbits similar to that of the earth. For, as the moon could not describe her curvilinear orbit without a force impelling her constantly towards the centre of the earth, so the earth and all the other bodies revolving about the sun could not describe their orbits without a similar constant force impelling them towards the centre of the sun. It having been found that the force, impelling the moon towards the earth, resides in the terrestrial mass itself, it was but natural to suppose that the force impelling the planets towards the sun, resided in the solar mass, and would be of the same nature as that of the earth relatively to the moon. To ascertain this it was enough to determine the intensity of the centripetal force for each of the known planets and see if this intensity was inversely as the square of their distance from the sun. This was found to be the fact, and from this fact the general law was deduced, that *bodies attract each other directly as their masses and inversely as the squares of their distances.* The celebrated laws of Kepler were at hand to afford the most convincing proof of the truth of the newly discovered law of universal gravitation, and each one of them was found to be a corollary following necessarily from it. The same law, from the time of its discovery to the present day, has been confirmed by such a number of facts and predictions, that we may confidently assert, that the existence of no physical law has been so triumphantly demonstrated as that of universal gravitation. It is enough to mention the discovery of the planet Neptune, the existence of which has come to our knowledge more by its effects of gravitation than by direct observation ; nay, these effects of the force of gravity exerted by the yet unknown and far removed planet submitted to calculations, enabled Le Verrier to point out the spot where it would be seen, and where in fact it was observed. Thus the same law gives to the so called Copernican system the character of a demonstrated fact.

36. *Ptolomaic and Pythagorean systems*—Coper-

nicus was not the first to admit that the solar system has the sun for its centre. Pythagoras, and the whole Italian school with him, maintained the same doctrine several centuries before the christian era. Ptolomy, with rare ability and with a precision of measurements, which, for the condition of his times, almost surpasses credibility, admitting the earth to be the centre of the universe, devised a system so complete and so perfect that it needs only an inversion to be identical with the Copernican. But the supposed immobility of the earth compelled Ptolomy to introduce into his system a complication which, though well adapted to explain satisfactorily the astronomical phenomena then known, had, by no means, that character inseparable from all the laws of nature, simplicity of principles, attended by fertility and variety of effects. This criterion, probably, was the cause which induced Pythagoras and his followers to adopt their system, and which afterwards induced Copernicus and Galileo to defend it, the later of whom defended it even to excess. But notwithstanding the weighty argument in favor of the Copernican system, drawn from the said criterion, no physical proof could be brought to demonstrate the identity of the system with the reality of the fact prior to the Newtonian discovery.

37. *Kepler's laws*—Kepler, however, by the discovery of his famous laws, so much increased the probability of the Pythagorean system, as to cause it scarcely to differ from certainty. Kepler, a contemporary of Galileo and a disciple of Tycho, availing himself of the numerous and exquisite observations made by his teacher on the planet Mars, found: first,

that the planet describes an elliptical orbit, one of the foci of which is in the sun ; secondly, that the radius vector of this ellipse, being supposed to follow the planet would describe equal areas in equal times. He instantly extended these qualities to the orbits of the other planets, led by a conviction that such must have been the case. Another law was likewise established by the same intuitive genius of Kepler, respecting the ratio between the mean distance of the planets from the sun and the time required by them to describe the whole orbit. These three laws, the accuracy of which has been verified by subsequent observations and calculations, and more yet, by the discovery of the law of universal gravitation, may be briefly enunciated as follows:

I. *The orbit of each planet is an ellipse, one of the foci of which is occupied by the sun.*

II. *The areas described by the radius vectors are proportional to the times.*

III. *The squares of the periodical times of the planets are as the cubes of their mean distances from the sun.*

The solar system, as it was known until the last hundred years, consisted of six planets, which, proceeding outwards from the sun, received the mythological names of *Mercury*, *Venus*, the Earth, or *Tellus*, *Mars*, *Jupiter* and *Saturn*. Sir William Herschel, on the night of March 13, 1781, added a seventh by the discovery of a planet, since called *Uranus*, revolving outside of the orbit of Saturn. On comparing the successive distances of the several planets from the sun, it was observed by Kepler, that a remarkable numerical harmony prevailed among them. Thus, if we begin from Mercury, the nearest planet to the sun, and measure the intervals between planet and planet, proceeding outwards, it will be found that each successive interval is almost exactly double the one before, subject, nevertheless, to a striking exception in the case of the interval between Mars and Jupiter. This deficiency supplied grounds for a conjecture, that a planet was wanting in the system, whose position between Mars and Jupiter would be such as to fill the vacant place in the progression. Towards the close of the last century, Prof. Bode, of Berlin, revived this question, and an association of astronomers was formed to organize and prosecute a course of observations, with the special purpose of searching for the supposed undiscovered member of the solar system.

On the first day of the present century, Prof. Piazzi, then engaged at Palermo in the formation of his catalogue, noticed a small star of about the 7th or 8th magnitude which was not registered in preceding catalogues. On the night of the 2nd of Jan. again observing it, he found that its position, relatively to the surrounding stars, was changed. The object appearing to be invested with a nebulous haze, he took it at first for a comet, and announced it as such to the scientific world. Its orbit, however, being computed by Prof. Gauss, of Göttingen, it was found to have a period of 1652 days, and a mean distance from the sun expressed by 2,735, that of the earth being 1; thus filling with striking precision the vacant place in the series of the planets. *Ceres* was the name given to this new member of the system. Soon after the discovery of Ceres, the planet passing into conjunction, ceased to be visible. In searching for it after it emerged from the sun's rays in March, 1802, Dr. Olbers noticed on the 28th, a small star in the constellation of Virgo, at a place which he had examined in the two preceding months, and where, he knew, no such object was then visible. It appeared as a star of the 7th magnitude. In the course of a few hours, he found its position visibly changed in relation to the surrounding stars. In fine, the object proved to be another planet, bearing a great analogy to Ceres, and what was then totally unprecedented in the system, moving in an orbit at very nearly the same mean distance from the sun, and having therefore nearly the same period. Dr. Olbers called this planet *Pallas*. This circumstance, connected with the minuteness of these two planets, suggested to Olbers the startling hypothesis, that a single planet of the ordinary magnitude, formerly existed at the distance indicated by Bode's analogy ; that it was broken into small fragments of which Ceres and Pallas were two ; and, in fine, that it was very likely that many other fragments, smaller still, were revolving in similar orbits. It was urged in support of this conjecture, that, according to the established laws of mechanics in the case of a catastrophe, as an explosion or a collision, the fragments would necessarily continue to revolve in orbits not differing much in their mean distance from the sun from that of the original planet. Whatever may be said concerning Dr. Olbers' hypothesis, his prediction that other similar small planets, or as they are called *Asteroids*, describing orbits of nearly equal mean distances, has been abundantly fulfilled. But let that which we have said of them, suffice for the present.

Let $S$ be the centre of the sun and of the system to which the sun gives its name. Supposing the orbits of the planets on the same plane, their mutual relative positions will be represented by the Figure 27, in which the sun *S* is the centre or lowest point of the system. The more the orbits recede from it, the higher is the position of the corresponding planets. Thus the orbits *M* and *V* of Mercury and Venus being nearer the centre than *T*, the orbit of the earth, are called inferior orbits, and the planets, *inferior planets*. The orbits *M*, *A*, *I*, *S*, *U*, *N*, of Mars, of the Asteroids, of Jupiter, of Saturn, of Uranus and of Neptune being at a greater distance from the sun than the orbit *T* of the earth, are called superior orbits and the bodies describing them *superior planets*. All these bodies come under the general name of *primary planets*, to distinguish them from the *secondary planets*, or *satellites*, which revolve about primary planets as these latter do about the sun. We have seen that the earth is attended by one of these satellites. Mars, which was supposed to be alone has been recently found to be accompanied by two minute satellites. The last four superior planets are attended by more than one, with the exception of Neptune, about which, so far, only one satellite has been found to revolve. These are the members of the solar system so far known to us.* The planets never, we may say, abandon their centre; for the sligthly elliptical form of their orbits, keeps them always at nearly the same distance from the sun. But other members are more erratic. These are the comets, the orbits

* There probably exists an intra-mercurial planet, and during the total eclipse of this present year, 1878, observers made a special effort to ascertain its existence. Two of them reported that they had seen it.

of which are ellipses having like the planets, one of their foci in the centre of the sun, but the other far removed from this; hence while, when they approach one of these foci, they go very near, and occasionally almost touch the surface of the solar sphere, when they are in the vicinity of the other focus, they are almost out of the planetary system. Another peculiar quality connected with the motion of comets is, that in some the direction of this motion is *retrograde*, i. e., in the direction opposite to the order of the Zodiacal signs, while the motion of others is *direct*, or according to the order of the signs, like that of all the planets, which, consequently, apparently move from West to East.

This sketch of the solar system presents a natural division of the subject, which remains yet to be treated in the following articles of the present chapter. The first will treat of the inferior, the second of the superior planets with their satellites; and the last of the comets.

## ARTICLE II.

### INFERIOR PLANETS.

There are but two well known inferior planets in the system namely, Mercury and Venus; the mean distance of the first, which is the nearest to the sun, is about 34 millions of miles; the mean distance of the second, is about 65 millions; the mean distance of the earth, as we have seen, is 92 millions of miles, or, taking for unity of measure, as is ordinarily done, the mean distance of the earth from the sun, the mean distance or radius of the orbit of Mercury will be expressed by 0.370; the mean radius of the orbit of Venus by 0.706. The concentric circles (Fig. 28), represent, approximately, the relative magnitude of the three orbits. It may be asked, how do astronomers know that these and other planets describe nearly circular orbits about the sun, on planes more or less inclined to the plane of the ecliptic? To give a detailed account of the methods by which astronomers determine the distances of the planets from the sun, their orbits and the elements thereof, would require more space than is allowed by the character of a brief cosmographical essay. To form, however, some idea of the manner by which they can obtain a knowledge of these elements, let us suppose Mercury to reach the point *t* of its orbit, the remotest point which it can reach for a spectator on the earth at *T*. Suppose the orbit to be circular, the visual ray *Ttm* will be a tangent to this circle, and the triangle *TtS* right-angled in *t*. The angle *STt* of the triangle is given by direct observation, being the angle formed by the visual rays, one of which is directed to the centre of the sun, another to the planet; the hypothenuse—*TS* besides is known, being the distance of the earth from the sun; hence the side *St* of the triangle can be determined, as also the side *Tt'*, and consequently the distance of the planet from the sun and from the earth. A circle described with the radius *St* will nearly represent the orbit of the planet. Trigonometry supplies the means to determine the position of the plane of this orbit relatively to the plane of the ecliptic, as the apparent position of the planet, seen from the earth and referred to the ecliptic, may be daily obtained by observations and by resolutions of triangles. The same positions may, besides, be referred to the centre of the sun and this is called the *Heliocentric* position of the planet relatively to the ecliptic. A series of observations and calculations of this kind shows that the orbit of the planet is on a plane, and that this plane is inclined to the plane of the ecliptic, and the intersection of these two planes passes through the centre of the sun. This line of intersection is called the line of *nodes*. Since both the earth and the sun are on the plane of the ecliptic (the *ground plane* to which the planes of planetary orbits are referred), the planet cannot pass through the nodes without being seen at once from the sun and from the earth on this plane, and then only, because then only its *Geocentric* as well as its Heliocentric position is on the plane of the ecliptic. An easy means is thus offered to determine the period of the revolution of the planet about the sun, this period being measured by the time which intervenes between two successive transits through the same node. These few remarks are sufficient to give an idea of the manner in which astronomers, applying theoretical principles to practice, have been enabled to determine all the elements of planetary orbits, and the inclination of their planes to that of the ecliptic. Let us return to our planets.

Let $T$ be any point of the terrestrial orbit; draw from it $TV$, $Tv'V'$, tangents to the orbit of Venus and $Ttm$, $Tt'm'$ tangents to the orbit of Mercury; the same orbits referred to the celestial sphere, will embrace that of Venus, the arc $vv'$; and that of Mercury, $mm'$, the sun referred to $S$ bisecting each of these two arcs. The equal angles $STm$, $STv$ and their correspondents on the other side, are called angles of greatest *elongation*, either East or West, according as the planet is to the East or to the West of the sun. The greatest elongation of Mercury never exceeds 29°; that of Venus, never 47°. It is plain from the Fig. itself, that since in the vicinity of the points of contact *t*, *c*, *t'*, *c'*, the curve nearly coincides with the tangential visual rays *Tm*, *Tv*, *Tm'*, *Tv'*, the planets in the vicinity of the same points will appear stationary. It is likewise plain, from elementary geometry, that the arc *t'pt*, of the orbit of Mercury, towards the earth, is less than the opposite arc *tft'*, this difference is still greater between the corresponding arcs *cqc'* and *cgc'* of the orbit of Venus. The arrows in the Fig. indicate the motion of the planets in their orbits according to the order of the signs; but when the planets describe the arcs *t'pt*, *c'qc*, their motion becomes apparently retrograde. When the motion of the planet is retrograde, the planet is nearer to the earth than when its motion is direct; this difference of distances is especially remarkable with regard to Venus, the apparent diameters of which, when at *q* and when at *g*, the nearest and the farthest points, are in the approximate ratio of the diameters of the Figure 29. More exactly, the smaller diameter subtends an arc of 9″, 6; the greater an arc of 61″, 2. It follows, moreover, from what precedes that the period of retrograde motion, especially for Venus, is shorter than that of the direct motion of the planet.

If the orbits of the inferior planets were on planes coinciding with the plane of the ecliptic, each inferior conjunction of the planet with the sun, would be attended by the transit of the same planet over the solar disk. This however, is not, and cannot be the case, except when the inferior conjunction takes place in or near the lines of the nodes, a circumstance which very seldom happens, especially with respect to Venus; the intervals which separate successive transits of this planet over the disk of the sun, are 8 and 113 years. This phenomenon is much valued by astronomers on account of its affording them the opportunity of rectifying the distance of the planet from us and from the sun. Suppose (Fig. 30), the distance $AB$ of two spectators on the surface of the earth, to be known, and let them direct the visual rays $AVS'$, $BVS$, to the planet whose centre is $V$, actually passing over the solar disk $LN$. The two isosceles triangles $ABV$, $SVS'$, are similar; hence

$$SS' = AB \frac{SV}{BS - SV}.$$

Now, if the distance of the sun from us is determined with precision, and the distance of the planet from the sun is correct, the distance $SS'$ measured with the means afforded by practical astronomy, will be found to correspond exactly with the value of $SS'$ from the preceding formula; otherwise, a correction is needed in the position of Venus between the earth and the sun. This correction is obtained by means of long and intricate calculations. The angle $AVB$ which the visual rays from $A$ and $B$ form in $V$ is called the angle of *parallax*, or simply the *parallax*.

If the transit of the inferior planets over the solar disk is a rare occurrence, the phases of these two planets similar in every respect to those of the moon, are observable in every revolution about the sun. For, when the planet is describing that portion of its orbit between the sun and the earth, the greater part of the illuminated hemisphere is invisible from the earth and the whole illuminated hemisphere disappears when the planet passes through its inferior conjunction; afterwards it begins to appear again, increasing gradually until the whole of the illuminated hemisphere becomes visible when the planet reaches the superior conjunction.

The period required by a planet from the time in which it passes through any point of its orbit until it returns to the same point again, is called *sidereal* revolution, for the reason that a visual ray from the centre of the sun to the planet would refer the planet to the same point of the firmament, when it returns to the same point of its orbit; and if for one of the positions of the planet in the orbit, the planet referred to the firmament would coincide with a star, when it returns to the same point of the orbit, it will coincide with the same star. This sidereal revolution, or sidereal year is, as we have said already, different for different planets: that of Mercury is $87^d$, 96, or nearly three months; that of Venus $224^d$, 70, or more than seven months. Taking for unity of measure the diameter of the earth, observations have shown that the diameter of Mercury is 0.39; that of Venus 0.97; or in geographical miles the length of the diameter of Mercury is 2689; that of Venus 6079. Other observations have been directed to find, if the same planets revolve about their axes, and the result obtained has been that Mercury and Venus revolve about an axis, during a time nearly equal to that in which the earth revolves about the terrestrial axis; some doubt, however, concerning these results is left by the difficulty of observing spots, or other well marked points, on the surfaces of these globes, from the motion of which the rotation of the same globes might be inferred. These globes seem to be environed, moreover, by an atmosphere; that of Venus, analogous to ours, and that of Mercury, considerably denser.

We have given the mode of determining with some approximation the distance of an inferior planet from the sun; before we commence the following article, we may here see another geometrical method of determining in like manner, the distance of a superior planet from the sun. Let $TT'L$ (Fig 31), be the orbit of the earth, and suppose the earth to be at $T$ when a superior planet, the orbit of which is represented by $mm'$, is in the ascending node, and let $P$ be this point. The planet will be referred to the point $S$ of the celestial sphere. The return of the planet to the same node, will take place after one revolution about the sun, and if the earth would be in the same position $T$ of her orbit, a spectator on it, would refer the planet $P$ to the same point $S$ of the celestial sphere. But the earth will not be in the same point of her orbit, but in $T'$ v. gr.; so that the same point $P$ at the same distance $SP$ from the sun, will be seen from two different points of the terrestrial orbit and the visual rays $TP$ and $T'P$ with the chord $TT'$ form a triangle. If the angles $PTT'$, $PT'T$, and the side $TT'$ between them, be known, the length of the sides $TP$, $T'P$ will be also known. Now, the point of the orbit occupied by the earth, can be always known; the radius of the terrestrial orbit is also known; hence from the triangle $TST'$ the chord $TT'$ and the angles $STT'$, $ST'T$, become known. Observ-

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ing the planet we know, moreover, the angles *STP* and *ST′P* which form the visual rays from the earth to the sun and to the planet; hence also the angles *PTT′*, *PT′T* become known; therefore, the distance of the planet from the earth, at the time of the two observations, can be determined by the resolution of the triangle *TT′P*. But the distance to be found is *SP;* for this purpose, take either of the triangles *STP* or *ST′P*, in each of which we know two sides and the included angles opposite to *SP;* each of these triangles resolved, will give the length *SP*, or distance of the planet from the sun.

## ARTICLE III.

### SUPERIOR PLANETS.

38. *Mars*—Of all the superior planets Mars is the nearest to the earth; its mean distance from the sun is about 140 millions of miles; hence taking for unity of measure the distance of the earth from the sun, that of Mars will be nearly represented by the number 1. 5. The concentric circles of the Fig. 32 represent, to a certain proximity, the relative magnitude and position of the two orbits. The diameter of Mars is only superior to that of Mercury, i. e., 3548 miles in length and compared with that of the earth taken as unity of measure is numerically expressed by 0.51. Its volume is consequently something more than one eighth that of the earth; it is a small planet and was believed to be unattended, like Venus and Mercury, by satellites. But on the night of August the 11th, 1877, Prof. Hall of the Naval Observatory, Washing-

ton, discovered a satellite circulating around the planet Mars. Five days later the same astronomer found a second one, nearer to the planet. The mean radius of the orbit of the first is 14360 miles, that of the inner only 5806. The outer describes its orbit in 30 hours and 17 minutes, the inner in 7 hours and 39 minutes. According to these data the orbital velocity of these satellites is not so great as might be supposed, indeed we find in other members of the solar system much greater velocities; but the period of the orbital revolution of the inner satellite is the shortest known in our system. On account of this short period, during one revolution of the planet about the axis, the satellite goes through all its phases more than three times, whereas our moon requires about a month to exhibit her corresponding phases once. Much uncertainty exists as yet concerning the diameters of these little attendants of Mars. Some admit that the diameter of the inner one ranges between one and twenty miles.

The planet Mars is easily discernible by the deep reddish color it reflects and, since its orbit is outside that of the earth, it may be seen in opposition as well as in superior conjunction with the sun. Thus the earth being at $T$ and Mars at $M$ in the same rectilinear direction $STm$ with the sun, but on the opposite side, the planet is in opposition; if the earth being at $T$ and Mars at $M'''$, in the same rectilinear direction $TSM'''$ with the sun, the planet is in conjunction. It is equally plain that the planet may be seen at any angle of elongation from the sun. Mars presents phases not with the same order as all those visible on the moon and on the inferior planets. Let $M'$, v. gr., be the position of Mars seen from the earth at $T$, the plane $aa'$ perpendicular to the visual ray $TM'$ and passing through the centre of the planet, separates the visible from the invisible hemisphere; another plane $cc'$ perpendicular to $SM$, the radius from the sun to the planet, divides the illuminated from the dark hemisphere. Now the two planes $aa'$, $cc'$, do not coincide; hence the spectator at $T$ cannot see the whole illuminated hemisphere, since a part of the dark hemisphere is turned towards him; hence the phase. The greatest portion, however, of the planet's disk appears always illuminated, the angle $TM'S$ never reaching 90°, and in conjunction as well as in opposition, the visible disk is totally illuminated.

The rotation of Mars about one of its diameters is well ascertained. It is performed in a time a little longer than that of the earth, i. e., in 24 hours, 37 minutes and 23 seconds. The facility of obtaining this period is owing to the well marked spots observable on the planet's disk. They are of a deep bluish color; a circumstance which has suggested the idea that they may be seas like ours. The largest of these spots has a kind of triangular form, branching off in three different directions; one of these branches appears like a canal between two reddish continents. Two more spots are visible near the poles; these spots are white or yellowish, they seem uniform and terminate regularly like polar zones; but, observed with good instruments, they change their aspect. From Fr. Secchi's observations, the northern one has the form of a trilobitic leaf, the other is spiral. Another yellowish spot is between one of the polar and a branch of the large triangular spot. Herschel was of opinion that the white spots are glaciers similar to ours. A probable indication of atmosphere on the same planet is given by the gradual diminution of light towards the edges of the disk.

The greater the difference between the transverse and the conjugate axis of an ellipse, the more the ellipse recedes from the circular form. The index of the greater or less departure from the circular form, is the so called eccentricity, the value of which is given by the formula

$$E = \sqrt{\frac{a^2 - b^2}{a^2}};$$

in which $a$ represents the semi-transverse, and $b$, the semi-conjugate axis of the ellipse; now the value of $E$ for the planet Mars is greater than for any other planet, Mercury and the Asteroids excepted. For Mercury the value of $E$ is 0.2, and for Mars 0.09; the eccentricity of the other planets does not reach 0.06; thus the ratio between the transverse and the conjugate axis of Mars is a little less than 1 : 0. 9, while that of Mercury is a little more than 1 : 0. 8. This circumstance of a perceptible eccentricity, together with the vicinity of the planet to the earth, offered to Tycho the facility of observing with success this planet, and afforded to his disciple Kepler the materials to discover his laws. These favorable circumstances, however, do not diminish the praise deservedly due to the labors of Tycho, on account of their being common to all; because a less assiduous and less able observer, with the means science possessed at that time, would have failed to obtain the results which proved so valuable in the hands of Kepler.

39. *Asteroids*—Although the diameter of Mars is,

like the diameters of the two inferior planets, less than the diameter of the earth; still the difference of magnitude of these four planets is not very great if compared with the last four superior planets. Thus these eight bodies may be divided into two classes of large and small planets; the small being near to, the large far from the sun. But between these two sections a greater number of small bodies and probably much greater than that already known, is revolving about the sun, occupying, as we have said, the place of the missing planet in the scale of distances from the system's centre. The discovery of this large tribe of members of the solar system, which totally belongs to the present century, has aroused, in a remarkable manner, the vigilance of amateur observers, to several of whom the discovery of a good number of them is due. Professional astronomers, without neglecting the same researches, which have likewise been attended with success, have, moreover, directed their labors to determine the elements of the orbits of these bodies, and to find out other qualities pertaining to them, as has been done for the other members of the planetary system. It is enough for us, briefly to epitomize here the results of these lalors.*

We may begin by observing that the nodes of the orbits of the Asteroids are nearly all in two parts of the firmament, diametrically opposite to each other; i. e., at about 0° and 180° of longitude; for some, the ascending node being near 0°, for others, near 180°. This circumstance renders it easy to find them, and seeing all of them in a certain period of time, it has

* The Smithsonian Report for 1876, contains a list of the Asteroids up to Feb. 7, 1877; to this date their number was 172.

been demonstrated that, notwithstanding their number, so small are they that the total amount of their volumes would not form a planet of the magnitude of the earth. They are susceptible of division into various groups, differently disposed, a circumstance which seems to render improbable the opinion of one original planet of which the Asteroids are the fragments. On the other hand, no reason seems to impel us to admit this original planet. Nay, if we would, by analogy, infer the condition of the planetary system from the other works of nature, in all of which order and variety are so admirably associated, it seems much more probable that, such as they are, these small members of the solar system have been launched into space by creative power, to circulate in it around their centre of attraction. The eccentricity of the Asteroids, and the inclination of their planes to that of the ecliptic are, in general, greater than those of the other planets. Although the mean distance of these bodies from the sun is nearly the same for all, there are yet differences, which, taken in connection with the eccentricity of their orbits, cause the space occupied by them to be very extensive.

We have seen that the distance of Mars from the sun, taking that of the earth from the same centre as unity of measure is about 1.5. The mean distance of the Asteroids ranges commonly between 2.2 and 2.8. Some of the nearest, however, in their *Perihelion*, or nearest point to the sun, come even as near as 1.8, almost reaching the limits of the orbit of Mars; while the remotest known in their *Aphelion*, or remotest point from the sun, go as far as 3.8. We see no improbability in supposing others, invisible to us on account of their size and distance, going farther still, and having thus the small planets, filling as it were, the whole place between Mars and Jupiter, and being in a measure the connecting link between the great and minor planets.

The presence of the Asteroids does not much change the mechanical condition of the solar system, but their discovery has given a different aspect to it, and, in a cosmical point of view, is justly regarded as a discovery of great consequence. Under the same point of view, more importance has been of late attached to the phenomena known as meteoric stones and shooting stars. The reality of the facts connected with the first class of these phenomena has been frequently derided and those of the second class have been admitted to be atmospherical phenomena. The certainty, however, of the facts, and a more careful analysis of the same have given them much more importance. From investigations made on this subject, it appears that they are phenomena of a cosmical character, and by no means limited to the regions of the atmosphere. They are, we may say, the scattered and minute fragments of the system, but belonging to the same mechanism with the planets. It is not, therefore, out of place to dwell somewhat upon this subject, before we pass to the larger planets.

40. *Meteoric stones and shooting stars*—Different facts have been well ascertained with regard to meteorites, all of which show the same cause of the phenomena. Their fall is often preceded by the appearance of streaks of light passing with great velocity across a part of the firmament, and is accompanied by explosions. Sometimes a small dark cloud is observed to form suddenly in a perfectly clear sky, and

explodes with a noise resembling a succession of discharges of artillery, while a shower of stones is hurled from it. Such clouds, moving over an extensive tract of country, have sometimes thrown down thousands of meteoric stones of different magnitudes, but alike in their constituents and external appearance. Another circumstance of importance is that these bodies seldom strike the surface of the earth in a vertical or nearly vertical direction, but generally in a direction very oblique to the plane of the horizon, which is shown by the manner in which they penetrate the earth. Their velocity, which is discovered by observations on their motion and by the depth to which they penetrate into the ground, is also worthy of attention. These observations have shown that the velocity of aerolites belongs to the motion which characterizes the bodies of the solar system. The physical condition and analysis of the constituents of such masses present several circumstances worthy of notice. In whatever way they fall, their form, their external crust and their constituents exhibit a general and striking resemblance. When recently fallen their temperature is more or less elevated, their surface is shining, black and apparently burnt, Their constituents are commonly iron, nickel, cobalt, manganese, chromium, copper, arsenic, tin, potash, soda, sulphur, phosphorus and carbon, comprising perhaps one fourth of the elementary substances to which terrestrial bodies have been reduced by chemical analysis. It is important to observe that the iron and nickel are almost always in the metallic form ; these metals, when found in the earth, are combined with oxygen. The crust, by which meteorites are almost invariably surrounded, is only a few hundredths of an inch in thickness, and is described by Humboldt as being highly characteristic. This black crust is separated from the light grey mass beneath it by a clearly defined line. Humboldt observes that the greatest heat of porcelain furnaces can produce nothing similar to the crust of the aerolites, so distinctly separated from the unaltered mass within. Such are the circumstances attending these meteors. They have been explained by different hypotheses, the atmospheric, the volcanic, the lunar and the planetary. The first supposes that the matter composing aerolites has been drawn up from the surface of the earth, in a state of minute subdivision, as vapor is drawn from liquids, and afterwards consolidated into masses in the higher regions of the atmosphere from which they fall. But the objections to this hypothesis, are so unanswerable that it has been altogether abandoned. The second hypothesis, which has more apparent probability, supposes that meteoric stones are ejected from volcanoes, with sufficient force to carry them to great elevations, in falling from which they acquire the velocity and force with which they strike the earth; the obliquity of their direction is explained by the supposition that they are projected from volcanoes in corresponding oblique directions. This hypothesis has been rejected on account of the difference between volcanic substances and the substance of meteorites; for although the elements do not differ yet their combination is entirely different. Moreover, it is found that meteoric stones fall on parts of the earth so remote from volcanoes, and at periods so distant from any known extensive eruption, that it is impossible to admit that they have proceeded from this cause. The lunar hypothesis supposes meteorites to be bodies ejected from lunar volcanoes with a force great enough to bring them within the sphere of the predominating attraction of the earth. This hypothesis, suggested in 1660 by Terzago, and revived by Dr. Olbers on the occasion of the great fall of meteorites at Sienna on the 16th of June, 1794, has engaged, for a number of years, the attention of eminent scientists such as Laplace, Biot, Brandes and Poisson. More accurate investigations, however, have shown that this hypothesis cannot be maintained, first, because the known velocity arising from a volcanic activity is not sufficient to throw materials beyond the sphere of prevailing action of the lunar globe on them, and therefore the supposition of the attraction of the earth is gratuitous; secondly, on account of the great improbability of the existence of active volcanoes on the moon; nay more, after the careful and extensive selenographic labors of Beer, Madlers and others, we may admit as a demonstrated fact the absence of active volcanoes on the moon.

The planetary hypothesis, which is the only one remaining is generally taken as the true explanation of the phenomenon of aerolites. According to it, aerolites are planetary bodies which the earth encounters in its annual course around the sun. These bodies compared with the volumes of the planets, without even excluding the Asteroids, are of excessively minute dimensions and are like atoms scattered in the space occupied by the planetary system. This opinion, according to the testimony of Plutarch (De plac. phil. 11. 13), was entertained by ancient philosophers. If we could obtain some knowledge of the laws which have caused preexisting matter to concur in the formation of the planetary system, we might, perhaps, see in them fragments of the same materials which form the planets, and which escaped from the agglomeration of the large masses. The light and the explosions, as well as the occasional apparition of a cloud, are well explained by the planetary hypothesis. The great velocity with which meteorites move is attended by a corresponding friction and condensation of air, when they enter into the atmospheric regions, such as to raise the temperature of the surface of these bodies to a degree of intense ignition; which effect being produced very rapidly causes a great difference between the temperature of the interior and that of the exterior part of the aerolite; this circumstance may concur to the fracture and the scattering about of minute particles, which give the cloudy appearance to the phenomenon. That the combustion of the meteorites does not penetrate deep into the interior we have seen to be a well ascertained fact, as it is also well known that this combustion is highly intense.

The phenomena of shooting stars belong to the same class and are explained in the same manner. There are, however, some peculiarities attending them, which deserve to be briefly noticed. The principal are their regular periodical recurrence, their velocity, their distance from the surface of the earth, which circumstances have determined modern observers to abandon the opinion previously entertained that they are only atmospheric phenomena. The fact alone of their periodical recurrence seems to exclude the atmospheric explanation. For if the occurrence of shooting stars takes place regularly at certain fixed periods of the year, it is plain that they become visible to us when the earth returns to the same regions of space, in its annual revolution about the sun; and we may, with good reason, infer, that the cause of the phenomenon is not to be looked for in the atmosphere itself, but rather in those regions through, or near which our globe and its atmosphere pass during the annual motion. Now, the periodical recurrence of the phenomenon of shooting stars is a fact well ascertained. The ordinary and most abundant showers occur towards the middle of the months of August and November; but it results from a table, in which from various sources the dates of the most remarkble appearances of this class, from the eighth century to the present time have been collected, that they are visible also at other times of the year, although not often.

On the morning of the 12th of November, 1799, before sun-rise, Humboldt and Bonoland, then on the coast of Mexico, were witnesses of a remarkable exhibition of shooting stars and fire balls. They filled the part of the heavens extending due east to about 30° towards the north and south. They rose from the horizon between the east and the north-east, describing arcs of unequal magnitudes; many of them appeared to explode, but the greater number disappeared without emitting sparks; some had a nucleus apparently equal to Jupiter. This remarkable spectacle was seen at the same time in Cumana, on the borders of Brazil, in French Guiana, in the channel of the Bahamas, on the continent of North America, in Labrador and in Greenland. In some places in Germany many shooting stars were seen on the same day. A no less stupendous exhibition took place in North America on the night of the 12th of November, 1833; no less than 240,000 were noted in the interval of 9 hours, in only one place of observation in the State of Connecticut; and yet many also escaped notice. Such was their frequency that the heavens seemed to be on fire, so much so as to alarm the most indifferent. In 1834, similar phenomena occurred on the night of November, and in the following years also 1835 and 1836. In succeeding years their recurrence has presented nothing extraordinary. A more accurate study of this phenomenon dates from this period.

Two more facts which conspire with the periodical recurrence, to prove the extra atmospherical existence of minute bodies which become candent, when entering into the atmospherical regions, are their distance or height from the surface of the earth and their velocity. In the year 1798, an investigation of the height of shooting stars was undertaken by Brandes at Leipzig and Benzenberg at Dusseldorf. Having selected a base line about 9 miles in length they placed themselves at its extremities on appointed nights. The difference of the paths traced on the heavens, afforded data for the determination of the parallaxes and consequently the heights and the lengths of the orbits. On six evenings, between September and November, the whole number of shooting stars seen by both observers was 402; of these, 22 were identified as having been observed by each in such a manner that the altitude of the meteor above the ground at the instant of extinction could be computed. The least of the altitudes was about 6 English miles. Of the whole, there were 7 under 45 miles; 9 between 45 and 90; 6 above 90; and the highest was above 140 miles. There were only two observed so completely as to afford data for determining the velocity. The first gave 25 miles and the second from 17 to 31 miles per second. The most remarkable result was, that one of them certainly was observed to move in a direction away from the earth. A similar but more extended plan of observations was organized by Brandes in 1823. About 1800 shooting stars were noted between April and October by a considerable number of persons observing at the same time on appointed nights at Breslau, and the neighboring towns. The result from the observations was that the height of 4 was computed to be under 15 English miles; of 15 between 15 and 30 miles; of 22 between 30 and 45 miles; of 33 between 45 and 70; of 15 between 70 and 90; and of 11 above 90 miles. Of these last, 2 had an altitude of about 140; 1 of 220, 1 of 280 miles; and there was one of which the height was estimated to exceed 460 miles.—Of the 36 computed orbits, in 26 instances the motion was downwards, in one case horizontal, and in the remaining 9, more or less upwards. The velocities were between 18 and 36 miles a second; the trajectories commonly incurvated; and the predominating direction from north-east to south-west, different from that of the earth in its orbit.

Similar observations have been since made in many places: it will be enough to add here those made in Belgium in 1834, under the direction of Mr. Quetelet, who was chiefly anxious to determine the velocity of meteors. He obtained 6 corresponding observations, from which this element could be deduced; and the result varied from 10 to 25 English miles per second. The mean of the 6 results gave a velocity of nearly 17 miles per second, a little less than that of the earth in its orbit. All these facts and many more which could easily be added, do not give us a complete knowledge of the nature of the phenomenon, but they are undoubtedly sufficient to exclude the opinion of its atmospheric character. It belongs to the order of cosmic facts, like the planetary and cometary vicissitudes, and more especially like the similar fact of the aerolites. A circumstance which renders more probable the identity of the phenomena of aerolites and shooting stars, is a greater frequency of the first observed towards the epochs of the latter. Perhaps it is not far from the truth to add that aerolites are those shooting stars or fragments of them which coming nearer to the surface of our globe, happen to fall upon it, and present the already mentioned phenomena, on account of this vicinity. But a class of bodies met by the earth in certain determined regions of space cannot be supposed to be destitute of orbital motion ; otherwise all of them would be precipitated on the sun. The circumstance of their velocity and their direction, as already mentioned, is another proof that their motion does not depend on the vicinity of the terrestrial globe. It is indeed extremely difficult, with the present data, to determine anything certain about the periodical motion of these bodies. The circumstance of their orbital motion and of their regularly passing through certain regions of the terrestrial orbits, has induced some to admit that this tribe of minute bodies form a kind of ring, intersecting the orbit of the earth, and succeeding each other in rapid motion about the sun.

We will conclude the present subject by observing that the facts connected with it put us in direct communication with the matter outside of the earth, and scattered in celestial spaces, and give us a proof of the identity of the matter of the solar system.

There is an advantage in forming an hypothesis to explain the origin of these phenomena, whose existence was either disbelieved, or, if believed, a source of needless alarm, since eternal Wisdom admonishes us :—"Be not afraid of the signs of the heavens, which the heathens fear." Jer. 10. 2.

41. *Jupiter*—Next, in the series of planets beyond the Asteroids, the smallest of all, comes Jupiter, which is the largest in the system. It is attended by 4 satellites, or moons. Taken complexively with them it forms a system by itself subject, however, like the other planets, to the action of the other members of the solar system. The sight of this planet, together with that of its brilliant satellites, in the field of a good telescope, is truly magnificent. Galileo, soon after the invention of the telescope, was the first that saw the 4 satellites. The mean distance of this planet from the sun is 491 millions of miles, and taking for unity, the distance of the earth from the sun, the same distance is expressed by 5. 2. Thus the relative magnitude and position of the orbits of the earth and Jupster may be nearly represented by the concentric circles in Figure 33.

The diameter of Jupiter is 11. 6 times that of the earth, and its volume is consequently more than 1500 times the volume of the earth. The large circle *J* of the Fig. and the small circle *t* represent the relative magnitude of the globes of Jupiter and the earth. Jupiter has no perceptible phases. The position in which the enlightened hemisphere of this planet is most obliquely in view is when the earth is at $T'$ or $T''$, $JT'$, $JT''$ being tangent lines from the centre of the planet to the terrestrial orbit; but even then the planes of separation of the visible hemisphere is only 11° distant from that of the enlightened hemisphere; a difference too small to render the planet perceptibly gibbous. But the disk of Jupiter seen with a magnifying power as low as 30 is evidently oval, the lesser axis of the ellipsoid coinciding with the axis of rotation. This fact supplies a striking confirmation of the results attained in the measurement of the curvature of the earth, i. e., as in the case of the earth, the degree of oblateness of Jupiter is found to be that which would be produced upon a liquid globe of the same magnitude and having a rotation such as the planet is observed to have.

42. *Rotation and annual motion of Jupiter.—Its belts.—Its atmosphere*—Although the lineaments of light and shade on Jupiter's disk are generally subject to variations, permanent marks have occasionally been seen, by means of which the diurnal rotation and the direction of the axis have been well ascertained. The period of rotation, determined in the 17th century, by Cassini and Silvabelle, was found to be 9 hours 56 minutes; more recent observations, made with instruments far superior to those of earlier astronomers, have rectified the measure of this period, reducing it to 9 hours, 55 minutes, 26.5 seconds. The difference, however, is so small that much credit is deservedly given to the first observers. The sidereal period of Jupiter, i. e., the time employed by this planet to describe its orbit about the sun is 4332.6 of our days, i. e., nearly 12 of our years. Hence the annual period

of Jupiter consists of 10484.9 of its days. The rapid revolution of this planet about its axis, connected with the length of its radius, renders the motion of its surface astonishingly great. The equatorial points of the planet describe a little less than 8 miles per second while it is well known that a cannon ball when moving with the greatest attainable speed describes during the same time a space of less than half a mile. But if the velocity of the surface of Jupiter on account of its revolution about the axis is great; no less is the velocity of translation of its mass around the sun. From the data already mentioned, the mean distance of the planet from the sun is 491 millions of miles; hence the nearly circular orbit of the planet (the eccentricity is 0.04) is about 2946 millions of miles which the planet moves over in 4333 days; the distance therefore, which it travels is over 679,000 miles per day, 28,000 per hour, 466 per minute and 7.5 per second.

It is not easy, by mere numerical expressions of these enormous distances and motions, to acquire a distinct idea of them; this is better obtained by comparisons with examples with which we are more familiar. A cannon ball moving at the rate of 1000 miles an hour would take about half a century to fall from Jupiter to the sun, or to come from Jupiter to the earth; and a steam engine moving at 50 miles an hour would take 9 centuries to perform the same trip.

The small eccentricity of the orbit of the planet, combined with its small inclination to the plane of the ecliptic, which hardly exceeds 1° 18′, is of great importance in its effects of limiting the disturbances dependent upon its mass. If the orbit of Jupiter had an eccentricity and inclination as considerable as those of Juno, the perturbations produced by its mass upon the motions of the other bodies of the system would be much greater than they are at present. The axis of revolution of the planet has likewise a very small inclination to the plane of its orbit, so that the equator nearly coincides with the same plane; hence the seasons of Jupiter admit but little variation.

The planet when viewed with a good telescope exhibits a disk, the ground of which is of a light yellowish color, brightest near its equator, and melting gradually into a leaden-colored grey towards the poles, retaining, nevertheless, somewhat its yellowish hue. Upon this ground are seen a series of brownish-grey streaks, resembling in their form and arrangement the streaks and arrangement of our clouds, and giving thus a clear indication of the presence of an atmosphere. Many observers have noticed, besides, the color of these streaks to have a reddish tinge, a pale brick-red. The general direction is parallel to the equator of the planet, but sometimes a departure from strict parallelism is observable. Two are generally strikingly observable north and south of the planet's equator and separated by a bright yellow zone. These principal streaks commonly extend around the globe of the planet, being visible without change, during an entire revolution of Jupiter. This, however, is not always the case; for it happens, though rarely, that the streak at certain points appears broken and even sharply broken, so as to present to the observer an extremity so well defined and so unvarying for a considerable time as to supply the means of ascertaining, with close approximation, the time of the planet's revolution about its axis. We must add to this circumstance another more general and more convincing proof of the presence of an atmosphere on the planet. Although the belts have a much greater permanancy than the arrangement of the clouds of our atmosphere, they are, nevertheless, entirely destitute of that permanency which would characterize the features of the surface of the planet such as are observed on Mars; being subject to slow but evident variations, so that after the lapse of some months, the appearance of the disk is totally changed. The existence of the atmosphere of Jupiter is inferred also from the great difference of light at the central part and at the limb of the disk, which is evident not only from direct observation but also from the transit of the satellites over the planet. When the satellite enters on the disk, it is always brighter than the ground of the limb, but as it advances towards the centre, the difference of light gradually diminishes until, before arriving in the vicinity of the centre, this difference disappears altogether, and the satellite becomes invisible; it soon reappears, when near the centre, but as a spot less brilliant than the light of the disk; after the satellite has passed the centre, the phases are repeated in an inverted order. Another fact in proof of the atmosphere of Jupiter is taken from a circumstance attending the frequent eclipses of the same satellites. The light of the satellites, when entering the conical shadow of the planet, does not totally disappear in a short time as it would infallibly do if no atmosphere surrounded the Jovian globe; but their light is gradually and slowly dimmed, and before totally vanishing it assumes a dark reddish color. The analogy of these phases with those attending lunar eclipses leave no doubt concerning the existence of the atmosphere around the planet.

43. *Stations and retrogressions*—If the planet were seen from the sun, its motion would appear always in the same direction, and nearly uniform. But being seen by us from the earth, which moves around the sun, the planet at times appears stationary, and again changes its direct into a retrograde motion. This phenomenon, which is observable in the other superior planets, offers an excellent proof of the motion of the earth about the sun. The phenomenon may be illustrated by Fig. 34, where $mm'$ represents a portion of the Jovian orbit and $EE'E''E'''$ the orbit of the earth. The direction of the motion of the planet is, as indicated by the arrow, from $J$ to $J'$, and that of the earth from $E$ to $E'$. Hence while the earth passes from $E$ to $E''$, the motion of the earth and that of Jupiter are in the same direction, and while the earth passes from $E''$ to $E$ the motion of the earth is contrary to that of the planet. Hence the motion of the planet, referred to the celestial sphere and seen from the earth, must necessarily be apparently retarded, when the motion is in the same direction, and apparently accelerated, when the motion is in an opposite direction. Let $JJ'$ be the portion of the orbit described by Jupiter when the earth passes from $E$ to $E'$, between the planet and the sun ; the planet seen from $E$ will be referred to a point $s$ of the celestial sphere ; and seen from $E''$ it will be referred to the point $s'$ of the same sphere. Now, the position of the point $s'$ relatively to $s$ may be at a greater or less distance, or on one side or on the other of $s$, according to the difference in the motion of the

two planets. If the motion of Jupiter be such relatively to that of the earth, as represented in the Figure, the planet, instead of continuing in its direct motion, will apparently acquire a retrograde motion from $s$ to $s'$. Now this is the case; the motion of the earth overtakes, as it were, that of Jupiter, and the motion of the latter consequently assumes the apparent retrograde motion. But the circular form of the terrestrial orbit increases and diminishes gradually its motion in a direction parallel to that of the planet in its orbit; therefore, the planet passes gradually from its direct to its retrograde motion and vice versa; and before this transition takes place it appears stationary for a certain interval of time, and both its retrograde and its direct motion increase by degrees, until they reach a maximum and then diminish with inverted order. Jupiter appears stationary at about 66° on each side of its opposition.

44. *Jupiter's Satellites*—The satellites are, as we have said, small globes related to Jupiter in the same manner as the moon is to the earth; they constitute a system of four moons, accompanying Jupiter around the sun. They attract the notice of the observer by their brilliancy, but much more by the periods of their revolution. The 1st, or nearest to Jupiter, completes its revolution in 42 hours. In that brief space of time it goes through all its various phases; it is a thin crescent, halved, gibbous and full. It must be remembered, however, that the day of Jupiter is less than ten hours; this moon, therefore, has a month equal to a little more than four Jovian days, in each day passing nearly through a complete quarter. The second satellite completes its revolution in about 85

terrestrial hours or about 8 1-2 Jovian days. It passes, therefore, from quarter to quarter in about 21 hours, or a little more than two Jovian days. The movements and changes of phases of the other two moons of the planet, 3rd and 4th are not so rapid; the third passing through its phases in about 17 Jovian days, and the last and most distant from the planet in something more than 40 Jovian days. Thus if the planet were inhabited, the inhabitants of Jupiter would have four different lunar months of four, eight, seventeen and forty days. The orbits of these satellites are ellipses of very small ellipticity, inclined to the plane of the planet's equator at very small angles, as is made apparent by their motion being always very nearly coincident with the plane of that circle. The distance to which they depart on the one side or on the other of the planet is so limited, that the whole system is included within the field of any telescope of moderate magnifying power; the same elongation from the centre of the planet can be consequently measured with great precision by micrometers. It results from these measurements that the mean radius of the orbit of the first satellite is 6 semi-diameters of the planet; hence the prodigious velocity of this body about the planet. We have said that the distance of the moon from the earth is about 60 terrestrial semi-diameters; the distance of the first satellite of Jupiter from the centre of the planet is 6 semi-diameters of the same planet; but the semi-diameter of Jupiter being nearly eleven times that of the earth, it follows that the orbit of the said satellite has a radius, the length of which is 66 times the radius of the earth; it is therefore, an orbit larger than that of the moon. Now, the moon completes her orbital revolution in 29 1-2 days, the 1st satellite completes its own in 1 3-4 days, its orbital velocity being thus nearly 10 miles per second. The radius of the orbits of the other satellites, from the centre of the planet, given by the same semi-diameter, are for the 2nd, 9.6; for the 3rd, 15.4, and for the 4th, 26. All of them, therefore, relatively to the magnitude of the planet revolve much nearer to it than the moon does to the earth.

The satellites, when observed with instruments of sufficient power, exhibit perceptible disks and admit of pretty accurate measurement. From these approximate measurements it is found that the smallest of them, the 2nd, is equal to or a little greater than our moon; the largest of all, the 3rd, has nearly the magnitude of Mars. From calculations of the diameters of the satellites and their distances from the planet, it appears that the first of them, seen from Jupiter, would have an apparent diameter equal, or nearly so, to the apparent diameter of our moon, as seen from the earth; the second and third would have an apparent diameter, of about half that of the moon, and the last would be about 1-4 that of the moon. It may be easily imagined what various nocturnal phenomena would be witnessed by the inhabitants of Jupiter, when the various magnitudes of these four moons are combined with the quick succession of their phases, the rapid and apparent motion of the first and second and their frequent eclipses. The mutual attraction of the masses of the satellites and their motion, depending on the action of the primary planet and of the sun, render the calculation of their orbits very complicated. It has, however, been successfully subjected to analysis by Laplace and Lagrange. The third of the satellites, when examined with the excellent telescope of Merz, possessed by Fr. Secchi, in the Roman College, presented a remarkably oblate spheroidal form with some spots on it. It presents besides another interesting phenomenon. At times the disk assumes a circular form; whence Fr. Secchi infers that the third satellite has a very rapid rotation about its axis, and, moreover, that this axis, instead of preserving a parallel direction in space, moves with a conical motion. The motion of the satellite would thus resemble that of a top, in which, while it is spinning around its axis, the axis itself with slower motion frequently turns around, describing a cone the vertex of which is in contact with the ground.

One of the happiest thoughts of Galileo was that of deducing from the eclipses of the satellites of Jupiter, a mode of determining geographical longitudes. For the eclipses of these bodies are phenomena which occur at the same time for all the inhabitants of the globe. But to see how the circumstance of the identity of the absolute time, in which the phenomenon takes place, affords a means to determine geographical longitudes, it is necessary to present the subject in a somewhat developed manner.

45. *Sidereal and solar time*—The revolution of the earth about its axis, is, of its nature, uniform, constant, and invariable. The influences of the different bodies of the solar system, and especially that of the moon, might, indeed, alter this uniformity of rotation; but this is not the case, the action of these bodies, which manifests itself in a variety of ways in other terrestrial motions, being so arranged as to

leave totally undisturbed the rotation of our globe about its axis. This is a fact ascertained and confirmed by various observations and experiments extending over a period of several centuries. Hence the time of one complete revolution of the earth about its axis is an exquisite standard measure of time most valuable for many purposes, but especially for astronomical pursuits. This measure of time is called a *sidereal day*, and the time measured by this standard is called *sidereal time*. The reason of this name is taken from *sidus* a star, because when one revolution of the globe about the axis is accomplished, any one of the stars of the firmament reappears on the same spot on which it was visible at the commencement of the revolution; thus if a star happens to be on the meridian at the beginning of the revolution it will be on the meridian and on the same point of the meridian again when the revolution ends and a new one commences, so that the interval between the two successive appulses of the same star to the same point of the meridian is identical with the time of a complete revolution of the earth about its axis. The reason why stars return exactly to their former position after a revolution is accomplished, is not only on account of the uniform rotary motion of our globe, but also because they keep permanently the same place on the firmament. If during a diurnal revolution a star would move eastward or westward it would cross the meridian in the 1st case after and in the 2nd before the revolution is accomplished. Now that which does not take place with regard to the stars, is the case with the sun and with the other bodies of the solar system. Hence the interval of time between two successive appulses of the sun's centre to the meridian, or the solar day, has a different measure from the sidereal day, and since the apparent motion of the sun is eastward, the solar day is longer than the sidereal. Both days are divided into 24 hours, each hour into 60 minutes and each minute into 60 seconds, and the difference in the length of the day produces necessarily a corresponding difference in the subordinate division of hours, minutes and seconds. The difference between the solar and the sidereal day is nearly 4 minutes. If the receding of the sun eastward were constantly the same, the solar days although of a different length, would be, like the sidereal days, all equal; but this receding is variable; hence the length also of the solar days is variable. For the convenience of civil purposes a mean measure of the solar day has been adopted, which is always the same throughout the year. The solar day is, therefore, either the true *solar day*, or the *mean solar day*. When nothing is added the latter is commonly understood. The time referred to these two measures is called, like the days, *true solar time*, and *mean solar time*. But let us return to the sidereal measure.

46. *Circles of terrestrial longitude*—Let $PWP'E$ (Fig. 35), represent the terrestrial globe, and $PP'$ the axis of revolution. Circles formed by planes passing through this axis, or terrestrial meridians, are also called *circles of longitude*. These circles, together with those of latitude which are parallel to the equator, determine the position of the various points of the surface of our globe. We have seen that the circle of latitude is easily determined, its distance from the equator being equal to the altitude of the pole

above the horizon, but the angle which the plane of a circle of longitude makes with the plane of another similar circle taken as plane of reference cannot be determined with the same facility; there is no point or equivalent mark in the firmament giving any indication of this angle. But that which is not obtained by direct observation is obtained through the time. Conceive on the globe $A$ a number of circles of longitude equidistant from each other, v. g. four. The equator and every one of the parallels will be cut by them into 8 equal parts, each, consequently, being an arc of 45°. The same circles, seen at a proper distance from a point along $PO$ will appear as represented in the circle $B$, and the rotation of the globe from west to east, indicated in $A$ by the arrow parallel to $WE$, will appear in $B$ as indicated by the corresponding arrows. It has been agreed to take for the beginning of a sidereal day the instant in which a given point of the celestial sphere crosses the visible meridian, so that a sidereal clock or chronometer (time piece of exquisite workmanship) should invariably mark $0^h\ 0^m\ 0^s$ at the moment when that point passes through the meridian of the place where the time piece is situated. The point agreed upon is the *first point of Aries*, or the point of the equator crossed by the sun when passing from the southern to the northern hemisphere, which is the point of the Spring equinox. Let ♈ be this point: the planes of the various circles of longitude will, on account of the rotation of the globe, coincide successively with this point. If $WE$ produced passes through it, then ♈ is on the meridian for all the points of the circle of longitude $WE$, and for such of them, as are on the side of it, a well regulated sidereal clock, or chronometer, will mark $24^h$ or $0^h$ $0^m$ $0^s$. During three hours the circle *PE*, passes to the position *Pl;* hence when the sidereal time-piece marks three hours, the angle, which the plane of *Pl* forms with that of its preceding position, is an angle of 45°; during six hours the circle *PE* passes to the position *Pl′*, etc.; hence when the sidereal time-piece will mark 1, 2 hours, etc., the same plane of the circle of longitude forms with that of its first position angles of 15°, 30°, etc. If, instead of one moving circle, we take simultaneously all the circles of longitude, the hours marked by the sidereal clocks on them, will be all the hours and fractions thereof from $0^h$ to $24^h$. Their relative angular position will be determined by the difference of sidereal hours on them. A difference which cannot be obtained without the comparison of the time-pieces. Now, the eclipses of the satellites of Jupiter offer the means for such a comparison.

Suppose the position of the terrestrial globe to be that represented by the Figure *B* relatively to the first point of Aries when the eclipse of the 1st satellite of Jupiter takes place. The phenomenon being apparently instantaneous and simultaneous for every part of the globe from which it may be seen, the disappearance of the satellites, visible from the semi-circles of longitude *PE*, *Pl*, *Ph*, etc., will take place at different hours of the sidereal time for each of them. Comparing these hours of observation, from their difference, the difference of longitude is manifestly inferred. This mode of determining the difference of geographical longitude is well adapted for those places where sidereal time-pieces are at hand, and which admit of a delay, for the comparison. For other points of the globe, especially at sea, this mode is not practicable; yet the same phenomenon affords, even in this case, the means of determining the geographical longitude, provided the hour in which the eclipse takes place for the various points of the circle of longitude, taken as term of comparison, be known, and the sidereal clock be regulated according to the meridian of the place where the observation is made. We may here observe that the eclipses of the satellites of Jupiter are not the only phenomenon from which geographical longitude is determined. Any phenomenon which takes place at the same absolute time, for different points of the globe, may be used for the same purpose. The difference of absolute time would give a difference in the sidereal hour, resulting from a double cause, and unless the difference resulting from one of them be separately known, the one resulting from the other cannot be ascertained.

47. *Saturn and Saturnian system*—Beyond the orbit of Jupiter we encounter Saturn, the most marvelous object in the solar system; nay, till now, the Saturnian system is the most extraordinary known to exist among the celestial bodies. A stupendous globe nearly 800 times greater in volume than the earth, (its diameter is 9.18 times that of the earth) surrounded by two, at least, and probably by several thin, flat rings of solid matter, outside of which revolve a group of 8 moons. The discovery of the ring dates from the invention of the telescope; and Galileo, who was the first to see the satellites of Jupiter, was, likewise, the first to see, in 1610, this appendage of Saturn; he could not, however, discover the real form of it, which

in telescopes of that period presented the appearance of a winged planet or of three planets in contact with each other. Galileo called these appendages *ansae*, a name still retained. Huyghens, 46 years later, was the first to detect the real structure of this beautiful appendage. He also discovered one of the satellites; four others were discovered by D. Cassini, one by W. Herschel and the last contemporaneously by Lassell in England, and by Bond in America. The great distance of the Saturnian system does not permit us to see in it as much as we see with our telescopes on the Jovian system; several things, however, have come to our knowledge with regard to the body of the planet itself, to the rings and to the satellites.

48. *The Body of the planet*—The orbit of Saturn has a diameter over 9.5 times that of the earth. Fig. 36 represents, with a certain degree of proximity, the relative dimensions and position of the two orbits. The linear length of the Saturnian orbit is consequently over 5000 millions of miles, travelled over by the globe accompanied by all its attendants in a little more than 29 years. Thus the planet travels at the rate of about 462960 miles per day or 19208 miles per hour, i. e., a little more than 5 miles per second. The eccentricity of the orbit hardly surpasses that of the orbit of Jupiter; it is consequently nearly circular. Belts of light and shade, parallel in their general direction to the planet's equator, are observable on Saturn's globe similar to the belts of Jupiter and affording a like evidence of an atmosphere surrounding the planet. From observations made on apparent spots and inequalities on the disk of the planet, it has been ascertained to have a motion of

rotation upon the shorter axis of the ellipse formed by its disk in 10 hours and 29 minutes, a period 24 minutes longer than that of the rotation of Jupiter. A remarkable difference between the Saturnian and the Jovian spheres, is the inclination of the axis of revolution; the equator of Jupiter nearly coincides with the plane of its orbit, but the plane of the equator of Saturn has been observed to be inclined to that of the orbit 26° 48′, an inclination very nearly equal to that of our equator to the plane of the terrestrial orbit. Hence the year of Saturn is varied by the same succession of seasons and variety of climates as those of our globe.

49. *The Rings*—Improved telescopes and the multiplied number and activity of observers have furnished us with very interesting informations concerning the ring which encircles the body of Saturn. It has been ascertained that it consists of an annular plate of inconsiderable thickness nearly concentric with the globe and in the plane of its equator. It is not one uninterrupted plane, but results from several, perhaps many, concentric rings differing from each other in reflective power and in color. The principal division, commonly accepted, consists of 3 rings: the *external*, the *internal* and the *nebulous*. The first two are separated from each other by a dark streak which is remarkably perceptible on both sides of the ring. The external ring seems to be subdivided by a similar partition. The internal section is brighter than the external. The same section seems to be the assemblage of other concentric rings either in contact with each other or but slightly detached. The internal ring represents a gradation of light from the division towards the centre,

and from the centre towards the inner edge ; the central part being darker than the edges of which the external is the brighter. This gradation of light is not imperceptibly diminishing and increasing but it is formed by a series of minor rings, each having its own shade. This subdivision, however, is seen with difficulty, only with instruments of great power and under favorable circumstances. The most surprising result of recent telescopic observations is a ring composed of a matter slightly reflecting and, what is more surprising, transparent to such a degree that the body of the planet can be seen through it. In 1838 Dr. Galle noticed at the Berlin Observatory a gradual shading off of the inner ring towards the surface of the planet. The subject, however, attracted very little attention until towards the close of 1850, when Prof. Bond of Cambridge, Mass., and Mr. Dawes in England, not only recognized the phenomenon noticed by Dr. Galle, but ascertained its character and features with great precision. But the transparency of this ring was not fully ascertained until 1852. Excepting the comets, this is the only example of such a kind of reflecting transparent substance in the solar system.

50. *Dimensions of the rings*—The breadth of the rings, as well as of the interval which separates them from each other and from the planet, submitted to numerous and accurate micrometric observations taken by different astronomers, the results of which do not differ from each other by a fortieth part of the quantity measured, are here subjoined ; they are given by arcs and miles. Those obtained by Prof. Struve, reduced to the mean distance, seem to be preferred.

| | | |
|---|---|---|
| Diameter of the planet. . . . . . | 17″.98 | 76,060 |
| Exterior diam. of the extern. ring | 40″.08 | 169,526 |
| Interior " " " " | 35.28 | 149,204 |
| Breadth of the exterior ring . . | 2.40 | 10,161 |
| Exter. diam. of the intern. ring. | 34.46 | 145,762 |
| Interior " " " " | 26.66 | 112,758 |
| Breadth of the internal ring. . . | 3.90 | 17,176 |
| Width of the interval between the rings. . . . . . . . . . . . . . | 0.40 | 1,721 |
| Width of the interval between the planet and the internal ring. . | 4.33 | 18,346 |
| Breadth of the double ring including the interval. . . . . . . . . | 6.71 | 28,384 |

The thickness of the rings is so extremely minute, that the nicest micrometric observations have hitherto failed to supply the data necessary to determine it with any certainty. It is so inconsiderable that when the plane of the ring is directed to the earth and consequently the edge alone is presented to the eye it becomes invisible, or, if seen with telescopes of great power, is so imperfectly defined as to elude micrometric observations. When it was in this position in 1833, Sir J. Herschel observed it with a telescope which would have rendered visible a line of light one twentieth of a second in breadth, it would follow, consequently, that the thickness of the rings is less than 220 miles. Sir J. Herschel admits, however, that it may possibly be as great as 250 miles.

The ring of Saturn becomes invisible from the earth not only on account of presenting to us the edge but also because the part presented to the eye is not illuminated by the sun. This happens when the plane of the ring has such a position that its direction passes between the sun and the earth, which takes place within a certain limited distance of the planet's equinox, and cannot last more than five months.

51. *Rotation of the ring and motion of its plane*—The plane of the ring of Saturn is not of uniform thickness and, consequently, not a perfect plane. In 1848, when the last Saturnian equinox took place, a series of observations made at Bonn by Prof. Schmidt has demonstrated the existence of great inequalities of surface on the ring, having the character of mountains or elevations ; the same mountainous inequalities had been previously observed by Sir W. Herschel. The researches of Bessell, who has compared all the observations made on the rings from 1700 to 1833, concur to confirm the same fact or, at least, they prove that the different rings are not on the same plane. The form of the shadow of the body of Saturn on the ring, observed by Fr. Secchi, is another convincing proof of the same fact. In the series of his observations, Fr. Secchi has noticed, moreover, that the ring is slightly elliptical and not circular, as it might be supposed ; this ellipticity being inferred from the periodical diminution and increase of the transverse diameter of the same ring. This fact and the inequalities alluded to have enabled astronomers to ascertain the rotation of the ring about the planetary axis. It is not known yet, however, whether all the rings move like one mass or each of the concentric rings has its own rotary motion. According to the observations of Herschel, the internal ring would accomplish its revolution in 12 hours, and the external ring, from the observations of Fr. Secchi, would have a period of revolution of 14 hours and 15 minutes. These observations will not fail in being confirmed, and all doubts on the subject will thereby be removed. We must observe here that the distance of the internal

and of the external rings from the centre of the Saturnian system are such, that the rotary motion resulting from observation is in exact accordance with the principles of mechanics which require this motion to prevent the ring from falling on the planet. The stability of the system is furthermore secured by the motion of the whole annular mass about the centre of the planet. Messrs. Harding and Schwabe first observed that the annular mass of Saturn is not concentric with the body of the planet; a fact fully confirmed by the exquisite micrometric observations of Prof. Struve, who, besides, established that the centre of the annular mass moves in a small orbit around the centre of the planet.

52. *Satellites*—Saturn is, as we have said, attended by 8 satellites, 7 of which move in orbits whose planes very nearly coincide with the plane of the equator of the planet and of the rings. The orbit of the remaining satellite, which is the most distant, is inclined to the equator of the planet at an angle of about 12°, and to the plane of the planet's orbit, at nearly the same angle. These satellites have been designated numerically, like those of Jupiter, following the order of their distance from the planet. Some, however, preferring the order of their discovery have introduced considerable confusion. To obviate this inconvenience mythological names have been adopted for them, as for the primary planets, and such names as belong to the Saturnian family. The annexed table shows the correspondence of the numerical order from the planet upwards, with the mythological names: in the same table the name of the discoverer and the date of the discovery are given.

| | | | |
|---|---|---|---|
| I. | Mimas | Herschel, | 1789 |
| II. | Enceladus | " | " |
| III. | Tethys | Cassini. | 1684 |
| IV. | Dione | " | " |
| V. | Rhea | " | 1672 |
| VI. | Titan | Huyghens, | 1655 |
| VII. | Hyperion | Bond & Lassell, | 1848 |
| VIII. | Japetus | Cassini, | 1671 |

Before the discovery of Hyperion, the following metrical arrangement of the same names was proposed in the inverted order of their distances, as affording an artificial aid to the memory.

Japetus, Titan, Rhea, Dione, Titus, Enceladus, Mimas.

The absolute velocities of some of the Saturnian satellites are even greater than those of the satellites of Jupiter. The 1st describes its orbit in 22 hours 37 minutes; the 2nd in less than 1 day, 9 hours; the 3rd, whose orbit is equal to that of our moon, in 1 day, 21 hours; the 4th in 2 days, 17 hours; the 5th in 4 days, 12 hours; the 6th in 15 days, 22 hours; the 7th in 21 days, 6 hours; the last in 79 days, 7 hours.

53. *Uranus and Neptune*—Till 1781 Saturn was supposed to be the most distant planet from the centre of the system; on the 13th of March of that year, Sir W. Herschel, while occupied in one of his surveys of the heavens, noticed an object not registered in the catalogue of stars, and observing, after the lapse of some days that its place was changed, he announced it as a comet, but from repeated observations and calculations the orbit of the new object appeared to be

nearly circular and its plane to be inclined at a small angle to that of the ecliptic. Herschel, as a compliment to his friend and patron George III, called the planet *Georgian star;* but this name not being accepted by foreign astronomers, Laplace proposed that of *Herschel* with more success, because to some extent and for a time the name of Herschel was adopted. But this name was also abandoned and the new member of the system is now universally designated *Uranus.*

The mean distance of Uranus from the sun is more than 19 times that of the earth, i. e., about 1825 millions of miles; hence the orbit which the planet describes in 84 years is nearly 11000 millions of miles. Hence Uranus travels at the rate of about 327,000 miles per day, and consequently about 4 miles per second. Its diameter is about 35000 miles; hence its volume is about 110 times that of the earth.

Uranus, like the other major planets, is attended by a system of satellites. Herschel soon after discovering the planet announced the existence of 6 satellites accompanying the planet around the sun; he suspected, also, the existence of rings surrounding the planet. But subsequent observations have not realized this conjecture, nor the existence of the 6 satellites, of which only 4 have been seen by other observers. The names of the four satellites re-observed are Ariel, Umbriel, Titania and Oberon. Mr. Lassell (it would be difficult to say why), found these fabulous names taken from a kind of necromantic superstition of northern regions; an appropriate nomenclature for the four satellites. The period of the revolution of the 1st (Ariel) about the planet, is nearly 2 days 12 hours, and its distance from the planet in semi-diameters of the same planet is 7.44. The 2nd (Umbriel) performs its revolution in about 4 days, 3 hours, and its distance from the planet is 10.37. The 3rd (Titania) in 8 days, 16 hours, and its distance from the planet is 17.01. The 4th (Oberon) in 13 days, 11 hours; its distance from the planet being 22.75. These satellites present a remarkable singularity in the solar system. Their orbits are inclined to the plane of the orbit of the planet at an angle of 78° 58′ and their motions in these orbits are retrograde, i. e., their longitude, as seen from Uranus, continually decreases. This circumstance gives likewise a singular character to the phases of the satellites viewed from the planet. Twice, in each revolution of the planet, the plane of the satellite's orbit passes through the sun, and under these circumstances alone the satellites exhibit the same succession of phases to the planet, as the moon presents to the earth. At the two epochs exactly intermediate between the preceding, the plane of the satellite's orbit being nearly perpendicular to the line joining the sun and the planet; the satellite during the entire revolution suffers no change of phase, except such as may result from the diurnal parallax. In the intermediate position of the planet between the 4 just mentioned a complicated variety of phases take place; but the illuminated part of the satellite never diminishes so much as to become an imperceptible crescent nor increases so much as to become a complete disk like that of the full moon. The great distance of this member of the solar system from its centre, and consequently from us, does not enable us to see or to conjecture other particulars, especially such as belong to its physical character. But distant as it is, its orbit and motion have been ascertained with the same degree of accuracy with which those of the minor planets have been determined.

54. *The discovery of Neptune*—A convincing proof of this accuracy is given by the discovery of Neptune, a planet at a still greater distance from the sun than Uranus. To see how the exact knowledge of the Uranic orbit inferred from observations and from principles of mechanics can lead and has eventually led to the discovery of another planet, observe that the orbit of a planet results from the joint effect of its tangential force and of the force of gravitation. But the latter is a resultant of as many forces as there are members in the solar system. For although the sun is the principal centre of attraction and that which masters all the others, yet it is not the only one. Every planet is a centre of attraction and is attracted by all the others; hence the orbit of a planet can not be determined by calculation with perfect accuracy, unless the influence of all the agents concurring to produce it be taken into account. The problem is a very complicated one on account of the variety of centres of action, of their distances and different powers, of their mobility and of the mobility of the body influenced by them. If one of the centres of action be set aside, it is plain that the orbit, resulting from calculation, cannot correspond with the real one; a difference between the two must necessarily exist, more or less discoverable, according as the influence of the centre omitted is greater or less. It is plain also that from the principle of universal gravitation, i. e., "attraction is inversely as the squares of the distance", those centres which contribute the most to modify the

orbit of a planet are the bodies of the nearest planets, either inferior or superior. The problem with regard to Uranus had been resolved with the omission of the influence of a planet next and superior to it; hence the orbit resulting from the calculation was necessarily different from the real orbit of the planet. This difference has been detected, and the calculations based upon the supposition of a body circulating outside of the orbit of Uranus, enabled Le Verrier and Adams to find out the centre of perturbation and thus to discover the new planet.

The merit of this discovery, which constitutes one of the most signal triumphs of science, cannot be easily appreciated as much as it deserves, especially if taken in connection with the data previously prepared by practical and theoretical astronomy. It is enough to remark that the disturbing effect of planetary action modifies but slightly the orbital track of the different bodies, excepting comets; hence this difference, to be observed and verified, requires great perfection of instruments great ability of observation, and great accuracy of calculations, and the more so as the greater is the distance of the body observed. We must add to this that the least error in the calculations, incredibly laborious and complicated, considerably changes the results. Notwithstanding these difficulties the orbit of Uranus, as calculated in the supposition of the absence of superior planets, was, we may say, perfect, and subsequent observations have been so accurate as to show the difference between the supposed and the real orbit of the planet, and also to offer safe grounds for calculations still more complicated and colossal, which have been conducted with the greatest ability and perseverance to a successful result. Another difficulty connected with the solution of this problem is that the observed disturbances may be referred to the action of an infinite number of different centres of action. To strip the question, as far as possible, of this indefinite character, certain conditions, the existence of which might be regarded as in the highest degree probable, were assumed. Thus it was assumed that the orbit of the disturbing planet, was nearly in the plane of the orbit of Uranus; that its orbital motion was in the same direction as that of the other planets; that the form of the orbit was nearly circular, and, finally, the mean distance of the unknown planet from the sun was admitted to be in accordance with Bode's progression.

Assuming all these conditions as provisional data, two astronomers, neither of whom had attained the age or the scientific standing which could have given hope of their making this astonishing discovery, undertook to solve the problem, Le Verrier of Paris, and J. C. Adams of Cambridge, each without knowledge of what the other was doing, and believing that he stood alone in his adventurous and, as would then have appeared, hopeless attempt. Both solved the problem. Le Verrier was the first to call the attention of astronomers to the presence of the planet and to invite them to direct their researches to the regions of the firmament in which the planet would be visible. This suggestion was rejected in France. Thereupon he applied to Galle of Berlin, who acceded to his desire, and during the night of the 23rd of September, 1846, discovered the planet according to the indications received from Le Verrier. Neptune, when observed with common instruments, does not differ from a small star. S. C. Walker of the U. S. found that Lalande had seen the planet when making his catalogue, and had taken it for a star. Lalande made two observations in 1795, one on the 8th and the other on the 10th of May. He remarked the difference of position, but attributed it to an accidental error of observation. This observation of Lalande was of great value in the calculation of the orbit, which, though found before, required those corrections which prediction alone and the known disturbances could not supply.

55. *Elements of Neptune's orbit—Its Satellite*—The Neptunian globe is a little larger than Uranus. Its diameter is about 4.5 times that of the earth, whence its length in geographical miles is about 37,000; and its volume is 250 times that of the earth. The mean distance of Neptune from the sun is about 2800 millions of miles, more than 30 times the radius of the terrestrial orbit; hence the linear length of its orbit exceeds 16000 millions of miles. The period of its revolution about the sun being about 164.6 years, the rate of its tangential velocity is about 100 millions of miles per annum, i. e., above 270,000 miles a day. A satellite of this planet was discovered by Mr. Lassell in October, 1846, and was afterwards observed by other astronomers in Europe and in the United States. The motion and elements of the orbit of this satellite were determined by Otto Struve, in 1847, and more exactly in 1848-9 by his relative, August Struve. The radius of its orbit has been found to be about 14 times that of the planet. The inclination

of the same orbit to the plane of the orbit of the planet which nearly coincides with the plane of the ecliptic, is calculated to be 151°, and the satellite, like those of Uranus, revolves with a retrograde motion performing its revolution in 5 days 21 hours. It is probable that this is not the only satellite of Neptune, but its distance from us, which is nearly double that of Uranus, renders it extremely difficult to discover much concerning the planet and its appendages.

56. *Relative densities of the planets*—We will conclude the present article by giving the relative densities of the planets and of the sun, taking distilled water as the unit of measure. Sun, 1.42 ; Mercury, 6.48 ; Venus, 5.10 ; Earth, 5.55 ; Mars, 5.40 ; Jupiter, 1.29 ; Saturn, 0.73 ; Uranus 1.04, Neptune, 0.90. The density of our moon is about 3.40. From these relative densities we cannot infer that the materials which form the various planets are altogether lighter than those which form the Earth or Mercury, the most dense of all, as to explain the fact, it is sufficient to admit that only some portions of these bodies are specifically lighter, as gases, or to admit cavities in their structure.

## ARTICLE IV.

### COMETS.

Newton establishes in the first book of his *Principia* these reciprocal propositions which can be demonstrated with mathematical rigor. 1. A body which moves under the influence of a tangential and of a central force, which varies inversely as the square of the distance, must move in one or the other of the lines of the second order, known as the conic sections. 2. Whenever a body is observed to move around a centre of attraction in any one of these curves, the centre of attraction being its focus, the law of attraction is no other than that of gravitation. These propositions form the ground work of the entire theory of gravitation.

57. *The motion of comets is governed by the law of gravitation*—Subject to the above limitations, a body may move around the sun in any orbit, at any distance, in any plane, and in any direction. It may describe an ellipse of any eccentricity, from a perfect circle to the most elongated oval; it may move in a parabola, with its perihelion either grazing the surface of the sun, or beyond the orbit of Neptune; finally it may move around the sun in a hyperbola. From this and from the observed orbits of numerous comets we infer that comets are ponderable masses revolving about the sun by the action of gravitation, exactly as by the same action, planets revolve about the sun and satellites about their respective planets, but the form of their orbits, although belonging to the lines of the 2nd order, is very different from that of the orbits of the planets.

58. *Character of their orbits*—The ellipses described by them (if all cometary orbits are elliptical) have great eccentricity, and consequently their form is elongated. While, when at their perihelion, they almost touch the sun, or go nearer to it than any planet, when they approach their aphelion, their distance from the sun, is equal to, and more frequently much greater than that of the remotest planets. Two consequences follow this form of orbits, which render the determina-

tion of their elements very difficult. The first is the similarity of the elliptical curves at the extremities of the transverse axis to those of a parabola or hyperbola; the second is the astonishing tangential velocity which the comets acquire when near the solar regions and which does not allow us to see them for more than a short period, frequently too short to disclose the real character of the curve they describe and consequently the elements of their orbits. The same difficulty of ascertaining the true character of cometary orbits has, in some cases, left it undecided whether they are elliptical or parabolical. Analogy decided for the first, although we see no impossibility in the second form; in which case, the comet would never return to the sun, but would move on in the immensity of space, until it would meet some other centre and revolve about it. In such a supposition comets would pass from star to star, winding, as it were, through systems separated from each other by distances in comparison with which the dimensions of the terrestrial orbit, and, probably, the dimensions of the whole planetary system, totally disappear.

Other qualities distinguish cometary from planetary orbits. Their planes are inclined to the plane of the ecliptic with every variety of inclination; and their orbital motion, although frequently direct, is also occasionally retrograde, i. e., opposite to the motion common to all known planets. The number of comets is very great, 400 of them having been recorded in the annals of various countries before the end of the 17th century, the epoch rendered memorable by the discoveries and researches of Newton. In catalogues of the most certain of them, and of such as have been submitted to calculations, their number ascends to 220. The power of modern instruments and the zeal of numerous observers insure the discovery of some of these erratic bodies every year.

59. *Apparent form of comets*—Comets, more especially those which are visible without a telescope, present the appearance of a round mass of illuminated vapor or nebulous matter, to which is often attached a train, more or less extensive, of matter having a like appearance. The former is called the *head* and the latter the *tail* of the comet. Commonly the illumination of the head is not uniform, sometimes a bright central spot is seen in the nebulous matter, which is called the *nucleus*. The nucleus sometimes appears like a bright stellar point, and sometimes presents the appearance of a planetary disk. On examining the object with instruments of high optical power these appearances are ordinarily changed, and the object seems to be a mere mass of illuminated vapor from its border to its centre. When a nucleus is apparent, the nebulous haze which surrounds it and forms the exterior part of the head is called the *coma*. These few remarks comprise nearly everything that in general may be said with certainty regarding comets.

60. *Periodical comets*—Halley was the first to demonstrate the periodical return of comets and the elliptical form of their orbits. When comets appear among the planets and near the sun, the observations taken in order to determine their distance from us and from the sun, their motion, the character of their orbits, the position of the plane of these orbits relatively to the ecliptic, the line of the nodes, the perihelion's distance and other elements, are conducted in

the same manner as for planets, although, on account of the above mentioned causes, not with the same accuracy and frequently not with the same certainty as for planets. But if for a comet these elements be determined with sufficient precision, and the orbit has been found to be elliptical, the body will not fail to return and retrace the same path and establish by this and by the periods of its reappearance its identity.

61. *Halley's comet*—This is precisely what Halley has done; he has calculated the elements of the orbits for different comets, observed at former epochs, and found that these elements for some of them, were reproduced at certain uniform periods of time. Thus he found that a comet which appeared in 1456, reappeared in 1531, again in 1607 and finally in 1682. The comet presented an inclination of its orbit to the plane of the ecliptic of nearly 17°; the longitude of the node of about 49°, and that of the perihelion a little more than 301°; the perihelion's distance 0.58, and the motion retrograde, at each time of its apparition which occurred at intervals of between 75 and 76 years. Hence he predicted that the same comet would reappear in 1759 which actually took place. Calculations were then instituted to determine with the greatest attainable precision its orbit, and the exact period of its future reappearance in 1835; on which occasion Fr. De Vico, in the Roman College, noticed it about 15 days before all the other observers. It appears, moreover, from some researches made in Chinese histories, that reapparitions of this comet may be traced even so far back as 11 years before the Christian era. The orbit of Halley's comet extends on one side much beyond that of Neptune,

while on the other it comes near the sun at the distance of one half the radius of the terrestrial orbit, i. e., between the orbits of Mercury and Venus.

62. *Encke's comet*—A periodical comet, which is remarkable for the short duration of its period of 3 years and 4 months, is Encke's comet; so called from the name of the astronomer who calculated its entire orbit. It was first observed in Marseilles by Pons in 1818 on the 26th of November. In the following January, its path being calculated, Arago recognized it as identical with one which had appeared in 1815. Subsequently Encke of Berlin calculated the entire orbit, and his calculation was verified by the fact of the comet's return in 1822, and in succeeding years. The orbit of this comet is contained within that of Jupiter, i. e., its aphelion is at a distance from the sun equal to 4-5 of that of Jupiter, but its perihelion is within the orbit of Mercury, a clear indication of a great eccentricity and corresponding oval form of the orbit. The dimensions of the comet itself are quite small, and its light very feeble so that it can only be seen with the aid of good telescopes and not always with them, if other circumstances are not favorable.

Observations made on Encke's comet have disclosed a fact of great physical importance, although already admitted or supposed by scientists as indispensable for the explanation of numerous phenomena. The fact alluded to is the presence of a resisting medium, never manifested before by any of the members of the solar system. The reason why the resistance of a medium whose presence is not at all indicated by planets, may be and is made manifest by the motion of a comet, is obvious; for the less the density of the mass of a moving body, the greater is the effect of the resistance of the medium. This effect is, we may say, insignificant even with regard to the comet, but constant; it produces a decrease in the periodical time, to the amount of one day in ten revolutions, and consequently a change in other elements of the orbit.

It remains to be seen whether a like phenomenon will be developed in the motion of other periodical comets. Observations made on the motion of these bodies are as yet too recent to enable astronomers to pronounce decisively upon it. If the existence of a resisting medium were observed on the comets in general, the comet would, after the lapse of many ages, but yet within a definite interval of time, have the elements of its orbit changed, it might be absorbed by the sun, or gradually vaporized by the intense caloric of its photosphere. There are, however, other circumstances to be taken into account in connection with the motion of comets, some of which arise from their physical character, others from the disturbing action of other members of the system, especially the superior planets; and these disturbing causes can more than compensate for the effect of the said resistance.

63. *Biela's comet*—On the 28th of February, 1826, Biela, an Austrian officer, observed in Bohemia a comet, which was seen at Marseilles at about the same time by Gambart. This comet has been found to move round the sun in an oval orbit, the time of its revolution being about 6 years and 8 months. Since its discovery it has returned at the predicted times, and has been adopted as a member of our system, under the name of Biela's comet. It moves in an orbit whose plane is inclined at a small angle to

those of the planets. It is but slightly oval, the length being to the breadth in the proportion of about 4 to 3. When nearest to the sun, its distance is a little less than that of the earth, and when most remote from the sun, its distance somewhat exceeds that of Jupiter. Thus it ranges through the solar system between the orbits of Saturn and Venus.

One of the most extraordinary phenomena of which the history of astronomy affords any example, attended the appearance of this comet in 1846. It was on that occasion seen to resolve itself into two distinct comets, which, from the latter end of December, 1845, to the epoch of its disappearance in April, 1846, moved in distinct and independent orbits.. Mr. Plantamour, director of the observatory of Geneva, calculated the orbits of these two comets, considered as independent bodies, and found that the real distance between their centres (about 2-3 the distance of the moon from us) was subject to a very small variation while visible. A circumstance not surprising, considering the insignificant mass of such bodies and the corresponding disturbing action. The original comet was apparently a globular mass of nebulous matter, semi-transparent, even at its very centre; no appearance of a tail being discoverable. After the separation both comets had short tails parallel in their direction and at right angles to the line joining their centres; both had nuclei. From the day of their separation the original comet increased in brightness, until on the 10th of February they were sensibly equal. After this, the companion still increased in brightness, and from the 14th to the 16th was not only greatly superior in brightness to the original, but had a sharp and star-like nucleus, which might have been compared to a diamond-spark. The change of brightness was now reversed ; the original comet recovering its superiority and acquiring on the 18th the same appearance as the companion had from the 14th to the 16th. After this, the companion gradually faded and disappeared previously to the final disappearance of the original comet on the 22nd of April. The disappearance of the companion before that of the original comet, was not an indication of its real disappearance, but rather a consequence of the disparity in brightness which being then superior in the original comet, allowed this to be visible for a longer time than the other. That such must have been the case, seems to be demonstrated by the fact that in 1852, on the occasion of its reappearance, both sections were observed by Fr. Secchi and others, although differing considerably in brightness and not in the same relative position as observed on the former occasion.

Other comets are periodical but seldom have been well observed. De Vico's periodical comet, discovered in 1844, has not been reobserved in successive periods, because its vicinity to the earth on such occasions has never been such as to permit it to be discernible on account of its smallness.

64. *Physical constitution of comets*—After having ascertained the condition of comets and of their motion in relation to the sun and to the solar system, no other question presents itself more naturally than that concerning their physical character ; and why the same comet presents frequently such a number and variety of phases ? Why the appearances of one differ so much from those of another, and why all of them are so different from the planets ?

In reply to these questions, we shall briefly mention the hypotheses advanced by different scientists. But it is first necessary to give a statement of some of the principal phases of comets.

The appendage of a tail, in the popular mind, is inseparable from the idea of a comet; this conviction proceeds from the fact that most of the comets visible to the naked eye have this appendage; however, the greater majority of comets are not attended by tails. It has, morever, been well ascertained, by repeated and diligent observations, that those comets, which, when near the solar regions, appear attended by a tail, before approaching these regions and whilst at a great distance from the sun, they generally appear in the field of the telescope of a globular form more luminous towards the centre and resembling a light fog. When they depart from the sun, the volume of their head increases, and the tail disappears again, the nebulous mass regaining gradually the globular form. The development of the tail is effected by the action of the sun when these thin bodies come in sufficient proximity to it, and probably too, other circumstances unknown to us, favor this action of the sun. Other phenomena attending the approach of comets to the sun and their receding from it, are equally well ascertained. Upon approaching, their form changes rapidly, the nucleus becomes eccentric to the nebulous mass, and the part opposite to the sun, protrudes forward, and gradually fades away. The tail is then developed; in some it assumes enormous dimensions; during this period the phases of the comet are subject to great variations from day to day. Some of them spout out something like jets towards the sun, which curving back, afterwards form a magnificent tail. Such a phenomenon was observed in 1835 in Halley's comet before it reached the perihelion, and also in the great comet of 1858. The luminous jets are occasionally so numerous as to form a kind of uninterrupted fan on the side of the sun. The more common form of the tail is that of the two slightly curved branches, resembling those of an oblong parabola, the intervening space between them being darker than the branches themselves. If the tail forms a kind of paraboloidal bell, it is easy to account for the difference of light, which is brighter at the edges than in the centre. The same appendage is ordinarily straight but frequently, also, curved, as appeared so beautifully in Donati's comet in 1858; the form of which has been compared to a magnificent branch of a palm tree. Although the tail is on the opposite side of the sun, its axis never, perhaps, coincides with the radius which unites the centre of the sun with the head of the comet; in some rare cases the angle, which the axis of the tail forms with the radius, is very great, and in some other cases, also, the tail is turned towards the sun. The comet of 1823, which had two such appendages, had one of them turned towards the sun. Another remarkable circumstance attending this singular phenomenon, is that the tail does not attain its greatest development until the comet has passed the perihelion. From this period the phases change in an inverted order, the jets of light cease, the head becomes more globular, and the nucleus appears environed by a nebulous mass of more regular form. The more the comet recedes from the sun, the greater is the diminution of its light. The long tail comets leave, or seem to leave, a luminous trace in the space passed over by them, a circumstance which has induced the belief, that comets on these occasions lose a portion of their matter. The apparent and real length of some comets are truly enormous. That of 1858 reached 49° and its real length was no less than 46 millions of miles, equal to one half the distance of the earth from the sun; the apparent length of the comet of 1842 was 65° and its real length was 180 millions of miles. The comet of 1680 embraced an arc of 104°, its real length being 123 millions of miles.

65. *Light and mass of comets*—Two more qualities, which belong to the physical constitution of comets, are their light and their little density. The nebulous character of these bodies excludes the tests which, when applied to planets and to their satellites, manifest their opacity. Comets can neither present phases nor cast a shadow as perceptible and well defined as planets; the luminous rays from the sun must penetrate and pervade their mass as they penentrate that of our clouds. Indications of shadows have been, nevertheless, ascertained, such, namely, as are compatible with the nature of these bodies, and sufficient to prove clearly their opacity. Two more facts conspire to prove that comets receive their light from the sun; one is, that the light they transmit to us is polarized; the other, that the intensity of this light diminishes in proportion as the comet recedes from us, and ceases to be visible from the mere faintness of its light while it still subtends a considerable visual angle; it being certain, on the other hand, that as long as the visual angle of the object is of a perceptible measure, the brightness of a self-luminous body is

the same at all distances. Some instances are mentioned, however, of comets which showed such extraordinary brightness, and other indications of combustion as would seem to indicate the temporary self-luminous condition of some of them when approaching the sun. Arago, among other examples mentions a famous comet which appeared in the year 43 B. C. and which was visible by day to the naked eye. It was the comet which the Romans considered to be the soul of Cæsar, transferred to the heavens, after his assassination. In the year 1402, two remarkable comets were recorded; the first of which, in March, was so brilliant that the light of the sun at noon did not prevent its nucleus or even its tail from being seen; the second appeared in the month of June, and was visible also for a considerable time before sun set. Modern astronomers, as Lockyer, Secchi and others, think that comets, in general, besides reflecting the light they receive from the sun, shine by their own light.

The fact that the orbits of comets are lines of the 2nd order, sufficiently proves that these bodies are composed of ponderable matter. To this, another equally convincing proof may be added, taken from the great disturbing effects which the planets exercise upon them. But, on the other hand, notwithstanding the great number of comets, observed and unobserved, which constantly traverse the solar system in every conceivable direction, the motions of the various bodies of the system, great and small, planets and satellites, go on precisely as if no such visitors approached their neighborhood. Not the slightest disturbing effects produced by their attraction is discoverable.

To understand better the inappreciable density of cometary masses, it is enough to observe that the volumes of comets are frequently of great magnitude, occasionally being thousands and millions of times greater than the solar globe itself. Now, the density of the sun, which manifests the well known gigantic power over the whole system, is less than twice the density of distilled water; yet a density thousands and millions of times less than that of the sun, would render the comets, just mentioned, equally or more effective in their action than the sun. But a density some thousands and millions of times less than that of distilled water, is almost inappreciable. How much more so, then, must be that of the comets which gives no indications whatever of attractive power? Another fact convinces us that their density is exceedingly small. It is well known that the least mass of vapor or the thinnest veil of clouds is sufficient to diminish perceptibly the brightness of the stars, even of the most brilliant amongst them; but the least stars covered by the tail, or even by the head of the comets, show no perceptible diminution of light; although no comparison whatever can be made between the thickness of the stratum of a cloud and that of the body or tail of a comet. Let us limit ourselves to one example; on the occasion of the appearance of the magnificent comet of 1858, the stratum through which the stars of any magnitude were visible with undiminished brightness was found to be no less than 39-000 miles. Such is the smallness of density of cometary masses that some venture to assert that it is many millions of times less than the density of the air which remains after exhaustion in the receivers of our best air pumps. These remarks, based on undeniable facts, have, if nothing more, the advantage of disposing the mind to admit without much reluctance the presence of a fluid of prodigiously small density in the universe.

Prof. G. V. Schiaparelli, the present director of the Brera Observatory of Milan, has advanced a new view concerning comets. It substantially consists in this. Comets may be regarded as an agglomeration of small masses, say aerolites, gathered together by mutual gravitation in the regions of space far off from great centres of attraction. These collective masses move, however, by the law of universal gravity, towards that side on which this law effects them most, their motion, however, for a great length of time, possibly for ages, is exceedingly slow because of their great distance from the centre of attraction. On their journey they increase in volume by the accession of new fragments met in their way, until they have acquired a large dimension. Upon approaching the system which acts on them, suppose the solar system, their velocity gradually increases, and they tend, with more or less deviation, towards the centre of the system, i. e., the sun. When once they have entered into the system their acceleration increases with rapid progression, acquiring the prodigious velocity which belongs to this class of bodies when near the sun. But, as in our supposition the fragments of these masses are not cemented together and the side nearer the centre of attraction is acted upon more powerfully than the central and the opposite side, the gathered elements begin to separate from each other and form a train which must increase in proportion as the foremost part reaches its maximum velocity. Thus the tail of the comet is nothing more than a multitude of the separated fragments of the original aggregate, which give to it a foggy appearance. We find this explanation very ingenious. But perhaps not sufficient, alone, to explain all the phenomena we have mentioned above. The conjecture that those extraordinary apparitions of shooting stars are met by the earth in regions crossed by comets either simultaneously with the earth or previously, agrees perfectly with Prof. Schiaparelli's view.

Fr. Secchi's opinion in regard to comets, is that they are portions of a great nebula of a special nature, containing gases well known to us, not, however, in the same elementary state of siderial nebulæ but combined with Carbon, an element capable of many forms and which is found in some stars.

Comets have been frequently regarded as ominous messengers of terrestrial events, physical, physiological, social and political, which are supposed to accompany or to follow them. However absurd is the supposed connection between the appearance of a comet and other events, as the birth or death of an extraordinary man, the march of armies, the fall of empires, and others of a similar character; it is no less certain that at all times and in all countries, whether of barbarous or civilized nations this absurdity has been easily admitted; thus bearing testimony to the infirmity of the human mind. It is not equally absurd to connect physical effects, especially atmospherical, with the approach of a comet. If, as is admitted upon good foundation, a portion of the cometary mass is left by the comet in the planetary regions, when the comet resumes the globular form and departs from the sun ; this matter will or may be distributed among the planets by falling gradually on them. Now, the nature of this matter may be such as to modify in various ways the condition of our atmosphere, and produce extraordinary phenomena, either of a mechanical or physical character, affecting also the vegetable and the animal kingdoms. Hence, although nothing certain can be pronounced in favor of this opinion, still it cannot be rejected as an impossibility. More probable yet seems the case of the simultaneous transit, through the same point of a planetary orbit, of the planet and of a comet or comet's appendages, considering their vast number revolving in space. Lexell's comet was supposed to have passed among the satellites of Jupiter; and if that were the case, it is certain that the motion of these bodies was not in the least affected by it. The nearest approach to the earth ever made by a comet was in 1684, when one came within 216 semi-diameters of the earth, a distance not so much as four times that of the moon. One of the points at which the orbit of Biela's comet intersects the plane of the ecliptic is at a distance from the earth's orbit, less than the sum of the semi-diameters of the earth and the comet. Hence if the comet should arrive at this point at the same moment at which the earth passes through that point of its orbit which is nearest to it, a portion of the globe of the earth must penetrate the comet. The possibility of such a catastrophe was rumored before the return of this comet in 1832, and excited great alarm. But even if a collision would take place, such is the smallness of a cometary mass, without excluding the nucleus, that it is more probable that the earth would pass through it without perceptible effect, than that it would be subject to a dangerous catastrophe in consequence of it. We must suppose then, that when Laplace, whose authority is unquestionably great, referred to the possible case of a collision and of its consequence, the density of cometary masses was not so well known as at present. In his opinion such an encounter would be productive of effects no less destructive than geological cataclysms. These very cataclysms he seemed inclined to explain by preceding collisions of comets with our globe; nor would he reject this explanation notwithstanding the many and obvious evidences against the geological phenomena having been produced by such a cause, so true is it that "*quandoque bonus dormitat Homerus.*" Newton also maintained a singular opinion regarding comets, not as to their coming in collision with planets, but being destined to fall into the sun. In his opinion, comets are the aliment of combustion for the sun and for other centres of light, so that comets should be immensely more numerous than any other class of celestial bodies, and scattered and wandering everywhere and in every direction, throughout the universe. This opinion seems to have been cherished by Newton to the last hours of his life. A conversation is related which took place between him, being then 83 years of age, and his nephew, on this subject: "*I cannot say,*" said Newton, "*when the comet of* 1680 *will fall into the sun, possibly after* 5 *or* 6 *revolutions, but whenever that time shall arrive, the heat of the sun will be raised by it to such a point that our globe will be burnt and all the animals upon it will perish.*" He also explained the sudden splendor of the new stars observed by Hipparchus, Tycho and Kepler by the same cause. This opinion, though, notwithstanding the authority of Newton, is not apt to find many adherents. But, whatever be the nature of these mysterious bodies, we may safely say that they are not in space without some influence, and their number and their motion are not without some beneficial purpose to our system and perhaps to others also, to a greater extent and probably in many more ways than we are able to imagine.

66. *Zodiacal Light*—Notwithstanding the great difference between the sun and the comets, there is one point of apparent resemblance. This is an appendage to the solar globe, equally mysterious as cometary appendages, and known under the name of *zodiacal light*. Sir J. Herschel has advanced the conjecture that this phenomenon is produced by the same materials which compose comets, and which these bodies lose when approaching the sun, But, whatever be the origin of the phenomenon, it will be enough for us briefly to expose the fact and some of the circumstances attending it. The zodiacal light, which is visible, especially in the month of March, after sunset, and in September, before sunrise, resembles in its intensity that of twilight, but it differs from it in form and direction. It resembles a cone inclined to the plane of the horizon and extending towards the regions of the zodiac, occasionally reaching the meridian, and visible even long after the disappearance of twilight. It moves with the sun and appears to surround it like an oval spheroid of nebulous matter, the larger diameter of which coincides with the solar equator. It extends to a distance from the

sun, equal at least to the radius of the terrestrial orbit; hence it is the effect of some transparent substance diffused in the interior of the same orbit, but extremely rare, as is evinced by the feebleness of the light it reflects, and by the undisturbed motion of Venus and Mercury which continually pass through it, describing their orbits. It may also be a cloud of meteors, and in this case Sir J. Herschel's conjecture and the view of Prof. Schiaparelli in regard to comets would agree well with the fact.

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# STELLAR FIRMAMENT.

## ARTICLE I.

### SIMPLE STARS.

67. *General view of the Stellar Firmament*—The regions of space occupied by the solar system, vast as it is, form but a small portion of the universe. The inquisitive spirit of man, which naturally tends to the infinite and throws its searching glance beyond all limits, after having reached the extremities of the solar system, does not and cannot stop there, but goes forward through the interminable realms of space, compared with which the solar system is found to dwindle to a point. But what else may be found? Within the limits of our system the secrets yet to be disclosed are more numerous than the truths which science has gathered in centuries of investigations and labor. What may we expect to find in such remote regions as those of the stellar firmament? Truly very

little of that abundance of marvels which the creative power of God has profusely lavished on them; but even the little that science has succeeded in discovering is much and full of interest and magnificence. The first amazing fact which presents itself, is the vast space surrounding the solar system, which stands alone in the midst of an immeasurable solitude. We shall presently see that direct observation incontestably establishes this fact, which is, besides, fully confirmed by indirect observation. The presence of a mass, or of masses, in the neighborhood of the solar system would be attended by effects of gravitation discoverable in the motion of the planets, but this is not the case. Then comes the countless number of stars, self-luminous bodies like the sun, various in splendor, light, magnitude and distance; a great number of which present the same invariable brightness and apparent magnitude, as they preserve the same position in space; others are variable, some periodical. Many, like the sun, stand alone in the midst of a vast solitude, but many are accompanied by other stars, and are related to each other with the same tie of mutual attraction which connects the sun with the planets, and the planets with their satellites; they are suns revolving about other suns, and are distinguished from the others by the title of *double stars*. More amazing still are the numerous clusters which the telescope has discovered on every part of the firmament; they consist of innumerable stars crowded together. To these succeed the nebulæ.

68. *Parallax of stars*—It is a well known theorem of optics that the apparent dimensions *ab* (Fig. 37) of an object seen from a point *s*, vary inversely as the

distance of the same object from that point. Hence the angle $asb$ (which is the parallax) diminishes, when the distance of the object increases and at the distance $so'$ the angle $a'sb'$ of parallax is less than $asb$, and at the distance $so''$, the angle $a'sb''$ is less than $a'sb'$, etc. Hence also the sum $a + b$ of the angles of the triangle $asb$ is less than the sum $a' + b'$ of the angles of the triangle $a'sb'$ and $a' + b'$ is less than the sum $a'' + b''$ of the angles of the triangle $a''sb''$. The sum, however, of the two angles which increase with the distance from $s$ can never reach 180° as long as the dimensions of $ab$ are commensurable with its distance $so$ from $s$; and the sum of the same angles subtracted from 180° gives the parallax, i. e., the angle subtended by the dimensions $ab$ at $s$.

Let us now apply this reasoning to the case of the earth and the stars. The earth during 6 months passes from a point of its orbit to the opposite point, distant from the first in a rectilinear direction more than 180 millions of miles. Let $ab$ represent this distance, i. e., the diameter of the terrestrial orbit. Observing the same star $s$ from $a$ and from $b$ and measuring the angles $sab$, $sba$, the difference between their sum and 180° is the parallax of the star and the measure of the angle subtended by the diameter of the terrestrial orbit seen from that star. Suppose this parallax to be 1°. The diameter of the terrestrial orbit seen from that star, would be hardly equal to three times the apparent diameter of the moon (the sun would appear from that place smaller than Jupiter) and the distance of that star from the centre of our system would be 9168 millions of miles—nearly four times the distance of Neptune from the same centre. No star is found to have such a parallax, but for all of them, almost without exception, the sum of the angles *sab*, *sba*. is permanently equal to 180°. Hence their parallax, referred to the diameter of our orbit, is 0°, 0′, 0″. The diameter of the terrestrial orbit, therefore, compared with the distance of these bodies from us dwindles to a point ; also a sphere, whose diameter and distance from the same stars would be equal to the diameter and distance of the orbit of the earth from them, could have no other appearance than that of a point. For the same reason of the parallax being equal to zero, the distance of the stars from us is immeasurable. The supposition has been made of a star having 1″ of parallax when seen from the extremities of the diameter of the terrestrial orbit. The distance of this star from the sun would be 13 billions of miles, nearly 169 thousand times as distant as the earth is from this centre, and more than 5 thousand times the radius of the orbit of Neptune. Light travelling from such a star would require three years to reach our system.

Notwithstanding the great number of stars, upon which instruments of observation of unlooked for perfection, in the hands of the most able and zealous observers, have been directed, the results of these labors have not yet brought out one single star, the parallax of which would amount to 1″. It is a well demonstrated fact, therefore, that the solar system stands in the midst of a vast solitude, if the space between it and the stars be compared with its own dimensions. Prof. Henderson, during his residence at the Cape of Good Hope, succeeded in making a series of observations upon the star designated as *α* in the constellation of Centaur, which gave a parallax a little less than

1″, i. e., 0″.9. Messrs. Bessel, Struve and Peters have also succeeded in finding the parallax of some few more stars, but less than that of *α Centauri.* These stars are 61 *Cygni, α lyræ, Sirius,* 2 *Ursæ Majoris, Arcturus, Polaris and Capella.* The parallaxes of the two last, on account of their smallness, are very doubtful; those of the others are admitted as having been ascertained with tolerable certainty and precision. The annexed table, gives the amount of the parallaxes found, the corresponding distances of each star from the sun, and the time which their light requires to reach our system.

| STARS. | PARALLAX. | DISTANCE. The unit being the diam. of Neptune's orbit. | TIME. Time required for the light to reach our system |
|---|---|---|---|
| α Centauri | 0″.919 | 2600 | 3.2 years |
| 61 Cygni | 0″.348 | 7800 | 9.43 " |
| α Lyræ | 0″.261 | 10400 | 12.57 " |
| Sirius | 0″.230 | 18200 | 21.67 " |
| 2 Ursæ M. | 0″.133 | 20800 | 24.80 " |
| Arcturus | 0″.127 | 21666 | 24.98 " |
| Polaris | 0″.067 | 26866 | 31.13 " |
| Capella | 0″.046 | 61532 | 71.75 " |

Since the length of the diameter of Neptune's orbit is no less than 5000 millions of miles, hence the distance of Capella from us is more than 300 billions of miles. Yet Capella, admitting its parallax to be correct, is one of the few stars whose distance from us is measurable, the others being at distances which it is far beyond our power to measure, probably amounting to distances thousands and millions of times as great as that of Capella. Analogy is certainly in favor of this distribution in various ways.

69. *Precession, Nutation and Aberration*—Although the relative position of the stars is not changed by the change of place of the earth in space, yet the change of position of the axis of the earth, although slight, changes their position relatively to the equator and the equinoctial points. This apparently paradoxical effect may be illustrated by a comparison. The relative position of the masts of a multitude of ships stationed along the sea shore will be changed for a spectator who, being at a moderate distance from them moves more or less his position. When, however, the distance to which the spectator moves is sufficiently great, the change is imperceptible, which is precisely the case with the stellar parallax. But if the spectator be at sea either moving from place to place or remaining on the same spot, and being unaware of the rocking of the boat, refers this motion to the sea shore, he will see all the masts raised and depressed alternately, although his own motion, which is the cause of the apparent effect, is insignificant in comparison with that of translation, which proves insufficient to produce a relative change of position among the masts. The reason of the different apparent effect is that the least change in the horizontal position of the boat is sufficient to produce a perceptible angle of deviation between the surface or sides of the boat and the objects situated in a permanent position at a distance from it, which angle of deviation, whether the distance be great or small, is always the same;

while the change of parallax does not depend on the angular inclination of the place where the spectator is, relatively to the observed objects, but solely on the different points from which the visual rays are directed to the same objects ; it depends also on their distance from the spots of observation, and it is a change perceptible or not, according as the distance of the points of observation is sufficiently great or not, relatively to the distances of the observed object.

The earth, on account of its spheroidal form or protuberance of the equatorial regions, and on account of the inclination of its axis of revolution to the planes of the ecliptic and that of the lunar orbit, is acted upon by the attraction of the moon and of the sun otherwise than it would be if it were a perfect sphere. In this last supposition the inclination of the axis of revolution to the planes of the ecliptic and of the lunar orbit could not change the action of the sun and of the moon on the terrestrial globe, its mass being always in the same condition relatively to the attracting bodies. In the case of the spheroidal form the position of the axis modifies the mutual influences of the bodies. The discussion of this subject and its full development belong to celestial mechanics and are too complicated to find a place here. Some idea of it may, however, be obtained from the few remarks which we subjoin.

Let I, II, III (Fig. 38), be different positions of a globe which describes a circle the plane of which is represented by $oCo'$, and let the centre of this circle be also the centre of attraction of this globe. If the globe be a perfect sphere and of uniform density, the action of the centre on it will be, as we have remarked, the same whatever be the inclination of the axis $pp'$ about which the sphere may revolve ; but if a ring *ab* passing over the equatorial regions be connected with the sphere the action of the centre on the mass, composed of the sphere and of the ring, will be different according to the different inclination of the axis *pp'*. If the axis *pp'* be at right angles with the plane *oCo'*, the ring will coincide with the same plane and the action of the centre on it will remain unvaried all around the circular orbit ; but if the axis be inclined to the plaae of the orbit, as represented in the Fig., the action of the centre on the ring will be different for different points of the orbit. Taking position I, the portion *oa* of the ring on the side of *C* being nearer to the centre of attraction, is impelled towards it with a greater force than the opposite part *ob*, which difference of action produces the effect of bending the ring towards the plane of the orbit, and consequently brings the axis of the sphere towards a vertical position. In position II, in which the centre of the sphere is supposed to be on the line of intersection between the plane of the ring and that of the orbit, the ring is in the same condition relatively to *C* as if it was on the plane of the orbit. In position III, opposite to I, the action of *C* on the ring and globe is the same as in position I. In intermediate positions between I and II, and between II and III, the action of the centre *C* on the globular and annular mass is analogous to that of the two positions I and II, but bending the axis in a continually varying direction. It is enough for us, however, to have pointed out the cause of a change in the position of the axis of a globe revolving about a centre, when the axis of the globe is inclined to the plane of the orbit, and the globe is connected with a ring about the equatorial regions or the spheroidal protuberance, such as that of the terrestrial globe. A closer and complete investigation of the subject, in which the combined action of the sun and moon and all the modifying circumstances are taken into account, has found that this action on that portion of the terrestrial mass by which the spheroid exceeds the volume of a sphere, having for its diameter the axis of revolution of the globe, causes this axis to revolve about a perpendicular to the plane of the ecliptic, describing a conical surface, not the surface of an even cone, but, we may say, of a fluted cone. For, the description of this cone is accompanied by an oscillatory motion of the axis, approaching to and receding from that of the ecliptic, so that a section of the cone formed by a plane parallel to the plane of the ecliptic would have the form of an undulating line, as represented in Fig. 39. Observations and calculations show, moreover, that the time required by the axis of the earth to make a complete revolution around that of the ecliptic is 25,868 years. The motion of the axis of the equator about that of the ecliptic is necessarily attended by a constant change of position of the common line of intersection between the planes of these two circles, i. e., the line of equinoxes, so that this common diameter will, like the axis, perform a complete revolution of 360° during the same period of time, and its mean annual change, or angular motion on the plane of the ecliptic amounts to 50″.1. This motion of the equinoctial line manifestly changes the position of the equinoxes; and, since it is opposite to the apparent annual motion of the sun, it follows that the sun meets the equinoctial points before completing the whole circular motion of the ecliptic, whence it is called *Precession of the equinoxes* or simply *Precession.* The equinoxes being points of reference for every other point of the celestial sphere, it follows that the position of the stars referred to them is constantly changing. The oscillatory motion of the axis of the equator, and the consequent approaching and receding of the two planes of the equator and of the ecliptic is called *Nutation.* The stars, being referred to the plane of the equator, suffer, in consequence, an apparent change of position relatively to it.

Another apparent change in the position of the stars arises from the combined effect of the annual motion of the earth, and the motion of the light proceeding from them. This change is called *Aberration.* It is a well known principle of optics that the apparent position of an object is not in the direction of any ray emanating from that object, but in the direction of the ray which enters the eye. It is, moreover, demonstrated that the motion of the spectator, if it be such as to bear some proportion to that of light, causes the rays proceeding from the luminous object to enter the eye in a direction different from that in which they would enter it if the spectator were stationary. Suppose the motion of the spectator to be from *a* to *b* (Fig. 41), while the ray of light moves from *s* to *b* (and would enter the eye of a stationary spectator at *b* in the same direction *sb*), the resulting effect of these two motions causes the ray of light to enter the eye in the direction *s'b* and to present, consequently, the object at *s'* instead of at *s* on the plane formed by the linear motion of the spectator and that of the luminous ray.

The plane of the terrestrial orbit being differently situated, relatively to the various points of the stellar firmament, the annual motion of the earth affects differently the direction of luminous rays and for such stars that are in the neighborhood of the poles of the ecliptic, the effect of this motion is that of producing an apparent circular motion of the star about a centre, which is the point in which the same star would be seen if the earth were stationary; for those stars, the position of which coincides with the plane of the ecliptic, the effect of the annual motion of the earth is that of producing in them an apparent rectilinear and pendulum-like motion; and these are the only stars which are seen in their proper place, twice in a year; for during the rest of the year they apparently recede from their true position, now on one side and then on the other. The remaining stars are between the poles and the plane of the ecliptic, and for them the effect of the annual motion of the earth is manifested by an apparent elliptical motion of the same stars, approaching more or less to a straight line or to a circle according as these stars are more or less near the plane of the ecliptic, or more or less near the poles of the same circle, and the centre of the ellipse is the true position of the star.

Let us briefly indicate here how the aberration of light produces the various effects just mentioned. It is to be first observed that the effect of aberration depends only on the motion and direction of the motion of the earth and nowise on the place occupied by the earth in its orbit; so that if we represent by $mm'm''$ (Fig. 41), the terrestrial orbit, the effect of the aberration of stellar light would be the same if the earth instead of being at $m$, when its motion is that of the tangent *mt*, would pass through the centre of the orbit, moving in the direction *Cf* parallel to *mt*; or if the earth instead of being at *m′* or at *m″*, etc., when its motion is that of the tangents *m′t′*, *m″t″*, etc., would pass through the centre with the directions *Cf′*, *Cf″*, parallel to the tangents *m′t′*, *m″t″*, etc. We may consequently infer the effect of aberration produced by the motion of the earth in its orbit, from that which would result from the motion in the direction of the radius of the terrestrial orbit, taking successively and continually all the positions in the plane. We have seen that the effect of aberration is that of changing apparently the true place of the luminous object to another on the plane formed by the linear motion of the light and that of the spectator, and of transferring the luminous point from its true place to another in the direction in which the spectator moves. Consequently, since a star, situated on the pole of the ecliptic or near it, is a star whose light reaches perpendicularly the plane of the terrestrial orbit, it follows that when the motion of the earth is that indicated by *Cf*, the apparent position of the star will not coincide with the vertical to the orbit, but will be towards *f*; when the motion of the earth is that indicated by *Cf′*, the position of the star will be towards *f′*, then towards *f″*, and so on; and since the velocity of the motion of the earth is nearly uniform, the deviation from the vertical will be the same on every side, and the star, consequently, will apparently describe a circle, having for centre its true position. The light of those stars, which are situated between the poles and the plane of the ecliptic, reaches obliquely the terrestrial orbit. Supposing *C* (Fig. 42), to be the centre of this orbit, and a straight line passing through it, in a direction parallel to that of the luminous rays of the stars; this line will be perpendicular to only one of the diameters of the orbit. Let *mn* be this diameter. The diameter *pq* perpendicular to *mn* will form with the parallel to the luminous rays, two angles, one of which will be the minimum, and the other the maximum of all those formed by the radii of the orbit with the same parallel. Let *Cq* be the radius with which the minimum angle is formed and consequently *Cp* the one with which the maximum angle is formed, and let us examine the resulting effect of aberration when the motion of the earth is in the direction of the four radii *Cm*, *Cn*, *Cq*, *Cp*. In the case of the two first, the star will apparently deviate from its true position as much towards *f* and *f'* as when the luminous rays fall perpendicularly on the orbit. But when the motion is in the direction of *Cq* and *Cp*, although the star would apparently deviate towards *q* and towards *p*, it will deviate less than it does towards *f* and *f'*, on account of the motion of *Cq* being partially towards the star, and that of *Cp* as much from the star; and this motion towards or from the star, produces no effect of aberration. In other words, the motion in the direction of *Cq* is equivalent to a double motion, one directly towards the star, the other perpendicular to the line joining the star with *C*. The motion in the direction of *Cp* is likewise equivalent to a double motion, one directly from the star, and the other perpendicular to the line which joins the star with *C*. Now, only the motion in the direction of these two perpendiculars is productive of the effect of aberration; and since this motion is less than the actual motion of the earth, the effect of deviation towards $q$ and $p$ will be less than towards $f$ and $f'$, for which the motion of the earth is totally effective, The deviation will be so much the less towards $q$ and $p$, the more the line connecting the star with $C$ approaches the plane of the orbit. The deviation for the motion of the earth in the direction of those radii, that are between the four $Cm$, $Cn$, $Cp$, $Cq$, is greater than that corresponding to $Cp$ and $Cq$, and less than that corresponding to $Cm$ and $Cn$, increasing or diminishing gradually according as the radius representing the motion approaches to or recedes from $Cm$ and $Cn$. Hence the stars situated between the poles and the plane of the ecliptic, describe, apparently, ellipses approaching to a circle, for those that are near the poles, and to a straight line, for those that are near the ecliptical plane. The centre of these ellipses is occupied by the real place of the star. It is evident that the apparent motion of the stars, that are on the plane of the ecliptic, is rectilinear and oscillatory, and that the centre of the line is the true place of the star. As the fact of the aberration, with all its circumstances, proves the progressive propagation of light, it is also one of the best arguments in proof of the orbital motion of the earth about the sun.

70. *Magnitude of Stars*—When a telescope is directed to a star, the effect produced is strikingly different from that which we find when it is directed towards a planet. The telescope presents the latter with a distinct circular disk ; the star, as a mere lucid point whatever be the telescopic power employed. The effect of the telescope relatively to the stars, consists in increasing their brilliancy, and removing the radia-

tion which seems to surround them, when seen without the instrument. The absence of a perceptible disk in the stars, is rendered evident also by their occultation by the moon. When the moon is in the first and second quarter, as it moves over the firmament, its dark edge successively approaches different stars; and from time to time it passes between the stars and the eye. If a star had a sensible disk, the edge of the moon would gradually cover it, and the star would also gradually disappear. This is found not to be the case; the star preserves all its lustre until the moment it comes into contact with the edge, and then it is instantly extinguished, without the slightest appearance of diminution in brightness, even when the occultation is observed with the best telescopes. If, then, none of the stars have any discoverable magnitude at all, it may be asked, what is the meaning of the term magnitude applied to them? This term is referred to the comparative brightness and not to the real magnitude. Thus a star of the 1st magnitude means one of the greatest apparent brightness; a star of the 2nd magnitude, one which has the next degree of splendor, and so on.

The stars are also divided into visible and telescopic stars. Visible stars are such as may be seen with the naked eye; telescopic stars those that are seen with the help of an instrument. Both are classified by magnitudes, and this classification is continued from division to division; i. e., the first magnitude of telescopic stars keeps the numerical order immediately following the last magnitude of the stars visible to the naked eye. The different magnitudes commonly assigned to the visible stars are 7 in number; hence the stars which would be of the first magnitude among the telescopic, are of the 8th magnitude. The division, however, of the stars into visible and telescopic stars, as well as the subordinate classification into different magnitudes, is not easily obtained; some of the stars that are not visible to the naked eye in certain regions and under certain conditions of the atmosphere, become perceptible in other places or in different atmospheric conditions. The same stars, also, which are not visible when looked at directly, become visible to the naked eye when their light strikes the retina obliquely. We attribute to this well ascertained fact, the increased number of the stars which appear to shine in the firmament when its various regions are not looked at directly. The difference of brightness is likewise in many instances not easily discernible.

The number of stars increases rapidly with the decreasing order of magnitude. The stars of the 2nd magnitude are more numerous than those of the first; those of the 3rd much more numerous than those of the 2nd, etc. A probable explanation of this fact may be found in the following comparison. If we imagine a person standing in the midst of a wood, surrounded by trees on every side and at every distance, those which immediately surround him are few in number and appear the largest because close. The trunks or stumps of those which occupy a circuit beyond the former, are more numerous, the circuit being wider, but they appear smaller, because their distance is greater. Beyond these again, occupying a still wider circuit, will appear a proportionally augmented number whose apparent magnitude will again be diminished by increased distance, etc. It is the same with the stars ; we are placed in the midst of an immense cluster of them which surround us on every side at inconceivable and constantly increased distances ; those few that are the nearest to our system appear bright and large ; those which lie in the circuit beyond, and occupy a wider range are more numerous but less bright, and so on. Thus telescopic stars surpass greatly in number visible stars and the spectacle of the firmament presented through a good telescope on a clear night, which is not illuminated by the moon, is truly amazing; especially if the instrument be directed towards the regions of the milky way, and there moved in various directions. The stars that fill the field of the telescope there, are astonishingly numerous, nearly all invisible to the naked eye, although every one of them is a sun, perhaps brighter than the sun of our system.

71. *Periodic Stars*—The stars in general, as they are stationary in their apparent position, are equally invariable in their apparent magnitude and brightness. To this, however, there are several remarkable exceptions. Certain stars have been observed, sufficiently numerous (there being upwards of a hundred) to be regarded as a distinct class, which exhibit periodical changes of appearances and they are accordingly called *Periodical Stars.* Some attempts have been made to give an explanation of this singular phenomenon, but we must candidly acknowledge that the true cause of the variation is unknown. It may possibly be that the form of these exceptional bodies is not spherical, but flat, and hence revolving about an axis or diameter of the broad side, they present to us surfaces of real or apparently different magnitude,

thus increasing and diminishing the amount of light they transmit to us. They may, also, be spherical bodies, but differently illuminated on different sides which by rotation, being presented successively to us exhibit periodical changes. Or it may be conjectured that opaque bodies of large dimensions circulate around them, and these passing between us and the stars eclipse their light; or that they are systems, the centres of which are opaque but attended by self-luminous satellites or stars, which approaching to and receding from us at great distances vary, accordingly, the brightness of their light. These suppositions are all more or less liable to objections and much more still are others which we omit. The most remarkable periodical star is that called *o* (omicron) *Ceti*, in the neck of the Whale, first observed by David Fabricius, on the 13th of August, 1596. This star retains its greatest brightness for about 14 days, being then equal to a star of the 2nd magnitude. It then decreases continually for 3 months until it becomes invisible, and thus it remains for 5 months; then it reappears and increases gradually for 3 months, until it regains its maximum splendor. This period of about 331 days, is not always the same, and the gradations of brightness through which it passes are said to be subject to variations. Hevelius states that in the interval between 1672 and 1677, it did not appear at all. This would give an indication of an interrupted or diminished accension of a combustible substance covering the surface of that stellar body, and of an ordinarily periodical increase and diminution of the combustion. The star called *Algol* in the head of *Medusa* in the constellation of *Perseus*, affords a striking example of the rapidity with which these periodical changes sometimes succeed each other. This star generally appears as one of the 2nd magnitude; but an interval of 7 hours occurs at the expiration of every 62, during the first 3 1-2 hours of which it gradually diminishes in brightness till it is reduced to a star of the 4th magnitude, and during the remainder of the interval increases until it recovers its original magnitude. Recent observations have indicated a change in the period of the variation. The star δ *Cephei* is also remarkable for the regular periodicity of its lustre. It passes from the least to the greatest degree of brightness in 48 hours, and from its greatest to its least in 91 hours. The changes of lustre of β *Liræ*, according to the recent observations of Mr. Argelander, are very complicated and curious. Its entire period is 12 days, 21 hours, 53 minutes and 10 seconds, and in that time it first increases in lustre, then decreases, increases again and then decreases; so that it has two maxima and two minima. At the two maxima its lustre is that of a star of the 3.4 magnitude.

72. *Temporary Stars*—Phenomena in most respects similar to those just described, but exhibiting no recurrence, have been observed in other stars. From time to time stars have appeared in various parts of the firmament, have shone with extraordinary splendor for a limited period and then disappearing have never again been observed. The first star of this class recorded is one observed by Hipparcus, 125 B. C., the disappearance of which is said to have led that astronomer to make his celebrated catalogue of fixed stars. In the year 389, a star blazed forth near

2 *Aquilæ*, which shone for 3 weeks, appearing as brilliant as the planet Venus, after which it disappeared and has never since been seen. In the years 945, 1264 and 1572, brilliant stars appeared between the constellations of *Cepheus* and *Casseiopeia* The account of their positions are. however, obscure and uncertain, but the interval between the epochs of their appearance being nearly equal, it has been conjectured that they were successive returns of the same star. The appearance of the star of 1572 was very remarkable, and having been witnessed by the most eminent astronomers of that day, the account of it may be considered well entitled to confidence. Tycho Brahe whilst returning from his laboratory to his dwelling house, the 11th of November, found a crowd of peasants gazing at a star which he was sure was not visible half an hour before. It was as bright as Sirius and continued to increase in splendor until it surpassed Jupiter; finally it attained such a lustre that it was visible at mid-day. In December it began to diminish and altogether disappeared in March 1574. Another splendid star burst out suddenly on the 10th of October, 1604, in the constellation of *Serpentarius*, as bright as the preceding; it continued visible till October 1605. Mr. Hind saw, on the night of the 28th of April 1848, a star of the 5th magnitude in the constellation of *Ophiuchus* not visible before the 5th of that month; it continued to be visible and was observed until the year 1851. To this class of temporary stars may be referred those which have disappeared from the firmament. On a careful examination of the heavens and the comparison of catalogues, several stars formerly known are now ascertained to be missing.

These occasional and apparently anomalous apparitions and extinctions of stars are probably, the recurrence of regular and periodical phenomena, relatively to these stars like those of the preceding class. Certainly an extraordinarily great periodical length of recurrence is far from being an obstacle for such an hypothesis, when we consider the vast length of many of the periods of astronomical phenomena.

73. *Colors of the Stars*—The light of the stars is not of the same color in all, a somewhat yellowish color, similar to that of the sun, seems to prevail; but some present a brilliant color similar to that of the electrical spark issuing from mercury; others have a more or less reddish color, others are green or blue. The temporary stars, as that observed by Tycho, exhibit the phenomenon of a successive change of color, and of brilliancy. We know, moreover, that some of the stars have, at present, colors different from those they had at other epochs. For example, Sirius at present shines with a brilliant light which is far from being reddish, and yet Seneca, a diligent observer of nature, tells us that Sirius has been as reddish as Mars, and Horace confirms the same fact, where he says:

> "Persta atque obdura seu rubra canicula findet.
> Infantes statuas."—Sat. l. ii. s. v.

This beautiful phenomenon of the colors, and especially the change of color, is not easily explained; perhaps it depends only on the materials which maintain the combustion. It has been ingeniously suggested by Prof. Doppler that, admitting the undulatory theory of light, the motion may also influence the color of a luminous object. On account of the contrast the same phenomenon presents itself even in a more attractive aspect in double stars and clusters. But let us pass to something more in detail regarding these classes of stellar bodies.

## ARTICLE II.

### DOUBLE STARS AND CLUSTERS.

Many of the stars, which to the naked eye appear to be single, are found, when examined by telescopes of a certain power, to be two stars, placed so close together that they appear as one. These are called *double stars*. Since the labors of Sir W. Herschel who first catalogued 590 double stars, their number has been augmented to several thousands. We must, however, distinguish two classes of double stars, optically or apparently, and really double stars. Optically double stars are those whose apparent juxtaposition, or apparent vicinity is destitute of any real connection or companionship, and results merely from their linear position relatively to our system, although they are or may be as distant from each other as the nearest of them is distant from us. Really double stars, and those to which this appellation is particularly and exclusively applied, are not apparently but in fact relatively near to each other and connected together as the planets with the sun. This discovery is due to the labors of Sir W. Herschel who after having constructed his gigantic instrument and observed so many stars placed in proximity to one another, and which he thought at first to be only in apparent proximity or simply optically double stars, directed his attention to them in the hope of discovering their parallax, which if discoverable, could be detected much more easily in them than in simple stars. The object aimed at was not obtained, but he had not proceeded far in his researches when phenomena unfolded themselves before him, indicating a discovery of a much higher order and interest than that of the parallax. He found indeed that the relative position of the individuals of many of the double stars, which he examined, were subject to a change; but this change had no relation to the periodical motion of the earth; and although the periods connected with these observed motions, were developed afterwards, they manifested from the beginning intervals which neither agreed with each other nor with the earth's annual motion. Hence he concluded that these apparent changes of position were due to the real motion in the stars themselves, like that of the planets around the sun. The slowness of succession of changes required a long period of time before their motion could be certainly and accurately known; and accordingly although these researches were commenced in 1778, it was not until the year 1803 that the observations offered to Sir W. Herschel sufficient data to justify a positive conclusion respecting their orbital motion.

74. *Extension of the law of gravitation to the stars*—The moment the revolution of one star around another was ascertained, the idea of the extension of the principle of gravitation to those remote regions of the universe naturally suggested itself. An elliptical orbit is a test of the presence and sway of the law of gravitation. If then it could be ascertained, that the orbits of the double stars were ellipses, we would at once arrive at the fact, that the law of universal gravitation prevails throughout the universe. This fact

has been established. The first elliptical orbit was calculated in 1830 by Savary and then by Willarceau who showed that the motion of one of the most remarkable of these stars, i. e., ξ *Ursæ Majoris*, indicated an elliptical orbit described in the period of about 60 years. Prof. Encke, by another process, arrived at the fact that the star 70 *Ophiuchi* moved in an ellipse with a period of about 74 years. Several other orbits were ascertained and computed by Sir John Herschel, Madler, Hind, Smith and others. The stars and their periods are given in the annexed table.

| NAME OF THE STAR. | PERIOD OF REV. IN YEARS. | NAME OF THE STAR. | PERIOD OF REV. IN YEARS. |
|---|---|---|---|
| η Cor. Borealis | 42.50 | ξ Bootis | 117.14 |
| ξ Ursæ Maj. | 61.58 | μ Ophiuci | 80.34 |
| ω Leonis | 82.53 | δ Cygni | 178.70 |
| ζ Herculis | 36.36 | μ 2 Bootis | 649.72 |
| γ Virginis | 182.12 | α Centauri | 77.00 |

We have observed that one of the features which characterize these *binary stars*, and in general clusters of stars, is their color. Their orbits seem to be similar to those of our comets, more eccentric than those of the planets; thus the one revolving about the primary α *Centauri* presents an orbit, not much dissimilar in period and, perhaps, in dimensions to the orbit of Halley's comet. There is every probability, that each star is a centre of a planetary system like our own; and in the case of binary stars one system revolves around another, producing effects of a most attractive nature, especially such as are connected with the colors of the luminous centres, so that the best poetical genius would in vain endeavor to imagine anything like it. The opaque planets of each system would periodically have the luminous centres now in conjunction, now in opposition, or at a greater or less angular distance from each other. In the first case, both suns would rise and set together, and nights would follow highly brilliant days. In the second, while one of the suns sets, the other would rise and no day would be succeeded by night. In the latter supposition one sun would follow the other at a greater or less distance, and during a part of the day both would be seen at once in the heavens. The vicissitudes of light, which vary with the magnitude and distances of the luminous centres, are rendered more striking when the two suns diffuse light of a different color. Suppose one of the cases of observed combination to be that of a *crimson* with a *blue* star. If the blue sun rises first and presides for a time, alone in the heavens, it will diffuse a blue morning light. Its crimson companion, however, soon appearing and the light of both being blended, a white day will follow. As evening approaches, and the orbs descend towards the western horizon, the blue sun will first set, leaving the crimson alone in the heavens, and a red evening will close this succession of varying lights. As the year rolls on, these changes will be varied in every conceivable manner.

75. *Multiple Star and Clusters*—The same phenomena, with a still greater variety of combination, must be the necessary effect of multiple stars. When telescopes of the greatest efficiency are directed upon some stars, which to more ordinary instruments appear only double, they prove to consist of three or more

stars. In some cases one of the two companions is double, so that the whole combination is triple; in others, both are double, the whole being therefore a quadruple star. An example of this class is presented by the star ε *Lyræ*.

The discovered connection existing between several stars placed in proximity to each other, naturally suggests the idea that something analogous (but on a larger scale, and with a multiplicity of combinations of mutual actions, and with resulting effects certainly not easily discoverable) must take place in those accumulations of stars crowded together within a small space and which are met with in every part of the firmament. It may possibly be that science, in future ages, will be allowed to disclose, in some measure, these secrets. At present such clusters are mere objects of study and admiration. The cluster with which every one is familiar is that of the *Pleiades*, in the constellation of the *Bull;* it is one of the most scattered; and the reason of its being well known is that some of its stars (seven in number) are visible to the naked eye; common telescopes are sufficient to discern hundreds of them in it. The other clusters are more compact and more difficultly resolvable into separate stars, and when seen without an instrument, their ordinary appearance is that of a nebulous speck of dimensions never exceeding an arc of a few minutes; when observed with good instruments, the number of the stars composing them amounts to hundreds and thousands. It is not possible to form an idea of these objects without seeing them; so great is the number of the individual stars composing them, the variety of their color, the brilliancy and abundance of their lights. Fig. 43, which represents the central part of the cluster of *Perseus*, and is taken from the last work of *Le Stelle*, published by our lamented companion and friend, Fr. Angelo Secchi, will give an idea of their number within a space less than that occupied by the disk of the moon. Fig. 44 is another cluster in the constellation of *Sagittarius* scarcely visible to the naked eye. Its shape is that of a small cloud less than one half of the lunar disk. The stars forming this cluster are called caustics, because their arrangement bears a resemblance to caustic curves. Another group not far from the preceding, in which the stars seem to radiate from a central one, is represented by *A* Fig. 45. The next, *B*, is a cluster in the constellation of *Hercules* contained in a space less than the eleventh part of *A* and *C*. It belongs to that class of clusters that are called globular and are formed by a multitude of stars very minute and close to each other. The cluster of *Antinous*, represented by *C*, is remarkable for the uniformity of distribution and magnitude of the stars. Figs. 46 and 47 are two surprising clusters of the globular class, the first in the constellation of *Aquarius*, the second in that of *Canes venatici*. It is impossible to count the number of the stars which form these clusters.

76. *The Milky Way*—The Milky Way presents to the naked eye the appearance not of stars crowded together, but of a whitish nebulous light. It extends over a large portion of the celestial sphere, following nearly the direction of a great circle of the same sphere ; at a certain point it is bifurcated and diverges into two branches, which afterwards reunite, and at other places it throws out off-shoots. It was denom-

inated *Via Lactea*, or the *Galaxy* by the ancients, and it has retained both names. When this nebulous whiteness is submitted to telescopic examination, with instruments of adequate power, it proves to be a mass of countless stars. Some idea may be formed by the number of those susceptible of being counted in spaces of given extent. Sir W. Herschel states that in those parts of the Milky Way in which the stars are most thinly scattered, he sometimes saw 80 stars in each field. In an hour, the 15° of the firmament carried before his telescope were divided into sixty successive and distinct fields. Allowing 80 stars for each of these fields, there were thus exhibited in a single hour, without moving the telescope, 4800 distinct stars. But by moving the instrument at the same time in a vertical direction, he found that in a space of the firmament, not more than 15° long by 4° broad, he saw 50,000 stars large enough to be distinctly visible and counted. On presenting the telescope to the richer portion of the *Via Lactea*, Herschel found much greater numbers. In a single field he was able to count 588 stars; and for fifteen minutes, the firmament being moved before his telescope by the diurnal motion, no diminution of number was apparent, so that he estimated that in that space of time 116,000 stars must have passed in review before him.

77. *Probable connection of the Galactic Belt with other stars*—The Galactic Belt, besides the obvious appearance of an uninterrupted accumulation or immense system of stars, appears, from a careful examination of the heavens, to be the most dense portion only of a still wider system. The observations on which this conjecture is founded are due to the ability

and persevering ardor of Sir W. Herschel and of his no less illustrious son, Sir John Herschel. We will limit this subject to a brief statement of these observations and of the view of the same astronomers, which has been favorably received by the scientific world. The plane of reference of these observations is the great circle of the celestial globe, which bisect the Galaxy and which is, accordingly, called the *Galactic circle.* It intersects the celestial equator at two points, 19° east of the equinoctial points and is inclined to the equator at an angle of 63° and therefore to the ecliptic at an angle of 40°. Sir W. Herschel submitted that part of the heavens observable from his northern latitude to a rigorous telescopic survey and his son extended the survey into the southern hemisphere. The result proved that around the poles of the Galactic circle, or as they have been called the *Galactic poles,* the stars are more thinly scattered than elsewhere, and departing from them in any direction the number of stars included in the field of view of the telescope increases first slowly and then more rapidly; this increase continues as the telescope descends towards the Galactic circle, about which it reaches its maximum. The distribution, therefore, of the stars over the surface of the celestial sphere, follows a distinct and well defined law. An analysis of the observations of Sir W. Herschel, which was made by Prof. Struve, and a like analysis of the observations of Sir J. Herschel in the southern hemisphere, have determined the number of these stars, taking the average number of stars for each successive zone, measuring 15° in breadth and bounded by lines parallel to the Galactic circle as follows:

| Galactic Latitude. | Average number of Stars in a circle 15° in diameter. |
|---|---|
| N. from 90° to 75 | 4.32 |
| " " 75 " 60 | 5.42 |
| " " 60 " 45 | 8.21 |
| " " 45 " 30 | 13.61 |
| " " 30 " 15 | 24.09 |
| " " 15 " 0 | 53.43 |
| S. " 0 " 15 | 59.06 |
| " " 15 " 30 | 26.29 |
| " " 30 " 45 | 13.49 |
| " " 45 " 60 | 9.08 |
| " " 60 " 75 | 6.62 |
| " " 75 " 90 | 6.05 |

Although Sir W. Herschel had not inferred from his observations the law of numerical increase as shown above, still he had discovered it clearly enough to see in it the systematic arrangement of which the Galaxy is only a part. To form a correct idea of Sir W. Herschel's view on the subject, it must be observed that, in the supposition of a uniform distribution of stars in a space limited by a sphere of which the solar system would occupy the centre, no difference of numbers in the general arrangement of stars would be discoverable, by directing the visual ray towards any part of the celestial sphere, or, certainly, not such as to increase or diminish with a certain regular progression by approaching to or receding from certain regions of the firmament. But if we conceive the solar system to be placed at a distance from the centre of the sphere occupied by the stars, the appearance of the stellar firmament will be quite different; on one side the number of stars will be less than on any other, and moving the visual rays from that side in which their minimum appears, towards the side diametrically opposite, their number will constantly increase, until it reaches the maximum, on the same opposite side, on which, besides their greatest number, the stars will be at a greater distance from the solar system and consequently of smaller and smaller appearance, and forming a mass more and more compact. In this supposition the same mass of stellar bodies might have the same cloudy appearance from the solar system as the Milky Way, but it would be confined to a section of the celestial sphere similar to a polar zone. Although this is not the case, the above remarks, however, give us the key to find the arrangement which the stars may have to present to us an aspect similar to that of our firmament. For suppose the stars, partly individual, partly associated (double stars and clusters), to be distributed uniformly in a space not limited by a sphere, but embracing an equatorial zone, bisected on one side, and let the solar system occupy the centre of the sphere to which the bifurcated zone belongs. It is plain that the greatest number and most distant stars visible from the centre must be in the direction of the radii, and within the limits of the same zone, and the number and distance of the extreme visible stars will diminish in proportion as the direction of the visual ray approaches the poles of the zone. With this arrangement it would be easy to explain the phenomenon of the increasing number of stars from the Galactic poles to the Galactic circle, and how the *Via Lactea* is connected in one system with the remainder of the stars visible in the firmament; and this, in substance, is the explanation given by Sir W. Herschel. But in our supposition, the Milky Way would have the appearance of much regularity, and its cloudy appearance would, on every side, gradually vanish without throwing out irregular off-shoots, such as those which we see in reality. Hence, although the principle of the explanation is contained in the supposed arrangement, some modifications must be added. We may observe that the sections of such a stratum of stars, of which the sun is one, are necessarily different, if taken in different directions, and consequently the same stratum if seen from different points of space would appear of different forms; if seen v. gr., from any point of the axis of the Galactic circle it would have the form of a disk; seen from other points it would appear like an ellipse of irregular form. A section of the stratum made by a plane passing through the axis of the Galactic circle, and bisecting the diverging branches would be similar to the letter Y, and hence if the same stratum should be seen from some point of a perpendicular to this plane, its appearance would be that of the said letter.

78. *Probable connection between the members of the stratum of stars including the sun*—Having thus reduced the Galaxy with a multitude of other stars, one of which is our sun, within limits and into one system; it may be asked whether the individual members of this vast cluster are totally independent of each other or whether they are connected together by some link which would add to the completeness and unity of the system. There are two arguments

in favor of the existing connection, one taken from the nature of the force of gravity ; the other, from the fact of the motion of the sun. The force of gravity constantly diminishes with the increase of the distance but never becomes null ; hence, although the distance between star and star is exceedingly great as the distance of the sun is from them, yet not being infinite, the stars are not out of the reach of mutual influence. Nor can we say that the law of universal gravitation is limited to the solar system, since the facts, well ascertained concerning multiple stars, show that the same law extends alike to all the bodies in the universe. It follows, then, that the stars and the sun are, on account of this mutual influence, liable to motion ; but to determine this motion or influence is a problem of such complication and the data necessary for its solution are so hidden from us that no attempt can be made to solve it. We may however observe : First, that the action of each individual centre on another, cannot be but extremely insignificant and imperceptible. Secondly, the action of all the centres on each one taken individually may amount to a resultant of perceptible effect ; or the action of one section may be paralyzed by that of another, and the individual centre may be at rest according to the position of the latter in the stratum. Thirdly, if the effect of motion be produced on the stars, it may be such in every case as to be difficultly perceptible from our system, even supposing the most favorable circumstances, and after a long period of time. An exception, however, must be made with regard to the sun, as we will presently see. Fourthly, the motion of the individual centres, owing to the immensity of the distance, must be nearly rectilinear for a great extent of space and long duration of time. The reason why the action of the centres of the stratum on the sun must be more easily perceived than that on the other individual stars, is because the stars cannot give any other evidence of the effect of this action except by their own individual motion, while the motion of the sun together with its system, if perceptible, must be manifested by different apparent motions of the stars which are placed in favorable positions and distances from it. Suppose the sun to move with its system through space in any direction, an observer placed on the earth is, in this case, like a spectator on a steam boat, moving on a river, who perceives his progressive motion from that of the banks in a contrary direction. Thus the observer on the earth, if the motion of the solar system has sufficient velocity relatively to the distance of the stars placed laterally to the line of motion, will see them moving in a direction contrary to that of the system, but not all of them equally. Besides, the stars in the regions of the universe, towards which the motion of the system is directed, would appear to recede from each other, while, on the contrary, the stars in the opposite quarter would seem to be crowded more closely together.

Although no general effect of this kind has been manifested in any conspicuous manner among the fixed stars, yet many of these objects have been found in long periods of time to have shifted their position in a sensible degree. Thus, v. gr., the three stars, Sirius, Arcturus and Aldebaran, have undergone, since the time of Hipparcus, 130 B. C., a change of position southwards, amounting to more than half a degree.

The double star 61 *Cygni* has, in half a century, moved through nearly 4′.5. The stars ε *Indi* and μ *Cassiopeia* move in the same direction at the rate of 7′.74 and 3′.74 annually. Sir W. Herschel, in 1763, reasoning upon the proper motion which had then been observed arrived at the conclusion that such appearances might be explained by supposing that the sun has a motion directed to a point near the star λ *Herculis*. Several other estimates have been since given by others, but the mean of all of them differs but little from the point originally assigned by Herschel. No doubt seems to be entertained at present concerning the real motion of the solar system towards a definite direction; other circumstances attending this motion are for the present only conjectural. The fact, however, alone of the motion of the system towards a determined region is a sufficient argument for us in proof of the connection existing between the various centres composing the stratum of celestial bodies, one of which is the sun, and of the completeness and unity of system formed by the same stratum.

79. *Retrospective view*—The least of all systems, known to us, is the one formed by the earth with the moon. But the earth and the moon, although a complete system, is subordinate. It is a compound member, but only one member of another system gigantic in its dimensions, magnificent in the variety of its members, admirable in the multiplicity and order of its combination; such in fine as to reduce the terrestrial volume and mass to an insignificant globular grain. Yet the sun or even the solar system itself, notwithstanding its grand dimensions, becomes a mere point, when compared with the distance which separates it from

the stars, even the nearest to it. This immensity of space increases indefinitely in the stellar regions, stars succeeding stars at undiminished intervals of separation, and with constantly increasing numbers; some of them are individual, although, in all probability, centres of systems of opaque bodies like the sun. Others are associated two and two, or three or more connected together, with the same mutual influence, which governs the motions of the members of our system. Others form clusters, in all appearance and probability, connected together in a similar manner. Such an immeasurable creation presents to us a character of unity and a system before whose magnitude all the individual members and the distances of the contiguous centres diminish in a still greater ratio than the sun and the solar system do relatively to the sphere embracing the neighboring stars. But this system, compared with which the innumerable multitude of stars are like atomic sparkles of light, has its limits of definite magnitude. It is not given to man even so much as to conjecture the dimensions of these limits. It is, however, enough for his mind, to know their existence, to throw itself again with undiminished vigor into the abyss of space beyond them. What else is there, the mind instantly asks; what else is there beyond these limits? Are these the limits of the created world, or does a larger field remain still to be surveyed? Is this system of stellar bodies a solitary one in the universe or is it one among many relatively as far apart from one another as the various centres of the system are from each other? An answer to these questions will be briefly given in the next article.

But first let us add a few remarks concerning a subject which at present occupies the mind of scientists. We allude to the study of those constituents which in a state of incandescense render visible to us the sun and the stars. The spectroscope is the instrument by means of which the unexpected knowledge of these constituents has been obtained. The celebrated Fraunhofer, after the happy results of his study on the solar spectrum, was the first to undertake a similar study on the light of the stars. He found in general the stellar spectra much different from that of the sun. After Fraunhofer the same study was continued by Lamont and Donati. The latter in 1862, published a memoir in which the description and measurement of the spectra of 15 among the principal stars are given. But the scarcity of light proved an obstacle in his researches. To obviate this difficulty, Prof. Amici contrived a new prism, the construction of which no sooner became known in France, than the Optician Hofman considerably improved the same, and by means of this expedient, observers have been enabled to extend spectroscopic researches to stars even of the 9th magnitude. Among those who have distinguished themselves in the study of the stellar spectra, subsequently to the improvement of the spectroscopic apparatus, mention is made of Profs. Huggins and Miller, and also of Fr. Secchi, who to this study in particular devoted the latter part of his laborious and useful life. We shall conclude by mentioning some of the results obtained by these and other able scientists. In Sirius the presence of hydrogen under considerable pressure has been verified. The presence of sodium, iron and other metals has been detected in the spectrum of *α Orionis.* The spectra of the stars Arcturus, Aldebaran, Pollux and Capella, have shown the presence of sodium, calcium and iron. But the most remarkable fact observed in these investigations is that, though the stars are so numerous, yet their spectra are reducible to a few well defined forms. Fr. Secchi, after a number of years of observation, during which he passed in review about 4000 stars, reduces these forms to four *types*. The first of which is that of the white or bluish stars; the second that of the yellow stars, the spectra of which are equal to that of the sun; the third type is that of the orange or red-colored stars; the last, which pertains to some small stars of a blood-red color, presents singularities and variations with some resemblance, however, to those of the third type.

## ARTICLE III.

### NEBULÆ.

80. *How the stratum of stars including the solar system may have a nebular form*—We have observed that the probable form of the stratum of stars which includes the solar system is such that its sections made in different directions by planes passing through its central parts have a variety of forms, for the most part irregular; and even more irregular is the form which would be presented by the same cluster if observed from the different regions of space at a great distance from it, so as to be reduced to small dimensions not exceeding a few degrees or even a few minutes. We will first remark that such a distance, from

the simple principles of geometry, would be such as to be fifty, sixty or a hundred times and more as great as the most distant points of the stratum are from each other. Secondly, the appearance of so many myriads of stars gathered within such narrow limits could be no other except that of a nebulous light similar to that of the Galaxy and particularly to those parts of the Galaxy which, when seen with the telescope present stars in large numbers. We may now ask, are there any such objects to be met with in the firmament having the nebulous appearance just described? The answer to this question will be at once an answer to the questions of the preceding article. Yes there are objects of this appearance, and which accordingly have been called *nebulæ*, and although it is true that the presence only of objects of a nebulous appearance, is not a certain sign of their being clusters like the stratum which includes the sun, yet there is a probability, that in many cases they are real clusters of innumerable stars and we infer that the stratum of stars which includes the solar system, referred to other similar clusters is of a nebulous appearance, and one among many, scattered in the universe, at distances so prodigious from one another as to reduce to insignificance the immeasurable dimensions of the stratum in which we are.

Following the analogy of the distances between the celestial bodies and between the larger and minor systems known to us; we infer that the nebulæ must be scattered in the universe with the same diversity of distances,only incomparably greater than subordinate distances. Hence some among them must be nearer to our cluster than others succeeding them, and these again nearer than others, and so on. The power of those telescopes which is just sufficient to resolve only partially those systems that are nearest to us, will not suffice to resolve others that are at greater distances and which consequently will preserve their nebulous appearance; by increasing the power of the instrument, the number of nebulæ, totally or partially resolvable into their component stars, will become greater and greater, provided the nebulæ are nothing but masses of stars collected together. Now, this is precisely the fact with those patches of starry light, which are seen in so many regious of the heavens. some of which are resolvable into stars by ordinary telescopes; others require greater power and others greater still; and every increase of power and every efficient improvement the telescope receives increases the number of nebulæ which are converted into clusters. The nebulæ which were irresolvable before the time of Sir W. Herschel yielded in large numbers to the power of the instruments which that observer brought to bear upon them. The labors of Sir J. Herschel, the colossal telescope constructed by Lord Ross, and the erection of observatories in multiplied numbers in climates more favorable for observation. have all tended to augment the number of nebulæ which have been resolved. However, two classes of nebulæ must be distinguished, those resolvable into clusters, and those irresolvable. For although the greater the power of the telescopes employed in observing them the greater the number of those resolved into stellar clusters, yet not a few of them have proved refractory to this test and preserved their nebulous appearance in spite of any magnifying power.

Before the use of the spectroscope, the opinion was entertained that the persistent appearance of mere nebulosity was due to the want of telescopic power to resolve this class of nebulæ into stellar clusters. Not all, however, were of this opinion, for some astronomers maintained that these nebulæ were not groups of stars but enormous volumes of incandescent gases. The spectroscope has justified this suspicion and now all doubts are excluded concerning their gaseous character. Without entering into particulars it is enough to state that the light of those clusters which have the nebulous appearance presents a stellar spectrum, whereas that of irresolvable nebulæ has a different one, and precisely that spectrum which is produced by gaseous materials in a state of incandescence. We must add, however, that mixed spectra are occasionally observed in resolvable nebulæ, which indicates that these nebulæ are constituted partly of stars and partly of incandescent gas. Whether the entire absence of stars should be inferred, when the spectrum is exclusively nebular does not appear, since the light of the stars, which, perchance, may be found in the nebulæ, may be too feeble to reveal its presence through the spectroscope. Observations made on clusters, as well as nebulæ, totally or partially, resolvable and irresolvable, indicate an apparent gradation, which suggests the idea that all of them belong to the same category, and differ only in their stage of formation. This idea is magnificent, and presents to our mind a duration in keeping with the space in which these wonderful masses are scattered and in comparison with which geological periods dwindle into mere days. But whether this idea corresponds or not with the reality is more than we can say. What may be said without fear of mistake is, that if there is not agreement between the fact and the supposition, the reality far surpasses our conjectures.

81. *Catalogue of Nebulæ.*—Nebulæ have been frequently mistaken for comets. To prevent the danger in which observers, in search of comets, were of being misled by the resemblance of the nebulæ to comets, Messier, a celebrated observer of these erratic bodies, undertook to catalogue a number of nebulæ for the direction of other observers. This catalogue which was published in the *Connaissance des Temps* for 1784 contained 103 nebulæ; but their number is much greater. The catalogue of Sir J. Herschel contains above 4000 of which the places are assigned, and the magnitude, forms and apparent characters described; and it is admitted that, so long as telescopes are susceptible of improvement and the means of observations can be extended to places more favorable for observations, their number will be constantly increased.

The nebulæ are not dispersed indifferently on all parts of the heavens; they are wholly absent from some regions; in some rarely found; and crowded in others; in the southern hemisphere, however, their distribution is more uniform. Much indeed, cannot be said concerning these masses of stellar powder, to use Milton's expression, so far distant from us. Besides their stellar or gaseous constitution, their indefinite number and their distribution, observation gives but little at present. Something, perhaps even more than is anticipated, may result from a continued and diligent study of their forms and other particulars which the telescope and spectroscope have revealed to us, and of which mention has been made in a preceding number.

82. *Classification of the Nebulæ*—Some nebulæ observed with moderate telescopic power exhibit an appearance similar to planets and are accordingly called *planetary*; and are subdivided into globular and annular. Figs. 48, 49, 50, 51 and 53, are specimens of these nebulæ; the first of which is globular, the others annular. The same nebula (Fig. 48), which was discovered by Struve, looks at first sight in the field of the telescope like Saturn when the ring is half opened; but on closer inspection it assumes the form represented in the Figure, i. e., dense in the central part and fading away towards the perimeter. Ring-shaped nebulæ are numerous, differing, however, considerably from each other. Fig. 49 is a nebula of this kind in the constellation of *Andromeda*, which appeared to Lord Ross as perforated in the centre, but with a magnifying power of 1000 the central part is resolved into luminous points and appears as if surrounded by a bright crown of small diamonds. Above this crown there are, on the faintly luminous mass, streaks of more intense light destitute of brilliant points. According to the observations of Fr. Secchi, there is another annular nebula in the constellation of *Hydra*, similar to the preceding. It consists (Fig. 50), of an irregular crown of small stars surrounded by nebulous light of a beautiful sky-blue color. The interior part is slightly luminous with a small sparkling star in the centre. The sky-blue color is frequently noticed in the light of the nebulæ. In the constellation of *Antinous*, in a magnificent cluster of stars, a portion

of which is given in Fig. 45 (C) a small annular nebula is visible, (Fig. 51). The central part appears perforated, but in reality it is occupied by nebulous light. In the same central part three minute stars are visible, the largest of which does not exceed the 12th magnitude. Among the annular nebulæ the one represented in Fig. 53, is particularly noted. It is in the constellation of *Lyra*, and seems to be an elliptical ring, somewhat luminous in the central portion where a very minute star, perhaps two, are visible. The sides of this ring which would be crossed by the short axis of the ellipse form the brighter portion of the nebula, and luminous points shine very clearly in them; the remainig two sides are nothing more than a protracted nebulosity. The star between Figs. 53 and 56, is to be taken in connection with this nebula, and may serve the purpose of verifying any change which perchance may take place in it. But these examples of planetary nebulæ must suffice.

Another class of nebulæ is constituted of those which are designated as nebular stars. The nebula which is the 1533 in Herschel's catalogue is an example of this kind; its appearance is given in Fig. 52. It recalls to mind the zodiacal light which accompanies the sun.

A third class is termed elliptical nebulæ, so called, we may presume, on account of their oblong conformation. Two of these are represented in Figs. 54 and 57. The latter is the ordinary type. They are very numerous though small, and abound chiefly in the *Coma Berenicis*, and in the wings of the constellation of the *Virgin*. A general feature concerning them is a condensation of light in the central portion which fades away, passing through all the degrees of diminution as it approaches the imperceptible boundaries. They are, moreover, irresolvable. The nebula, however, represented in Fig. 54, which is in the constellation of the *Bull*, seems to be, partly at least, resolvable. The same nebula observed with instruments of great magnifying power presents off-shoots or branches which were qualified by Lord Ross as traces of spiral arcs. A fluid mass, liquid or gaseous, rotating about a central region, recedes from the centre in a flattened shape more or less according to the greater or less centrifugal force originated by the rotation. If this rotating mass be seen in a direction perpendicular to the axis of rotation it will appear like a line; if viewed in a direction forming with the axis of rotation an acute angle, the mass will appear elliptical, more or less oblong, as the angle of the visual ray is greater or less, if viewed in the direction of the axis itself, it will have a form approaching the circular, or rather the form of the beautiful spiral nebula in the constellation of *Canes Venatici* represented in Fig. 56.

According to Lord Ross *spiral nebulæ* are more numerous than was believed, but admitting the above explanation they would belong to the class of elliptical nebulæ.

To complete the classification we must mention *irregular nebulæ* or nebulæ of irregular form which also are very numerous. Prominent, among them, is the nebula in the constellation of *Orion*. Finally, another class is constituted of double and triple nebulæ, an example of which is given in Fig. 55. These, probably, are mutually connected. But this secret with many more will be fully disclosed to us when we shall be admitted, as we hope, to the intuitive and everlasting vision of the Author of these works; which, though so imperfectly known, do not fail even now to inspire us with a lofty idea of the glory of their Creator and of the mighty power of his hand, and make us exclaim with the prophet: "*The Heavens shew forth the glory of God, and the firmament declareth the work of his hand.*—(Ps. XVIII.)

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# THE CALENDAR.

We shall conclude this sketch of Cosmography by a few remarks concerning the Calendar.

*The true year* is the time the earth requires to complete the circuit of its orbit from any point back to the same point. The exact duration of this period is $365^d\ 5^h\ 48^m\ 50.2^s$. To take into account the fraction of a day in the ordinary computations of the *civil year* would occasion considerable embarrassment. Yet, were we to neglect it, the consequent displacement of the seasons would produce in time the greatest confusion. The Romans felt this inconvenience, and Julius Cæsar remedied the matter, in great part, by causing every fourth year to consist of $366^d$, the others of $365^d$. In the year of 366 days the sixth day before the calends of March is taken twice, hence this fourth year was called *bissextile*, though at present it is generally termed leap-year. The Calendar thus corrected was called the Julian Calendar, a name which it still retains. Were the true year a period of exactly $365^d$ $6^h$, the Julian Calendar would have required no further correction; but as before the introduction of this Calendar, the civil year was about $5^h$ $30^m$ shorter than the true year, so after its introduction the civil became $11^m$ $9.8^s$ longer than the true year. This difference amounts to $18^h$ $36^m$ $20^s$ in a century, and in one thousand years to $7^d$ $18^h$ $3^m$ $20^s$. Hence one thousand years after Cæsar reformed the Calendar the civil year began $7^d$ $18^h$ $3^m$ $20^s$ later than the true year. Thus a second amendment became necessary; it was not, however, till A. D. 1582 that the second correction was introduced.

The Fathers of the Ecumenical Council held at Nice in 325, having observed that the spring equinox occurred on the 21st day of March, decreed that Easter should be celebrated on the first Sunday after the full moon following this day. But, because of the the error in the Julian Calendar, during the Pontificate of Gregory XIII the spring equinox fell on the 11th instead of the 21st of March. This provident Pope thereupon ordered that measures should be taken to reform the Calendar. The error in the Julian Calendar, mentioned above, amounted to $3^d$ $2^h$ $25^m$ $20^s$ in four centuries, i. e., the civil was a little over three days ahead of the true year in that time. If, therefore, three leap-years were omitted every four hundred years, at the expiration of that period the civil would be in advance of the true year only $2^h$ $25^m$ $20^s$;

which difference would amount to a little more than one day in forty centuries. But let us see how the Gregorian Calendar has settled the difficulty. Every year divisible by four without a remainder was, according to the Julian Calendar, a leap-year ; the Gregorian adopts the same rule except in the case of those years which begin the centuries, and beginning from the year 1600, the succeeding century years 1700, 1800 and 1900, though equally divisible by four, the Gregorian Calendar renders ordinary years i. e., years of only 365 days each. The year 2000 it makes a leap-year, but the years 2100, 2200 and 2300 will consist of but 365 days each. Thus every four centuries three of those years which, according to the Julian Calendar, would be leap-years are rendered ordinary years by the Gregorian. But since at the end of 4000 years the civil would have gained one day over the true year, even omitting three leap-years every four centuries, hence the Gregorian Calendar ordains that the year 5600, 4000 years after 1600, shall consist of but 365 days. Thus the civil and the true year are made to keep equal pace with each other and consequently the displacement of the seasons is avoided.

On the introduction of his Calendar in 1582, Pope Gregory, to bring the spring equinox to the 21st of March, ordered the suppression of ten days. Hence, in the month of October of that year, the 15th day immediately followed the 4th.

This wise reform was readily adopted by all Catholic powers. The Protestants retained the Julian Calendar until compelled by inconveniences finally to adopt the Gregorian. The English introduced it in

1752, and the Protestants of Germany in 1775. Russia is the only nation in Europe which has stubbornly adhered to the Julian Calendar, and to avoid difficulties in public documents they have been obliged to affix a double date. Thus, the 3rd day of January 1878 is written January 3rd 15th.

But of late a movement has been put on foot in Russia, principally by merchants, with the view of securing the introduction of the Gregorian Calendar. And in fact a decree has been issued by the Russian government that it shall be adopted throughout the Empire beginning from January 1st, 1879.

*The Solar Cycle*—If every year consisted of 365 days, that is, of 52 weeks and 1 day, each year would end on the same day of the week on which it commenced. And, therefore, if a given year commenced on Sunday, the following year would begin on Monday, the next on Tuesday, and so on. Thus the same period, following the order of days of the week, would be repeated every seven years. But since leap-years throw the first day of the succeeding year two days forward in the week instead of one, hence the period is changed from seven to twenty eight years. In the course of 28 years there occur 7 leap-years, each one of which causes the subsequent year to begin two days later in the week than it began itself. Now 28 being the product of 7 by 4, hence at the expiration of 28 years 7 days have been gained 5 times, and consequetly the days of the 29th year will be repeated in the same order and under the same conditions as they were 28 years previously. In a period, therefore, of 28 years all the possible changes of the days on which the years begin are effected, and the point of the ecliptic, occupied by the sun on the different days of the week for any one year of a period, is the same as that which the sun will occupy on the same days of the corresponding year in the succeeding period. This period in which the same order of days and leap-years is restored is called the *Solar Cycle.*

Writers on Chronology date the beginning of Solar Cycles 9 years prior to the Christian Era. To find, therefore, the number of Cycles which have elapsed up to a certain time, we need only add 9 to the date and divide the sum by 28; the quotient will denote the number of Cycles that have elapsed and the remainder the year of the Cycle corresponding to the date. Thus by adding 9 to the year 1879 and dividing the sum by 28, we obtain a quotient 67 with 12 for a remainder; hence, the year 1879 is the 12th of the 68th Solar Cycle. This period, we must add, is of but little practical value, since the omission of three leap-years every four centuries renders it almost useless.

*The Roman Indiction*—This period, which was introduced in the reign of Constantine, January 1st 313, consists of 15 years. It is said to have been adopted as a substitute for the Olympiads. It is employed principally by writers on civil and canon law. Since 312 divided by 15 gives a remainder of 12, it follows that the first year of the Christian Era began with the fourth year of the Indiction. Hence adding 3 to any date and dividing the sum by 15 the remainder will be the year of the Indiction corresponding to the given date. Should the remainder be zero the year of the Indiction answering to the date will be the 15th.

*The Lunar Cycle and the Golden Number*—The moon revolves about the Earth in $29^d\ 12^h\ 44^m\ 3.2^s$. This measure of time multiplied by 235 gives $6939^d\ 16^h\ 32^m\ 32^s$, nearly equal to 19 Julian years which contain $6939^d\ 18^h$. Thus, $1^h\ 27^m\ 28^s$ is the only difference between 19 Julian years and 235 lunations. This coincidence caused the period of 19 years to be called a *Lunar Cycle*. Methon, an Athenian astronomer, 433 years B. C., was the first to notice the coincidence. This discovery pleased the Athenians so much that the year of this Cycle was annually written in golden figures on a pillar placed in a public square for that purpose. Hence the appellation *Golden number*. The first year of our Era was the 2nd year of a Lunar Cycle. Hence we can obtain the Golden Number corresponding to any date A, v. g.; since it is the remainder resulting from the division of A + 1 by 19. Thus, for the year 1879 the Golden Number is 18; as 1879 + 1 divided by 19 gives 18 for remainder. For the year 1880 there is no remainder, therefore the Golden Number for this year is either 0 or 19.

*The Epact*—Since a synodic revolution of the moon about the earth is accomplished in nearly 29.5 days, and twelve lunations constitute the lunar year, hence the number of days of this year is given by

$$29 \times 6 + 30 \times 6 = 354.$$

Hence the lunar year is eleven days shorter than the common solar year. Supposing both solar and lunar year to begin together, when the lunar year ends there are yet eleven days before the ordinary solar year expires. Consequently when the new solar year begins, the moon counts an age of 11 days. This age of the moon at the beginning of the solar year is called

*The Epact* from επακτος (added). The Epact is of much importance in the Ecclesiastical Calendar, since it determines the time for the celebration of Easter, and hence governs the movable feasts of the year, consequently great care is taken to determine the Epact very exactly. In the supposition that the lunar and solar year begin together (an occurrence which has taken place in the present century) the third year after this coincidence will have an Epact of 22 days. The Epact of the following year will be a full lunation of 30 days plus 3 days, leaving the full lunar month in the third year. The Epact of the fourth year will only be 3 days, and so on. If each year consisted of 365 days, and if twelve lunar months, alternately of 29 and 30 days, exactly represented the lunar year, it would be easy to assign the Epact for a given year. Since it would only be necessary to multiply by 11 the years that had elapsed from the time that the lunar and solar year began together up to date and then divide this product by 30, the remainder would give the Epact for that year. Suppose, for example, five years have elapsed since the last coincidence of the lunar and the solar year, 55 being the product of 5 by 11 and this divided by 30 giving 25 for remainder, hence the Epact for the sixth year will be 25. But owing to the recurrence of leap-years and other circumstances, the calculation for the Epact is more complicated.

It is customary to designate the Epacts for each year by the Roman letters, XI, XXII, etc. The years in which a lunar month is added, because the Epact of the following year exceeds a full lunation, are called *Embolismic* years from εμβολισμος (intercalation).

*The Dominical Letter*—Designating the first seven days of the year by the first seven letters of the alphabet A, B, C, D, E, F, G, and repeating these letters in the same order throughout the year; whatever be the first day of the year to which the letter A is affixed the same letter will designate the same day of the week during that year, and so for the remaining six letters. The letter which is affixed to the first Sunday is called the *Dominical Letter* of that year. Since years of 365 days each end on the same day of the week on which they began, hence for them A is the letter affixed to the last day. But leap-years, as they contain one day more, end with the letter B. In leap-years, also, the first day of March is designated by the letter E, whereas in other years D is the letter assigned to this day. Thus, suppose the year to begin on Monday, the first day of March will be Thursday, if it is a leap-year, Wednesday, if it is an ordinary year; but since all years are equal after the first day of March, hence after this date a leap year will be the same as an ordinary year which began one day later in the week, on Monday, for instance, instead of on Sunday. Now, for an ordinary year which commences on Sunday, the Dominical Letter is A throughout the year, if it begins on Monday, the Dominical Letter is G, and so on, as in the following table.

| 1ST DAY OF THE YEAR. | DOMINICAL LETTER. |
|---|---|
| Sunday | A |
| Monday | G |
| Tuesday | F |
| Wednesday | E |
| Thursday | D |
| Friday | C |
| Saturday | B |

But in leap years the Dominical Letter changes after the first of March; and if it has been A for the first two months it becomes G for the following months, or if it has been F to the end of February, it becomes E from February to December, etc. The Dominical Letter is, therefore, double for leap-years, and marked, for instance, B-A or D-C, the first belonging to the first two months of the year, the second to the ten remaining months. Passing from one letter to another immediately preceding in alphabetic order, a like change occurs for the Dominical Letters of succeeding years, with this difference, that in ordinary years the change is from one letter to the one immediately preceding; but when we pass from a leap-year to an ordinary year the change is from one letter to the second preceding that with which the leap-year commenced. From these rules we can find the Dominical Letter, say of the year 1979. The Dominical Letter of 1879 is E, in 100 years there are 24 leap-years, hence the change of the Dominical Letter will take place 124 times. This number divided by 7 gives 5 for remainder, ascending 5 letters from E we have the letter G. This is consequently the Dominical Letter for 1979.

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## SOLAR SYSTEM.



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## SOLAR SYSTEM.

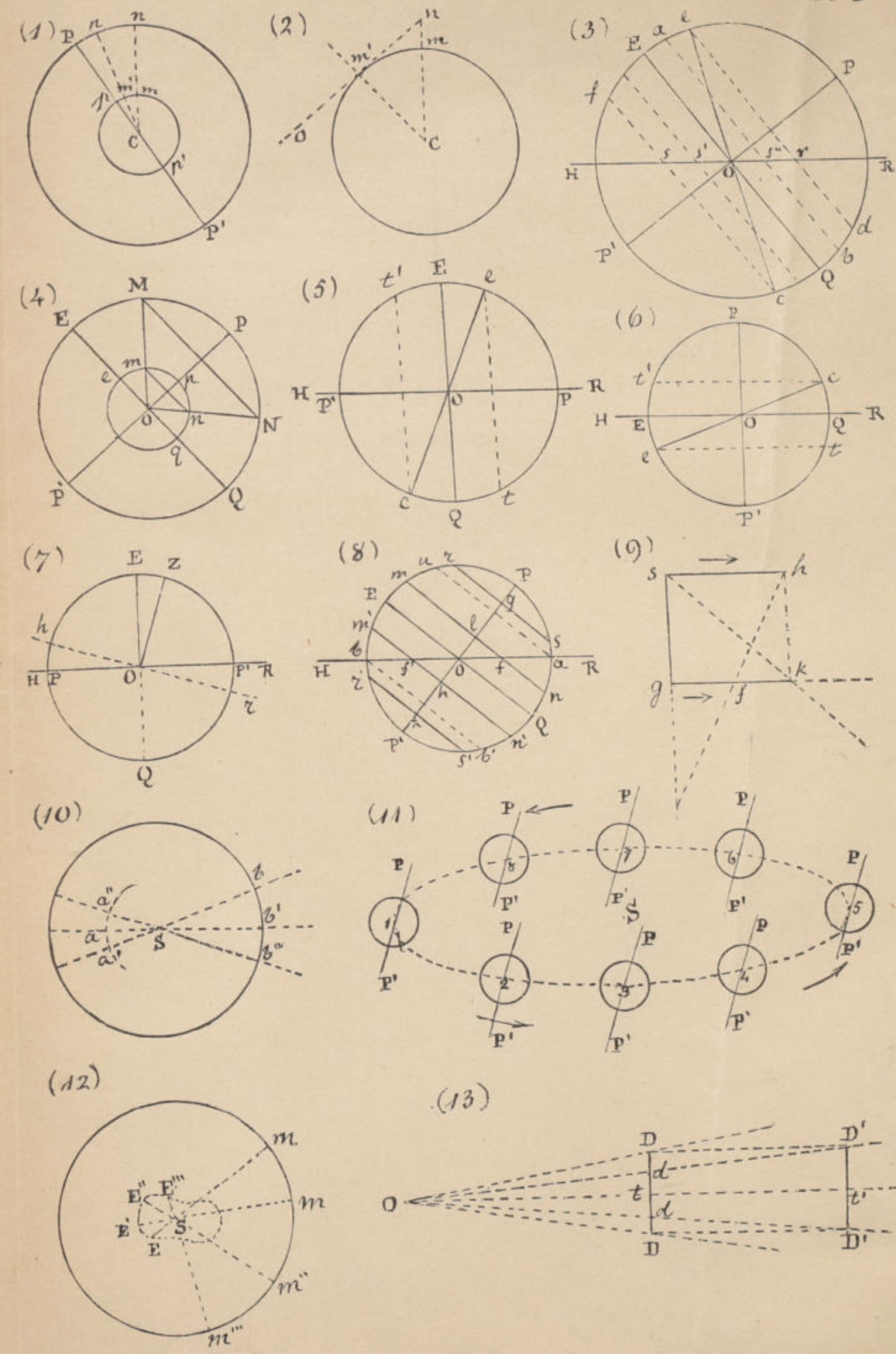


## STELLAR FIRMAMENT.



## THE CALENDAR.

Pl. I



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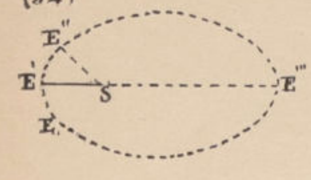


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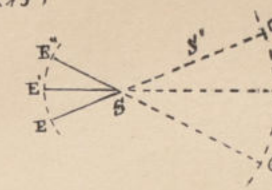


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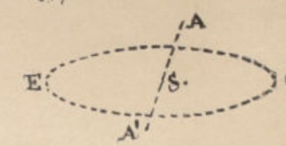


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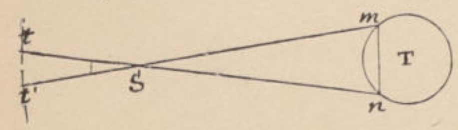


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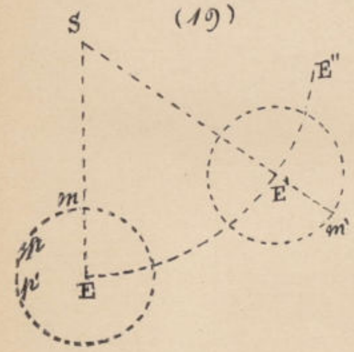


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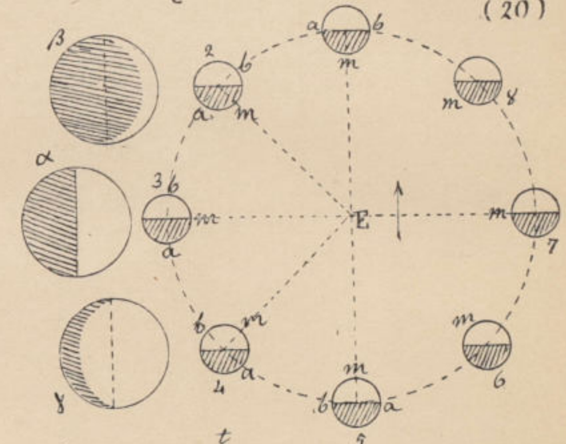


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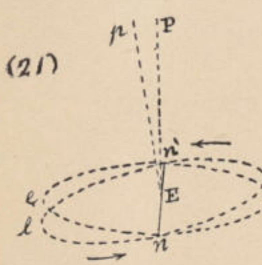


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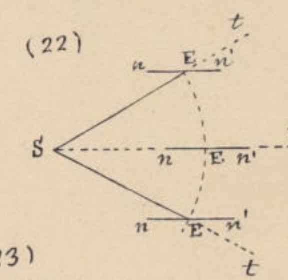


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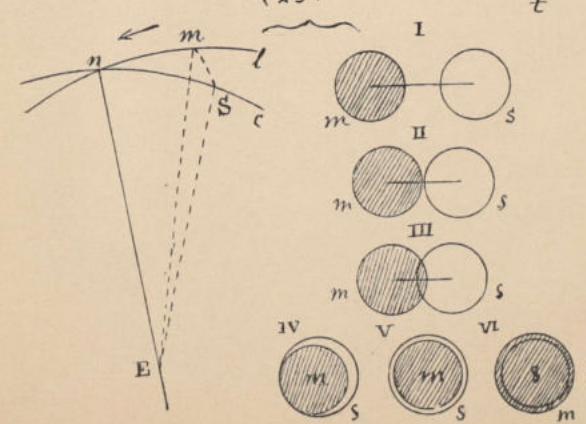


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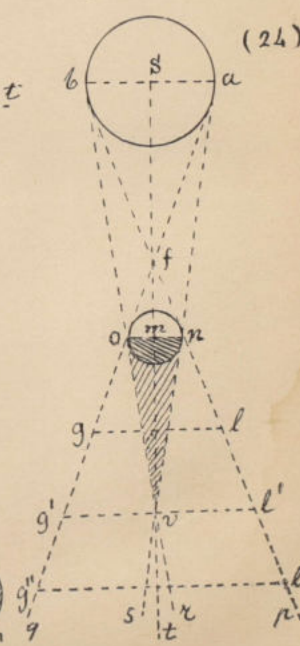

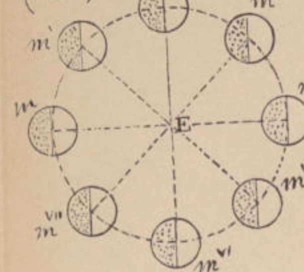

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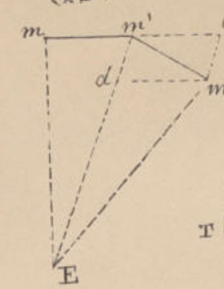

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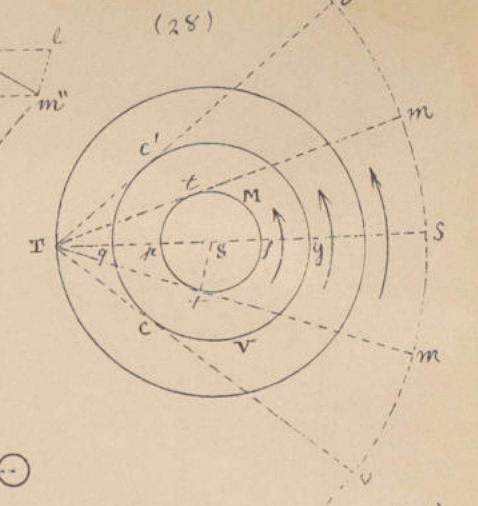

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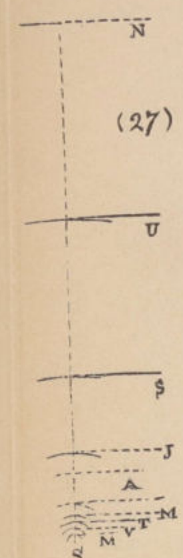

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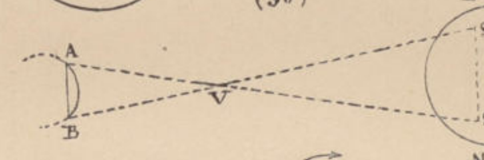

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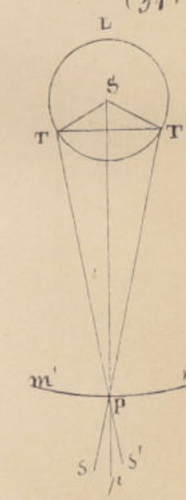

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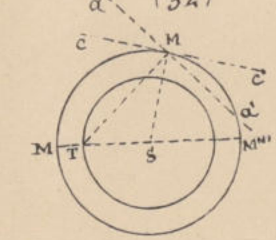

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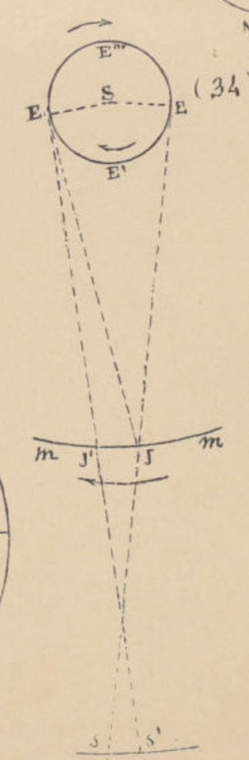

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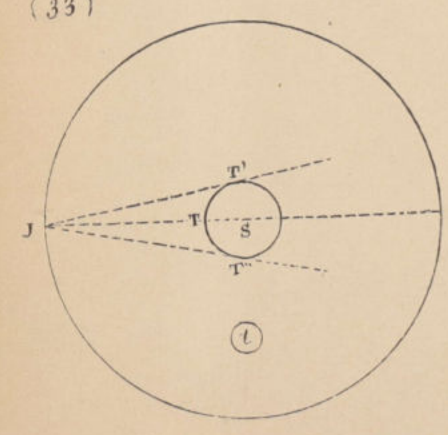

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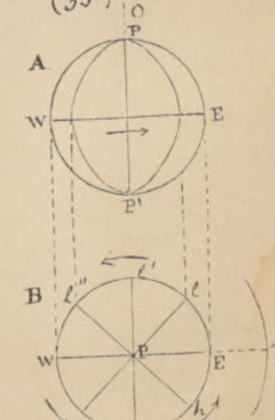

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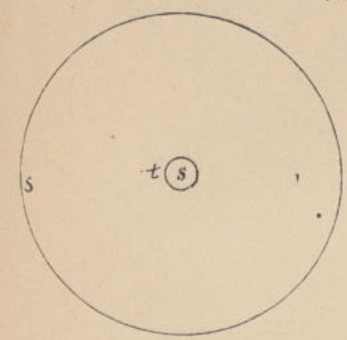

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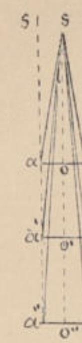

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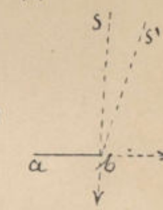

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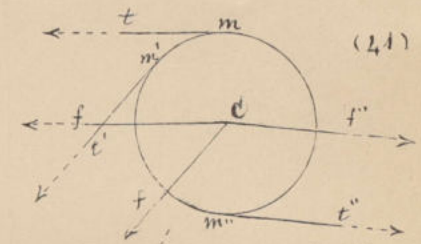

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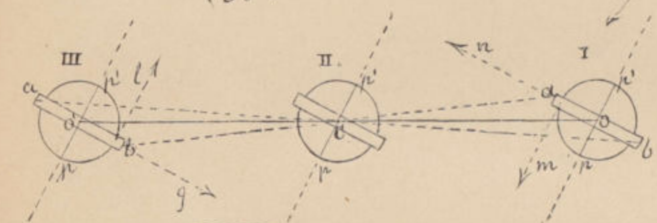

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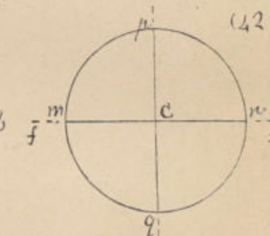

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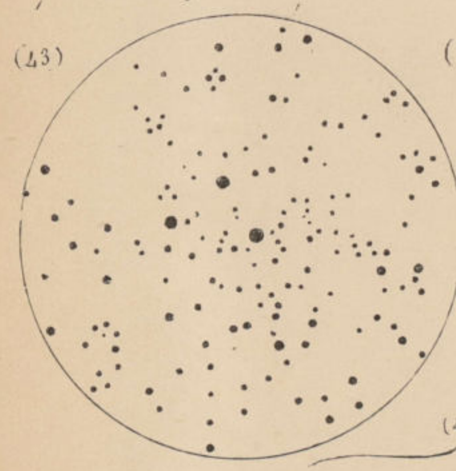

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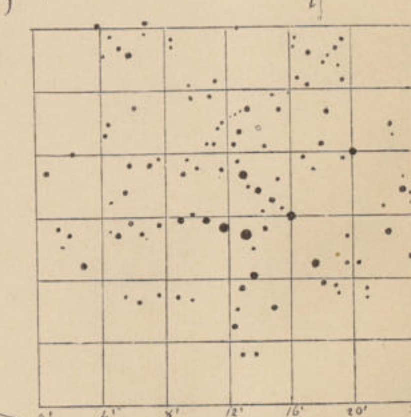

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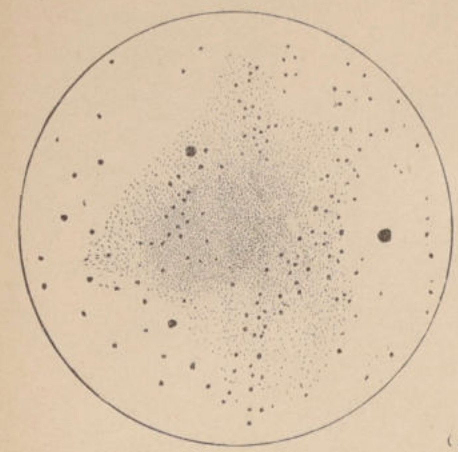

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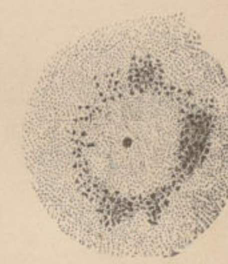

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