ELEMENTS

OF

ASTRONOMY.

DESIGNED FOR

ACADEMIES AND HIGH SCHOOLS.

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PREFACE.

The plan of the present volume is essentially the same as that of my Treatise on Astronomy, with the omission of most of the mathematical portions. That which I have retained requires only a knowledge of a few of the most elementary principles of Algebra, Geometry, and Plane Trigonometry; and without some mathematical knowledge, it is impossible to acquire an adequate idea of the substantial basis upon which the conclusions of Astronomy rest. If, however, a student is unable to understand the very simple mathematical portions of this volume, the descriptive part will generally be intelligible without them; and the portions which it would be found necessary to omit would not, in the aggregate, much exceed twenty pages. Great care has been taken to render every statement clear and precise, and it is important that the student, in his recitations, should be trained to a similar precision.

Astronomers are now generally agreed that the value of the solar parallax, which has been for many years universally accepted, is too small, but they are not agreed as to the precise value of this element which should be adopted. The value 8″.9, which I have employed in this work, is very nearly the mean of the values adopted by the most competent astronomers, and it is not probable that future observations will require any great change in the value of this important element.

CONTENTS.

CHAPTER I.

THE EARTH—ITS FIGURE, DIMENSIONS, AND DENSITY.—ROTATION.

Page
The Phenomena of the Diurnal Motion ... 9
The Figure of the Earth—how determined ... 15
Dimensions of the Earth—how determined ... 17
The Celestial and Terrestrial Spheres ... 21
Effects of Centrifugal Force upon the Form of the Earth ... 26
Measurement of an Arc of the Meridian ... 28
The Density of the Earth—how determined ... 32
Direct Proof of the Earth's Rotation ... 35
Artificial Globes—Problems on the Terrestrial Globe ... 37

CHAPTER II.

THE PRINCIPAL ASTRONOMICAL INSTRUMENTS.

The Astronomical Clock—its Error and Rate ... 41
The Transit Instrument—its Adjustments ... 42
The Mural Circle—Reading Microscope ... 47
The Altitude and Azimuth Instrument ... 51
The Sextant—its Adjustments and Use ... 52

CHAPTER III.

ATMOSPHERIC REFRACTION.—TWILIGHT.

The Law of Atmospheric Refraction ... 55
Refraction determined by Observation ... 56
The Cause of Twilight—its Duration ... 59

CHAPTER IV.

EARTH'S ANNUAL MOTION.—EQUATION OF TIME.—PARALLAX.

The Sun's apparent Motion—the Equinoxes, Solstices, etc. ... 62
The Change of Seasons—its Cause ... 66
The Form of the Earth's Orbit ... 69
Sidereal and Solar Time—Mean Time and Apparent Time ... 72

Page
The Equation of Time explained.......... 74
How to find the Time at any Place.......... 76
The Calendar—Julian and Gregorian.......... 79
Diurnal Parallax—Horizontal Parallax.......... 80
Problems on the Terrestrial Globe.......... 82
Problems on the Celestial Globe.......... 86

CHAPTER V.

THE SUN—ITS PHYSICAL CONSTITUTION.

Distance and Diameter of the Sun.......... 89
The Physical Constitution of the Sun.......... 90
Appearance and Motion of the Solar Spots.......... 92
Theory of the Constitution of the Sun.......... 97
The Zodiacal Light described.......... 99

CHAPTER VI.

ABERRATION.—PRECESSION OF THE EQUINOXES.—NUTATION.

Aberration of Light—its Cause.......... 101
Precession of the Equinoxes—its Cause.......... 103
Nutation, Solar and Lunar.......... 105

CHAPTER VII.

THE MOON—ITS MOTION—PHASES—TELESCOPIC APPEARANCE.

Distance, Diameter, etc., of the Moon.......... 107
Phases of the Moon—Harvest Moon.......... 110
Telescopic appearance of the Moon.......... 114
Has the Moon an Atmosphere?.......... 116
The Moon's Mountain Forms.......... 117

CHAPTER VIII.

CENTRAL FORCES.—GRAVITATION.

Curvilinear Motion—Kepler's Laws.......... 121
The Law of Gravitation—Motions of Projectiles.......... 123

CHAPTER IX.

ECLIPSES OF THE MOON.—ECLIPSES OF THE SUN.

Dimensions, etc., of the Earth's Shadow.......... 129
The Earth's Penumbra—its Dimensions.......... 131
Dimensions, etc., of the Moon's Shadow.......... 133
Different Kinds of Eclipses of the Sun.......... 135
Phenomena attending Eclipses of the Sun.......... 136
Rose-colored Protuberances—their Nature.......... 137

CHAPTER X.

METHODS OF FINDING THE LONGITUDE OF A PLACE.

Page
Method by Chronometers explained.. 140
Method by Eclipses—Lunar and Solar 141
Method by the Electric Telegraph—Transits of Stars.......................... 142

CHAPTER XI.

THE TIDES.

Definitions—Cause of the Tides.. 145
Velocity of the Tidal Wave... 149
The Tides modified by the Conformation of the Coast........................ 150
The Diurnal Inequality in the Height of the Tides........................... 151
Tides of the Gulf of Mexico—of the Coast of Europe......................... 152

CHAPTER XII.

THE PLANETS—THEIR APPARENT MOTIONS.

Number of the Planets—their Orbits.. 154
The apparent Motions of the Planets explained 156
The Elements of the Orbit of a Planet... 160
To determine the Distance of a Planet from the Sun 162

CHAPTER XIII.

THE INFERIOR PLANETS.

Greatest Elongations of the Planets—Phases 165
Mercury—its Period, Distance, Diameter, etc. 166
Venus—its Period, Distance, Diameter, etc...................................... 167
Transits of Mercury and Venus across the Sun's Disc......................... 169
Sun's Parallax—how determined.. 170

CHAPTER XIV.

THE SUPERIOR PLANETS.

Mars—Period—Distance—Phases—Appearance................................... 172
The Minor Planets—Discovery—Number, etc. 174
Jupiter—Distance—Diameter—Rotation, etc. 176
Jupiter's Satellites—Distances—Eclipses, etc. 178
Velocity of Light—how determined.. 180
Saturn—Period—Distance—Rotation... 181
Saturn's Rings—their Disappearance explained 182
Saturn's Satellites—their Number, Distance, etc. 185
Uranus—Period—Diameter—Satellites.. 186
Neptune—Discovery—Period—Satellite... 187

CHAPTER XV.

COMETS.—COMETARY ORBITS.—SHOOTING STARS.

	Page
Number of Comets—the Coma—Nucleus—Tail, etc.	189
The Nebulous Envelope—its Dimensions and Changes	191
The Tail—its rapid Formation—Dimensions, etc.	193
Halley's Comet—Encke's Comet—indications of a resisting Medium	199
Biela's Comet—Faye's Comet—Brorsen's Comet, etc.	202
Comet of 1744—Comet of 1770—Comet of 1843, etc.	205
Shooting Stars—Detonating Meteors—Aerolites	208

CHAPTER XVI.

THE FIXED STARS—THEIR DISTANCE AND THEIR MOTIONS.—NEBULÆ.

Classification of the Fixed Stars—their Brightness	215
The Constellations—how Stars are designated	217
Periodic Stars—Temporary Stars—Periodicity explained	220
Distance of the Fixed Stars—Parallaxes determined	222
Proper Motion of the Stars—Motion of the Solar System	225
Double Stars—Color of the Stars—Stars optically Double	227
Binary Stars—Periods—Masses, etc.	229
Clusters of Stars—Nebulæ	232
Classification of Nebulæ—Variable Nebulæ	234
The Milky Way—its Constitution and Extent	240
The Nebular Hypothesis—Conclusions from Geological Phenomena	241
Phenomena explained by this Hypothesis—Apparent Anomalies explained	243
How the Nebular Hypothesis may be tested	244

ASTRONOMY.

CHAPTER I.

GENERAL PHENOMENA OF THE HEAVENS.—FIGURE OF THE EARTH.—ITS DIMENSIONS AND DENSITY.—PROOF OF ITS ROTATION.—ARTIFICIAL GLOBES.

1. *Astronomy* is the science which treats of the heavenly bodies. The *heavenly bodies* consist of the sun, the planets with their satellites, the comets with numerous meteoric bodies, and the fixed stars.

Astronomy is divided into spherical and physical. *Spherical Astronomy* treats of the appearances, magnitudes, motions, and distances of the heavenly bodies, together with the theory of the methods of observation and calculation by which the positions of the heavenly bodies are determined. That portion of Astronomy which treats chiefly of the direct results of observation, without explaining the calculations by which the motions of the heavenly bodies are determined, is often called *Descriptive Astronomy.* That portion of Astronomy which treats chiefly of astronomical instruments and astronomical observations, together with the solution of those practical problems which arise in the course of those observations, is often called *Practical Astronomy.*

Physical Astronomy investigates the cause of the motions of the heavenly bodies, and, by tracing the consequences of the law of universal gravitation, enables us to follow the movements of the heavenly bodies through immense periods of time, either past or future.

2. *Diurnal Motion of the Heavens.*—If we examine the heavens on a clear night, we shall soon perceive that the stars constantly maintain the same position relative to each other. A map showing the relative position of these bodies on any night will represent them with equal exactness on any other night. They all seem to be at the same distance from us, and to be attached to the surface of a vast hemisphere, of which the place of the observer is the centre. But, although the stars are relatively fixed, the hemisphere, as a whole, is in constant motion. Stars rise obliquely from the horizon in the east, cross the meridian, and descend obliquely to the west. The whole celestial vault appears to be in motion round a certain axis, carrying with it all the objects visible upon it, without disturbing their relative positions. The point of the heavens which lies at the extremity of this axis of rotation is fixed, and is called the *pole.* There is a star called the *pole star*, distant about $1\frac{1}{2}$ degrees from the pole, which moves in a small circle round the pole as a centre. All other stars appear also to be carried around the pole in circles, preserving always the same distance from it.

3. *Determination of the Axis of the Celestial Sphere.*—Let the telescope of a theodolite, having a small magnifying power, be directed to the pole star; the star will be found to move in a small circle, whose diameter is about three degrees; and the telescope may be so pointed that the star will move in a circle around the intersection of the spider lines as a centre. The point marked by the intersection of these lines is, then, the true position of the pole. The surface of the visible heavens, to which all the heavenly bodies appear to be attached, is called the *Celestial Sphere.*

4. *Use of a Telescope mounted Equatorially.*—Having determined the axis of the celestial sphere, a telescope may be mounted so as to revolve upon a fixed axis which points toward the celestial pole in such a manner that the telescope may be placed at any desired angle with the axis, and there may be attached to it a graduated circle, by which the magnitude of this angle may be measured. A telescope thus mounted is called an *equatorial telescope*, and it is frequently connected with clock-work, which gives it a motion round the axis corresponding with the rotation of the celestial sphere.

5. *Diurnal Paths of the Heavenly Bodies.*—Let now the telescope be directed to any star so that it shall be seen in the centre of the field of view, and let the clock-work be connected with it so as to give it a perfectly uniform motion of rotation from east to west. The star will follow the telescope, and the velocity of motion may be so adjusted that the star shall remain in the centre of the field of view from rising to setting, the telescope all the time maintaining the same angle with the axis of the heavens. The same will be true of every star to which the telescope is directed; from which we conclude that all objects upon the firmament describe circles at right angles to its axis, each object always remaining at the same distance from the pole. The same observations prove that this movement of rotation of all the stars is perfectly *uniform.*

6. *Time of one Revolution of the Celestial Sphere.*—If the telescope be detached from the clock-work, and, having been pointed upon a star, be left fixed in its position, and the exact time of the star's passing the central wire be noted, on the next night, at about the same hour, the star will again arrive upon the central wire. The time elapsed between these two observations will be found to be 23h. 56m. 4s. expressed in solar time.

This, then, is the time in which the celestial sphere makes one revolution; and this time is always the same, whatever be the star to which the telescope is directed.

7. *A Sidereal Day.*—The time of one complete revolution of the firmament is called a sidereal day. This interval is divided into 24 sidereal hours, each hour into 60 minutes, and each minute into 60 seconds.

Since the celestial sphere turns through 360° in 24 sidereal hours, it turns through 15 degrees in one sidereal hour, and through one degree in four sidereal minutes.

8. *The Diurnal Motion is never Suspended.*—With a telescope of considerable power all the brighter stars can be seen throughout the day, unless very near the sun; and, by the method of observation already described, we find that the same rotation is preserved during the day as during the night.

All of the heavenly bodies, without exception, partake of this diurnal motion; but the sun, the moon, the planets, and the comets appear also to have a motion of their own, by which they change their position among the stars from day to day.

9. The *Celestial Equator* is the great circle in which a plane passing through the earth's centre, and perpendicular to the axis of the heavens, intersects the celestial sphere. The celestial equator is frequently called the *equinoctial.*

10. If a plummet be freely suspended by a flexible line, and allowed to come to a state of rest, this line is called a *vertical line.* The point where this line, produced upward, meets the visible half of the celestial sphere, is called the *zenith.* The point where this line, produced downward, meets the invisible half of the celestial sphere, is called the *nadir.*

Every plane which passes through a vertical line is called a *vertical plane* or a *vertical circle.*

That vertical circle which passes through the celestial pole is called the *meridian.* The vertical circle which crosses the meridian at right angles is called the *prime vertical.*

11. A *horizontal plane* is a plane perpendicular to a vertical line.

The *sensible horizon* of a place on the earth's surface is the circle in which a horizontal plane, passing through the place, cuts the celestial sphere. This plane, being tangent to the earth, separates the visible from the invisible portion of the heavens.

The *rational horizon* is a circle parallel to the sensible horizon, whose plane passes through the earth's centre. On account of the distance of the fixed stars, these two planes intersect the celestial sphere sensibly in the same great circle.

The meridian of a place cuts the horizon in the *north* and *south* points; the prime vertical cuts the horizon in the *east* and *west* points. These four points are called the cardinal points.

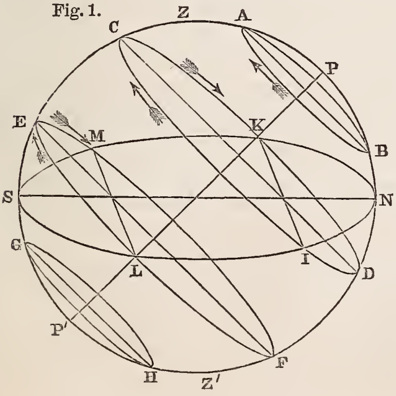
12. The *altitude* of a heavenly body is the arc of a vertical circle intercepted between the centre of the body and the horizon. The *zenith distance* of a heavenly body is the arc of a vertical circle intercepted between its centre and the zenith. The zenith distance is the *complement* of the altitude.

The *azimuth* of a heavenly body is the arc of the horizon intercepted between the meridian and a vertical circle passing through the centre of the body. Altitudes and azimuths are measured in degrees, minutes, and seconds, and they enable us to define the position of any body in the heavens.

The *amplitude* of a heavenly body at the time of its rising is the arc of the horizon intercepted between the centre of the body and the east point. Its amplitude at the time of its setting is the arc of the horizon intercepted between the centre of the body and the west point. If the azimuth of a star at rising is N. 58° E., its amplitude will be E. 32° N.

13. *Consequences of the Diurnal Motion.*—If an observer could watch the entire apparent path of any star in the sky, he would see it describe a complete circle; but as only half the celestial sphere is visible at one time, it is evident that a part of the diurnal path of a star may lie below the horizon and be invisible. Thus, in Fig. 1, let PP′ be the axis of rotation of the celestial sphere, and let NLSK be the horizon produced to intersect the sphere, and dividing it into two hemispheres. Also, let NS be the north and south line. If the parallel

Fig. 1.



circles passing through A, C, E, and G be the apparent diurnal paths of four stars, then it is evident that—

1st. The star which describes the circle AB will never descend below the horizon.

2d. The star which describes the circle GH will never rise above the horizon.

3d. The star which describes the circle CD will be above the horizon while it moves through ICK, and below the horizon while it moves through KDI.

4th. The star which describes the circle EF will be above the horizon while it moves through the portion LEM, and below the horizon while it moves through the portion MFL.

These stars are said to rise at I and L, and to set at K and M. They rise in the eastern part of the horizon, and set in the western.

With the star C, the visible portion of its path ICK is greater than the invisible portion KDI; while with the star E, the visible portion of its path LEM is less than the invisible portion MFL.

It is evident that all stars which lie to the north of the equator will remain above the horizon for a longer period than below it; while all stars south of the equator will remain above the horizon for a shorter time than below it; and stars situated in the plane of the equator will remain above the horizon and below it for equal periods of time.

14. *Culminations of the Heavenly Bodies.*—Since the meridian cuts all the diurnal circles at right angles, the stars will attain their greatest altitude when in this circle; and they are then said to *culminate*. Moreover, since the meridian bisects the portions of the diurnal circles which lie above the horizon, the stars will require the same length of time in passing from the eastern horizon to the meridian as in passing from the meridian to the western horizon.

The circumpolar stars cross the meridian twice every day, once *above* the pole and once *below* it. These meridian passages are called *upper* and *lower culminations*. Thus the star which describes the circle AB, Fig. 1, has its upper culmination at A, and its lower culmination at B.

15. *How the Pole Star may be found.*—Among the most remarkable of the stars which never set in the latitude of New York is the group of seven stars known as the Dipper, in the constellation Ursa Major, shown on the left of Fig. 2,

Fig. 2.

which also represents the constellation Ursa Minor near the middle of the figure, and Cassiopea on the right. The two stars α and β of Ursa Major are sometimes called the *Pointers*, because a straight line drawn through them and produced will pass almost exactly through the pole star in Ursa Minor, and thus the pole star may always be identified whenever the Pointers can be seen.

16. *What Stars never set.*—If a circle were drawn through N, Fig. 1, the north point of the horizon, parallel to the equator, it would cut off a portion of the celestial sphere having P for its centre, all of which would be above the horizon; and a circle drawn through S, the south point of the horizon parallel to the equator, would cut off a portion having P′ for its centre, which would be wholly below the horizon. Stars which are nearer to the visible pole than the point N never set, while those which are nearer to the invisible pole than the point S never rise.

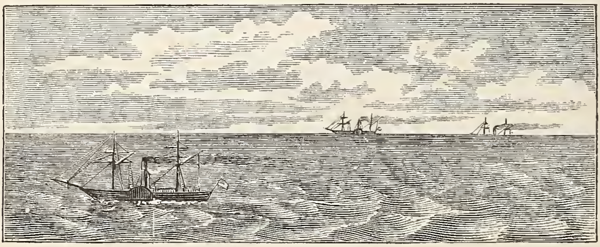
17. *Why a Knowledge of the Dimensions of the Earth is important.*—The bodies of which Astronomy treats are all (with the exception of the earth) *inaccessible.* Hence, for determining their distances, we are obliged to employ *indirect* methods. The eye can only judge of the *direction* of objects, and can not accurately estimate their distance, especially if they are very remote; but by measuring the bearings of an inaccessible object from two points whose distance from each other is known, we may compute the distance of that object by the methods of trigonometry. In all our observations for determining the distance of the celestial bodies, the base line must be drawn upon the earth. It therefore becomes necessary to determine with the utmost precision the form and dimensions of the earth.

18. *Proof that the Earth is Globular.*—That the earth is a body of a globular form is proved by the following considerations:

1st. Navigators have repeatedly sailed entirely round the earth. This fact can only be explained by supposing that the earth is rounded; but it does not alone furnish sufficiently precise information of its exact figure, particularly since, on account of the interposition of the continents, the path of the navigator is necessarily somewhat circuitous, and is limited to certain directions.

2d. When a vessel is receding from the land, an observer

Fig. 3.



from the shore first loses sight of the hull, then of the lower part of the masts and sails, and lastly of the topmast. Now, if the sea were an indefinitely extended plane, the topmast, having the smallest dimensions, should disappear first, while the hull and sails, having the greatest dimensions, should disappear last; but, in fact, the reverse takes place. If we suppose the surface of the sea to be rounded, the different parts of a receding ship should disappear as they pass successively below the line of sight AB, Fig. 4, which is tan-

Fig. 4.

gent to the surface of the sea. So also land is often visible from the topmast when it can not be seen from the deck. An æronaut, ascending in his balloon after sunset, has seen the sun reappear with all the effects of sunrise; and on descending, he has witnessed a second sunset.

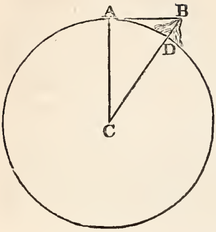
3d. If we travel northward following a meridian, we shall find the altitude of the pole to increase continually at the rate of one degree for a distance of about 69 miles. This proves that a section of the earth made by a meridian plane is very nearly a circle, and also affords us the means of determining its dimensions, as shown in Arts. 20 and 21.

4th. Eclipses of the moon are caused by the earth coming between the sun and moon, so as to cast its shadow upon the latter, and the form of this shadow is always such as one globe would project upon another. This argument is conclusive; but, before it can be appreciated, it is necessary to understand many principles which will be explained in subsequent chapters.

5th. The most accurate measurements made in the manner described in Arts. 38 to 41 not only prove that the earth is nearly globular, but also show precisely how much it deviates from an exact sphere.

19. *First Method of determining the Earth's Diameter.*—The considerations just stated not only demonstrate that the earth is globular, but also afford us a rude method of computing its diameter. For this purpose we must measure the height of some elevated object, as the summit of a mountain, and also the distance at which it can be seen at sea. Now it has been ascertained that one of the peaks of the Andes, which is four miles in height, can be seen from the ocean at the distance of 179 miles. Let BD, Fig. 5, represent this mountain, and AB the distance at which it can be seen from the ocean, the line AB being supposed to be a tangent to the surface of the water at the point A. Then, since BAC is a right-angled triangle, we have by Geom., Book IV., Prop. II.,

Fig. 5.



$$CB^2 = CA^2 + AB^2.$$

If we represent the radius of the earth by R, we shall have

$$(R+4)^2 = R^2 + 179^2,$$

from which we find that R equals nearly 4000 miles.

It is immaterial from what direction the mountain is observed, or in what part of the world it is situated, we always obtain by this method nearly the same value of the earth's radius, which proves that the curvature of the earth is nearly the same in all azimuths and in all latitudes, and demonstrates conclusively that the earth is nearly a sphere.

20. *Second Method of determining the Earth's Diameter.*—Having ascertained the general form of the earth, it is important to determine its diameter as accurately as possible. For this purpose we first ascertain the length of one degree upon its surface—that is, the distance between two points on the earth's surface so situated that the lines drawn from them to the centre of the earth may make with each other an angle of one degree.

Fig. 6.

Let P and P′ be two places on the earth's surface distant from each other about 70 miles, and let C be the centre of the earth. Suppose that two persons at the places P and P′ observe two stars S and S′, which are at the same instant vertically over the two places—that is, in the direction of plumb-lines suspended at those places. Let the directions of these plumb-lines be continued downward so as to intersect at C the centre of the earth. The angle which the directions of these stars make at P is SPS′, and the angle, as seen from C, is SCS′; but, on account of the distance of the stars, these angles are sensibly equal to each other. If, then, the angle SPS′ be measured, and the distance between the places P and P′ be also measured by the ordinary methods of surveying, the length of one degree can be computed. In this way it has been ascertained that the length of a degree of the earth's surface is about 69 statute miles, or about 365,000 feet.

Since a second is the 3600th part of a degree, it follows that the length of one second upon the earth's surface is very nearly one hundred feet.

Since the plumb-line is every where perpendicular to the earth's surface, two plumb-lines at different places can not be parallel to each other, but must be inclined at an angle depending upon their distance. This inclination may be found by allowing one second for every hundred feet, or more exactly by allowing 365,000 feet for each degree.

21. The *circumference* of the earth may be found approximately by the proportion

1 degree : 360 degrees :: 69 miles : 24,840 miles,

which differs but little from the most accurate determination of the earth's circumference as stated in Art. 41. The diameter of the earth is hence determined to be a little over 7900 miles.

Since the earth is globular, it is evident that the terms *up* and *down* can not every where denote the same absolute direction. The term *up* simply denotes *from* the earth's centre, while *down* denotes *toward* the earth's centre; but the absolute direction denoted by up at New York is diametrically opposite to that which is denoted by up in Australia.

22. *Irregularities of the Earth's Surface.* — The highest mountain peaks slightly exceed five miles in height, which is about $\frac{1}{1600}$ of the earth's diameter. Accordingly, on a globe 16 inches in diameter, the highest mountain peak would be represented by a protuberance having an elevation of $\frac{1}{100}$ inch, which is about twice the thickness of an ordinary sheet of writing-paper. The general elevation of the continents above the sea would be correctly represented by the thinnest film of varnish. Hence we conclude that the irregularities of the earth's surface are quite insignificant when compared with its absolute dimensions.

23. *Cause of the Diurnal Motion of the Heavens.*—The apparent diurnal rotation of the heavens was formerly explained by admitting that the heavenly bodies do really revolve about the earth once in 24 hours. But it will hereafter be shown conclusively that the fixed stars are material bodies of vast size, and situated at an immense distance from us; and hence, if they really revolve about the earth once in 24 hours, they must move with a velocity exceeding a thousand millions of miles in a second. This rapid motion in a circle would generate a centrifugal force well-nigh infinite, which could only be balanced by the attraction of a central body of enormous size. The earth is too insignificant to produce the required effect, and hence this hypothesis is utterly inconsistent with the fundamental principles of Mechanics.

The appearances which we have described may be perfectly explained by supposing that the stars remain stationary, and that the earth rotates upon an axis once in 24 hours in a direction opposite to that in which the heavens seem to revolve. Such a rotation of the earth would give to the celestial sphere the appearance of revolving in the contrary direction, as the forward motion of a boat on a river gives to the banks an appearance of backward motion; and, since the motion of the earth is perfectly uniform, we are insensible of it, and hence attribute the change in the situation of the stars with respect to the earth to an actual motion of the heavenly bodies. The apparent motion of the heavens being from east to west, the real rotation of the earth, which produces that appearance, must be from west to east.

The hypothesis of the earth's rotation is rendered probable by the analogy of the other members of our solar system. All the planets which we have been able satisfactorily to observe are found to rotate on their axes, and their figures are generally such as correspond to the time of their rotation.

The doctrine of the earth's rotation does not, however, rest simply on probability or analogy, but is positively demonstrated by several phenomena, which will be described in Arts. 42, 48, and 49.

24. The *earth's axis* is the diameter around which it revolves once a day. The extremities of this axis are the terrestrial *poles*; one is called the *north pole*, and the other the *south pole*.

The terrestrial *equator* is a great circle of the earth perpendicular to the earth's axis.

Meridians of the earth are great circles passing through the poles of the earth.

25. The *latitude* of a place is the arc of the meridian which is intercepted between that place and the equator. Latitude is reckoned north and south of the equator from 0 to 90 degrees.

A *parallel of latitude* is any small circle on the earth's surface parallel to the terrestrial equator. Every point of a parallel of latitude has the same latitude. These parallels diminish in size as we proceed from the equator toward either pole.

The *polar distance* of a place is its distance from the nearest pole, and is the complement of the latitude.

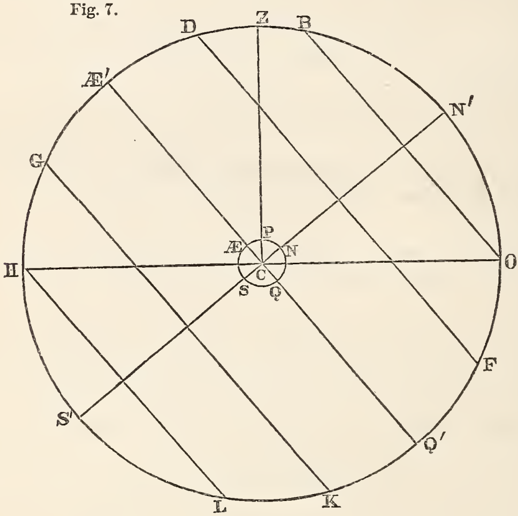
26. The *longitude* of a place is the arc of the equator intercepted between the meridian passing through that place and some assumed meridian, to which all others are referred. This assumed meridian is called the *first meridian*. Longitude is usually reckoned east and west of the first meridian from 0 to 180 degrees. Sometimes it is reckoned from the first meridian westward entirely round the circle from 0 to 360 degrees.

Different nations have adopted different first meridians. The English reckon longitude from the Royal Observatory at Greenwich; the French from the Imperial Observatory at Paris; and the Germans from the Observatory at Berlin, or from the island of Ferro (the most westerly of the Canary Islands), which is assumed to be 20 degrees west of the Observatory of Paris. In the United States we sometimes reckon longitude from Washington, and sometimes from Greenwich.

The longitude and latitude of a place designate its position on the earth's surface.

27. *The Altitude of the Pole.*—Let SÆNQ represent the earth surrounded by the distant starry sphere HZOK. Since the diameter of the earth is insignificant in comparison with the distance of the stars, the appearance of the heavens will be the same whether they are viewed from the centre of the earth or from any point on its surface. Suppose the observer to be at P, a point on the surface between the equator Æ and the north pole N. The latitude of this place is ÆP, or the angle ÆCP. If the line CP be continued to the

Fig. 7.



firmament, it will pass through the point Z, which is the zenith of the observer. If the terrestrial axis NS be continued to the firmament, it will pass through the celestial poles N′ and S′. If the terrestrial equator ÆQ be continued to the heavens, it will constitute the celestial equator Æ′Q′. The observer at P will see the entire hemisphere HZO, of which his zenith Z is the pole. The other hemisphere HKO will be concealed by the earth.

The arc N′O contains the same number of degrees as Æ′Z, each being the complement of ZN′; that is, *the altitude of the visible pole is every where equal to the latitude of the place.* Also, the arc ZN′ is the complement of ON′; that is, the zenith distance of the visible pole is the complement of the latitude.

It will be perceived that, in proceeding from the equator to the north pole, the altitude of the north pole of the heavens will gradually increase from 0 to 90 degrees. This increase in the altitude of the pole is owing to the fact that in following the curved surface of the earth, the horizon, which is continually tangent to the earth's surface, becomes more and more depressed toward the north, while the absolute direction of the pole remains unchanged.

If the spectator be in the southern hemisphere, the elevated pole will be the south pole.

28. *How the Latitude of a Place may be Determined.*—If there were a star situated precisely at the pole, its altitude would be the latitude of the place. The pole star describes a small circle around the pole, and crosses the meridian twice in each revolution, once above and once below the pole. The half sum of the altitudes in these two positions is equal to the altitude of the pole—that is, to the latitude of the place. The same result would be obtained by observing any circumpolar star on the meridian both above and below the pole.

29. Circles which pass through the two poles of the celestial sphere are called *celestial meridians* or *hour circles.* If two such circles include an arc of 15 degrees of the celestial equator, the interval between the instants of their coincidence with the meridian of a particular place will be one hour.

30. The *right ascension* of a heavenly body is the arc of the celestial equator intercepted between a certain point on the equator called the vernal equinox, and the hour circle which passes through the centre of the body. Right ascension is sometimes expressed in degrees, minutes, and seconds of arc, but generally in hours, minutes, and seconds of time. It is reckoned eastward from zero up to 24 hours, or 360 degrees.

If the hands of the sidereal clock be set to 0h. 0m. 0s. when the vernal equinox is on the meridian, the clock (if it neither gains nor loses time) will afterward indicate at each instant the right ascension of any object which is then on the meridian, for the motion of the hands of the clock corresponds exactly with the apparent diurnal motion of the heavens. While 15 degrees of the equator are passing the meridian, the hands of the clock will move through one hour.

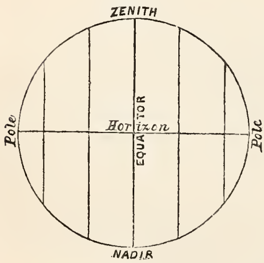
The sidereal day, therefore, begins when the vernal equinox is on the meridian, and the sidereal clock should always indicate 0h. 0m. 0s. when the vernal equinox is on the meridian.

31. The *declination* of a heavenly body is its distance from the celestial equator measured upon the hour circle which passes through its centre. Declination is either north or south, according as the object is on the north or south side of the equator. North declination is generally regarded as positive, and south declination as negative.

The position of an object on the firmament is designated by means of its right ascension and declination.

The *north polar distance* of a star is its distance from the north pole, and is the complement of the declination.

Fig. 8.

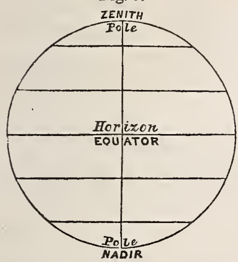


32. *A Right Sphere.*—The diurnal motion of the heavenly bodies presents different appearances to observers in different latitudes. When the observer is situated at the terrestrial equator, both the celestial poles will be in his horizon, the celestial equator will be perpendicular to the plane of the horizon, and hence the horizon will bisect the equator and all circles parallel to it. The heavenly bodies will appear to rise perpendicularly on the eastern side of the horizon, and set perpendicularly on the western side. Such a sphere is called a *right sphere*, because the circles of diurnal motion are at right angles to the horizon.

Since the diurnal circles are bisected by the horizon, all the stars will remain for equal periods above and below the horizon.

33. *A Parallel Sphere.*—If the observer were at one of the poles of the earth, the celestial pole would be in his zenith, and therefore the celestial equator would coincide with his horizon. By the diurnal motion, the stars would move in circles parallel to the horizon, and the whole hemisphere on the side of the elevated pole would be continually visible, while the other hemisphere would always remain invisible. This is called a *parallel sphere.* In a parallel sphere, a star situated upon the equator would be carried by the diurnal motion round the horizon, without either rising or setting.

Fig. 9.



34. *An Oblique Sphere.*—At all places between the equator and the pole, the celestial equator is inclined to the horizon at an angle equal to the distance of the pole from the zenith—that is, equal to the complement of the latitude of the place.

A parallel of declination, BO, Fig. 7, whose polar distance is equal to the latitude of the place, will lie entirely above the horizon, and just touch it at the north point. This circle is called the circle of *perpetual apparition*, because the stars which are included within it *never set.* The radius of this circle is equal to the latitude of the place.

The parallel of declination HL, whose distance from the invisible pole is equal to the latitude of the place, will be entirely below the horizon, and just touch it at the south point. This circle is called the circle of *perpetual occultation*, because the stars which are included within it *never rise.* The radius of this circle is also equal to the latitude of the place.

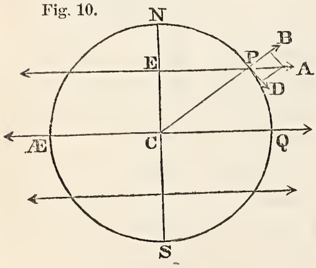
One half of the celestial equator will be above the horizon and the other half below it. Hence every star on the equator will be above the horizon during as long a time as it is below, and will rise at the east point, and set at the west point.

With the exception of the equator, all diurnal circles comprised between the circles of perpetual apparition and occultation will be divided unequally by the horizon. The greater part of the circle DF will be above the horizon, and the greater part of the circle GK will be below the horizon; that is, all stars between the celestial equator and the visible pole are longer above than below the horizon, while all stars on the other side of the equator are longer below than above the horizon.

The celestial sphere here described is called an oblique sphere, because the circles of diurnal motion are oblique to the horizon.

35. *Effects of Centrifugal Force.*—We have proved that the earth has a globular form, and that it rotates upon its axis once in 24 sidereal hours. But, since the earth rotates upon an axis, its form *can not be that of a perfect sphere;* for every body revolving in a circle acquires a centrifugal force which tends to make it recede from the centre of its motion. Thus a stone whirled round in a sling acquires a tendency to fly off in a straight line; and when a sphere revolves on its axis, every particle not lying immediately upon the axis acquires a centrifugal force which increases with its distance from the axis.

Fig. 10.



Let NÆSQ, Fig. 10, represent a sphere which revolves on an axis NS, and let P be any particle of matter upon its surface, revolving in a circle whose radius is EP. This particle, by its motion in a circle, acquires a centrifugal force which acts in a direction EP perpendicular to the axis of rotation. This centrifugal force, which we will represent by PA, may be resolved into two other forces PB and PD, one acting in the direction of a radius of the earth, and the other at right angles to this radius. The former force, being opposed to the earth's attraction, has the effect of diminishing the weight of the body; the latter, being directed toward the equator, tends to produce motion in the direction of the equator.

The intensity of the centrifugal force increases with the radius of the circle described, and is therefore greatest at the equator. Moreover, the nearer the point is to the equator, the more directly is the centrifugal force opposed to the weight of the body.

The effects, therefore, produced by the rotation of the earth are—

1st. All bodies decrease in weight in going from the pole to the equator; and,

2d. All bodies which are free to move tend from the higher latitudes toward the equator.

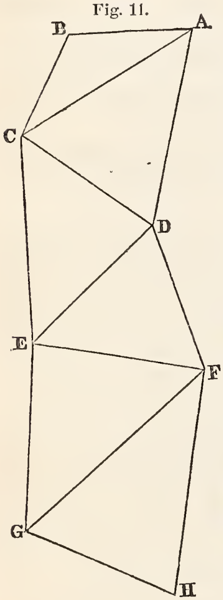
By computation, we find that at the equator the centrifugal force of a body arising from the earth's rotation once in 24 sidereal hours is $\frac{1}{289}$ part of the weight; and, since this force is directly opposed to gravity, the weight must sustain a loss of $\frac{1}{289}$ part.

This loss of weight from centrifugal force is greatest at the equator, and diminishes as we proceed toward either pole.

36. *Effect of Centrifugal Force upon the Form of a Body.*—We have seen that a portion of the centrifugal force represented by PD, Fig. 10, causes a tendency to move toward the equator. If the surface of the sphere were entirely solid, this tendency would be counteracted by the cohesion of the particles. But a large portion of the earth's surface is liquid, and this portion must yield to the centrifugal force, and flow toward the equator. The water is thus made to recede from the higher latitudes in either hemisphere, and accumulate around the equator. Thus the earth, instead of being an exact sphere, assumes the form of an oblate spheroid, a solid having somewhat the figure of an orange. The amount of the deviation from an exact sphere depends upon the intensity of the centrifugal force, and the attraction exerted by the earth upon bodies placed on its surface. A sphere consisting of any plastic material, like soft clay, may be reduced to a spheroidal form by causing it to rotate rapidly upon an axis.

37. *Weight at the Pole and Equator compared.*—We have found that at the equator the loss of weight due to centrifugal force is $\frac{1}{289}$. From a comparison of observations of the length of the seconds' pendulum made in different parts of the globe, it is found that the weight of a body at the pole actually exceeds its weight at the equator by $\frac{1}{194}$. The difference between the fractions $\frac{1}{194}$ and $\frac{1}{289}$ is $\frac{1}{590}$; that is, the actual attraction exerted by the earth upon a body at the equator is less than at the pole by the 590th part of the whole weight. This difference results from the greater distance of the body at the equator from the centre of the earth.

Fig. 11.



38. *How an Arc of a Meridian is measured.*—Numerous arcs of the meridian have been measured for the purpose of accurately determining the figure and dimensions of the earth. These arcs are measured in the following manner:

A level spot of ground is selected, where a *base line*, AB, from five to ten miles in length, is measured with the utmost precision. A third station, C, is selected, forming with the base line a triangle as nearly equilateral as is convenient. The angles of this triangle are measured with a large theodolite, and the two remaining sides may then be computed. A fourth station, D, is now selected, forming, with two of the former stations, a second triangle, in which all the angles are measured; and, since one side is already known, the others may be computed. A fifth station, E, is then selected, forming a third triangle; and thus we proceed forming a series of triangles, following nearly the direction of a meridian.

The bearing of each side, that is, its inclination to the meridian line, must also be measured, and hence we can compute how much any station is north or south of any other, and hence we can determine the distance between the parallels of latitude passing through the most northerly and southerly points. The latitude of these two stations must now be determined, whence we obtain the difference of latitude corresponding to the arc measured. We thus have the measure of an arc of a meridian expressed in miles, and also in degrees, and hence, by a proportion, we may find the length of an arc of one degree.

This method is the most accurate known for determining the distance between two remote points on the earth's surface, because we may choose the most favorable site for measuring accurately the base line; and, after this, nothing is required but the measurement of angles, which can be done with much less labor and with much greater accuracy than the measurement of distances.

39. *Verification of the Work.*—In order to verify the entire work, a second base line is measured near the end of the series of triangles, and we compare its measured length with the length as computed from the first base, through the intervention of the series of triangles.

In the survey of the coast of the United States, three base lines have been measured east of New York, the shortest being a little more than five miles in length, and the longest more than ten miles, and the two extreme bases are distant from each other 430 miles in a direct line. In one instance the observed length of a base differs from its length, as deduced from one of the other bases, by *six inches;* in no other case does the discrepancy exceed *three inches.* This coincidence proves that none but errors of extreme minuteness have been committed in the determination of the position of the intermediate stations stretching from the city of New York to the eastern boundary of Maine.

40. *Results of Measurements.*—In the manner here described, arcs of the meridian have been measured in nearly every country of Europe. These surveys form a connected chain of triangles, extending from the North Cape, in lat. 70° 40′, to an island in the Mediterranean, in lat. 38° 42′. An arc has been measured in India extending from lat. 29° 26′ to lat. 8° 5′. An arc has been measured in South America extending from the equator to more than three degrees of north latitude. An arc of four degrees has also been measured in South Africa. The operations for the survey of the coast of the United States will ultimately furnish several important arcs of a meridian, but these observations are not yet fully reduced.

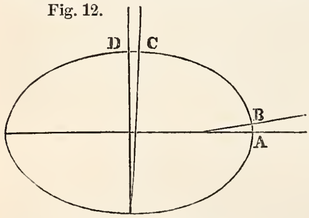
These measurements enable us to determine with great accuracy the length of a degree of latitude for the entire distance from the equator to the north pole. The results are:

A degree at the equator	=68.702	miles, or	362,748	feet.
" in latitude 45°	=69.048	"	364,572	"
" at the pole	=69.396	"	366,410	"
Difference of equatorial and polar arc	= 0.694	"	3662	"

41. *Conclusion from these Results.*—If the earth were an exact sphere, a terrestrial meridian would be a perfect circle, and every part of it would have the same curvature; that is, a degree of latitude would be every where the same. But we find that the length of a degree increases as we proceed from the equator toward the poles, and the amount of this variation affords a measure of the departure of a meridian from the figure of a circle.

A plumb-line must every where be perpendicular to the surface of tranquil water, and (since the earth is not a sphere) can not every where point exactly toward the earth's centre. Let A,B be two plumb-lines suspended on the same meridian near the equator, and at such a distance from each other as to be inclined at an angle of one degree. Let C and D be two other plumb-lines on a meridian near one of the poles, also making with each other an angle of one degree. The distance from A to B is found to be *less* than from C to D, whence we conclude that the meridian *curves more rapidly* near A than near C. The two plumb-lines A and B will therefore intersect at a distance less than the equatorial radius, and the plumb-lines C and D will inter-

Fig. 12.



sect at a distance greater than the polar radius; but the difference is purposely exaggerated in the figure. If the figure were made an exact representation of a section of the earth, it could not be distinguished from a perfect circle.

It is found that all the observations in every part of the world are very accurately represented by supposing a meridian of the earth to be an ellipse, of which the polar diameter is the minor axis.

The equatorial diameter of this ellipse is		7926.708	miles.
The diameter in latitude 45°	"	7913.286	"
The polar diameter	"	7899.755	"
Difference of equatorial and polar diameter is		26.953	"

Thus we find that the equatorial diameter exceeds the polar diameter by $\frac{1}{294}$ of its length. This difference is called the *ellipticity* of the earth.

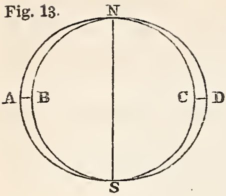
The circumference of the earth, measured upon a meridian, is 24,857.43 miles; or a quadrant from the equator to the north pole is 6214.357 miles.

From measurements which have been made at right angles to the meridian, it appears that the equator and parallels of latitude are very nearly, if not exactly circles. Hence it appears that the form of the earth is that of an *oblate spheroid*, a solid which may be supposed to be generated by the revolution of a semi-ellipse about its minor axis. This conclusion leaves out of account the mountains upon the earth's surface, and refers simply to the surface of the sea.

42. *Loss of Weight at the Equator explained.* — It has been mathematically proved that a spheroid whose ellipticity is $\frac{1}{294}$, and whose average density is double the density at the surface (which is the case with the earth, Art. 46), exerts an attraction upon a particle placed at its pole greater by $\frac{1}{590}$ part than the attraction upon a particle at its equator; and this we have seen (Art. 37) is the fraction which must be added to the loss of weight by centrifugal force to make up the total loss of weight at the equator, as shown by experiments with the seconds' pendulum.

This coincidence may be regarded as demonstrating that the earth *does* rotate upon its axis once in 24 hours.

Fig. 13.



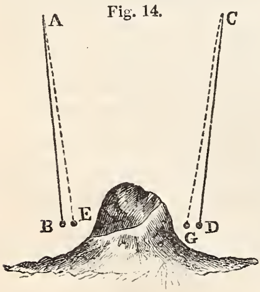
43. *Equatorial Protuberance.*—If a sphere be conceived to be inscribed within the terrestrial spheroid, having the polar axis NS for its diameter, a spheroidal shell will be included between its surface and that of the spheroid having a thickness AB of 13 miles at the equator, and becoming gradually thinner toward the poles. This shell of protuberant matter, by means of its attraction, gives rise to the precession of the equinoxes, as will be explained hereafter, Art. 177.

44. *The Density of the Earth.*—Several methods have been employed for determining the average density of the earth. These methods are generally founded upon the principle of comparing the attraction which the earth exerts upon any object with the attraction which some other body, whose mass is known, exerts upon the same object.

First Method.—By comparing the attraction of the earth with that of a small mountain.

In 1774 Dr. Maskelyne determined the ratio of the mean density of the earth to that of a mountain in Scotland by ascertaining how much the local attraction of the mountain deflected a plumb-line from a vertical position. This mountain stands alone on an extensive plain, so that there are no other eminences in the vicinity to affect the plumb-line. Two stations were selected, one on its northern and the other on its southern side, and both nearly in the same meridian. A plumb-line attached to an instrument designed for measuring small zenith distances was set up at each of these stations, and the distance from the direction of the plumb-line to a certain star was measured at each station the instant the star was on the meridian. The difference between these distances gave the angle formed by the two directions of the plumb-lines AE, CG. Were it not for the mountain, the plumb-lines would

Fig. 14.



take the positions AB, CD; and the angle which they would in that case form with each other is found by measuring the distance between the two stations, and allowing about one second for every hundred feet.

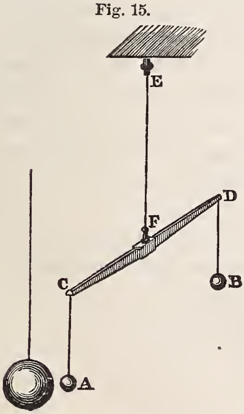
The disturbance of the plumb-lines caused by the attraction of the mountain was thus found to amount to 12″. It was computed that if the mountain had been as dense as the interior of the earth, the disturbance would have been about 21″. Hence the ratio of the density of the mountain to that of the entire earth was that of 12 to 21. By numerous borings, the mean density of the mountain was ascertained to be 2.75 times that of water. Hence the mean density of the earth was computed to be 4.95 times that of water.

From similar observations made in 1855 near Edinburg, the mean density of the earth was computed to be 5.32.

45. *Second Method.*—The mean density of the earth has been determined by comparing the attraction of the earth with that of a large ball of metal, by means of the torsion balance.

In the year 1798, Cavendish compared the attraction of the earth with the attraction of two lead balls, each of which was one foot in diameter. The bodies upon which their attraction was exerted were two leaden balls, A, B, each about two inches in diameter. They were attached to the ends of a slender wooden rod, CD, six feet in length, which was supported at the centre by a fine wire, EF, 40 inches long. The balls, if left to themselves, will come to rest when the supporting wire is entirely free from torsion, but a very slight force is sufficient to turn it out of this plane. The position of the rod CD was accurately observed with a fixed telescope. The large balls were then brought near the small ones, but on opposite sides, so that the attraction of both balls might conspire to twist the wire in the same direction, when

Fig. 15.



it was found that the small balls were sensibly attracted by the larger ones, and the amount of this deflection was carefully measured. The large balls were then moved to the other side of the small ones, when the rod was found to be deflected in the contrary direction, and the amount of this deflection was recorded. This experiment was repeated many times.

These experiments furnish a measure of the attraction of the large balls for the small ones, and hence we can compute what would be their attraction if they were as large as the earth. But we know the attraction actually exerted by the earth upon the small balls, this attraction being measured by their weight. Thus we know the attractive force of the earth compared with that of the lead balls; and, since we know the density of the lead, we can compute the average density of the earth. From these experiments Cavendish concluded that the mean density of the earth was 5.45.

A much more extensive series of experiments made with the greatest care in 1841 indicated the mean density of the earth to be 5.67, and this is regarded as the most reliable determination hitherto made.

46. *Comparative Density at the Surface and at the Centre.*—The average density of the rocks found near the earth's surface is about 2.6, which is not quite half the average density of the earth. Hence we conclude that the density of the earth goes on increasing from the surface to the centre, and at the centre it may have the density of iron, or perhaps even of gold. This increased density may be supposed to be the result of the pressure of the superincumbent mass sustained by bodies at great depths below the surface.

47. *Volume and Weight of the Earth.*—Having determined the dimensions of the earth, we can easily compute its volume, and we find it amounts to

259,400 millions of cubic miles.

Knowing the density of the earth, we can also compute its weight. A cubic foot of water weighs $62\frac{1}{2}$ pounds; hence a cubic foot of a solid whose specific gravity is 5.67 will weigh 354 pounds. If we multiply the number of cubic feet in the earth by 354, we shall have its weight expressed in pounds. We thus find the weight of the earth to be

6,000,000,000,000,000,000,000 tons,

or *six sextillions of tons.*

This number must not be regarded as fanciful or conjectural, but as a legitimate deduction from the most accurate observations which have hitherto been made, liable, however, to some slight alteration if more accurate observations should hereafter be obtained.

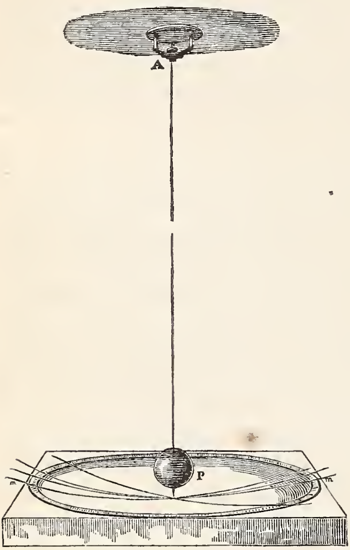
48. *Direct Proof of the Earth's Rotation.*—A direct proof of the earth's rotation is derived from observations of a pendulum. If a heavy ball be suspended by a flexible wire from a fixed point, and the pendulum thus formed be made to vibrate, its vibrations will all be performed in the *same plane.* If, instead of being suspended from a fixed point, we give to the point of support a slow movement of rotation around a vertical axis, the plane of vibration will still remain unchanged. This may be proved by fastening the wire to a spindle placed vertically, and giving to the spindle a slow movement of rotation (say four or five revolutions per minute) round the vertical axis; the ball will be seen to rotate on its axis, without, however, changing its plane of vibration.

Suppose, then, a heavy ball to be suspended by a wire from a fixed point directly over the pole of the earth, and made to vibrate, these vibrations will continue to be made in the same invariable plane. But the earth meanwhile turns round at the rate of 15 degrees per hour; and, since the observer is unconscious of his own motion of rotation, it results that the plane of vibration of the pendulum *appears* to revolve at the same rate in the opposite direction.

If the pendulum be removed to the equator, and set vibrating in the direction of a meridian, the plane of vibration will still remain unchanged; and since, notwithstanding the earth's rotation, this plane always coincides with a meridian, the plane of vibration will appear fixed, and no motion of the plane will be observed.

The apparent motion of the plane of vibration is zero at the equator, and 15 degrees per hour at the poles. In going from the equator to the pole, the apparent motion of the plane of rotation increases steadily with the latitude, and at New Haven amounts to about 10 degrees per hour.

Fig. 16.



It is indispensable to the success of this experiment that the pendulum should commence oscillating without any lateral motion. For this purpose the pendulum is drawn out of the vertical position, and tied to a fixed object by a fine thread. When the ball is quite at rest the thread is burned, and the pendulum commences its vibrations. Experiments of this kind have been made at numerous places.

When the experiment is performed with the greatest care, the observed rate of motion coincides very accurately with the computed rate, and this coincidence may be regarded as a direct proof that the earth makes one rotation upon its axis in 24 sidereal hours.

49. *Second Proof of the Earth's Rotation.*—A second proof of the earth's rotation is derived from the motion of falling bodies. If the earth had no rotation upon an axis, a heavy body let fall from any elevation would descend in the direction of a vertical line. But, if the earth rotates on an axis, then, since the top of a tower describes a larger circle than the base, its easterly motion must be more rapid than that of the base. If a ball be dropped from the top of the tower, since it has already the easterly motion which belongs to the top of the tower, it will retain this easterly motion during its descent, and its deviation to the east of the vertical line will be nearly equal to the excess of the motion of the top

Fig. 17.

of the tower above that of the base during the time of fall.

Let AB represent a vertical tower, and AA′ the space through which the point A would be carried by the earth's rotation in the time that a heavy body would descend through AB. A body let fall from the top of the tower will retain the horizontal velocity which it had at starting, and, when it reaches the earth's surface, will have moved over a horizontal space, BD, nearly equal to AA′. But the foot of the tower will have moved only through BB′, so that the body will be found to the east of the tower by a space nearly equal to B′D.

This space B′D, for an elevation of 500 feet in the latitude of New Haven, is but a little over one inch, so that it must be impossible to detect this deviation except from experiments conducted with the greatest care, and from an elevation of several hundred feet.

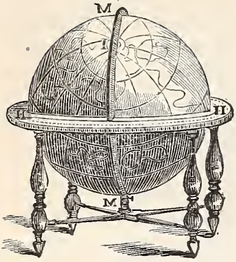
50. *Results of Experiments.*—Repeated experiments have been made in Italy and Germany for the purpose of detecting the deviation of falling bodies from a vertical line. The most satisfactory experiments were made in a mine 520 feet deep, with metallic balls an inch and a half in diameter. According to the mean of over a hundred trials, the easterly deviation was 1.12 inch, while the deviation computed by theory should have been 1.08 inch. These experiments must be regarded as proving that the earth does rotate upon an axis.

ARTIFICIAL GLOBES.

51. Artificial globes are either terrestrial or celestial. The former exhibits a miniature representation of the earth, the latter exhibits the relative position of the fixed stars. The mode of mounting is usually the same for both, and many of the circles drawn upon them are the same for both globes.

An artificial globe is mounted on an axis which is supported by a brass ring, MM, designed to represent a meridian, and is called the *brass meridian*. This ring is supported in

Fig. 18.



a vertical position by a frame in such a manner that the axis of the globe can be inclined at any angle to the horizon. The brass meridian is graduated into degrees, which are numbered from the equator toward either pole from 0 to 90 degrees.

The horizon is represented by a broad wooden ring, HH, placed horizontally, whose plane passes through the centre of the globe. It is also graduated into degrees, which are numbered in both directions from the north and south points toward the east and west, to denote azimuths; and there is usually another set of numbers, which begin from the east and west points, to denote amplitudes. This wooden ring is called the *wooden horizon.*

Upon the wooden horizon are commonly represented the signs of the ecliptic, with divisions into degrees, and also the months, and days of each month, so arranged as to show the sun's place in the ecliptic for every day of the year.

On the terrestrial globe, hour circles are represented by great circles drawn through the poles of the equator; and on the celestial globe corresponding circles are drawn through the poles of the ecliptic, and small circles parallel to the ecliptic are drawn at intervals of ten degrees. These are for determining celestial latitude and longitude. The ecliptic, tropics, and polar circles are drawn upon the terrestrial globe, as well as upon the celestial.

About the north pole is a small circle graduated so as to indicate hours of the day and minutes; while a small index, I, called the *hour index*, attached to the brass meridian, points to one of the divisions upon this hour circle. This index can be moved so as to point to any part of the hour circle.

There is usually a flexible strip of brass, equal in length to one quarter of the circumference of the globe, which is graduated into degrees, and may be applied to the surface of the globe so as to measure the distance between two places, or it may measure the altitude of any point above the wooden horizon. Hence it is usually called the *quadrant of altitude.*

PROBLEMS ON THE TERRESTRIAL GLOBE.

52. *To find the Latitude and Longitude of a given Place.*—Turn the globe so as to bring the given place to the graduated side of the brass meridian; then the degree of the meridian directly over the place will indicate the latitude, and the degree of the equator under the brass meridian will indicate the longitude east or west of the first meridian.

Verify the following by the globe:

	Lat.	Long.		Lat.	Long.
Paris	$49°$ N.	$2\frac{1}{3}°$ E.	San Francisco...	$37\frac{3}{4}°$ N.	$122\frac{1}{2}°$ W.
New York.........	$40\frac{3}{4}°$ N.	$74°$ W.	Cape Horn	$55\frac{3}{4}°$ S.	$67\frac{1}{4}°$ W.

53. *The Latitude and Longitude of a Place being given, to find the Place.*—Bring the degree of longitude on the equator under the brass meridian, then under the given degree of latitude on the brass meridian will be found the place required.

Examples.

1. What place is in lat. 30° N. and long. 90° W.?
   Ans. New Orleans.
2. What place is in lat. 23 N°. and long. 113 E°.?
   Ans. Canton.
3. What place is in lat. 38° S. and long. 145° E.?
   Ans. Melbourne.

54. *To find the Distance from one Place to another on the Earth's Surface.*—Place the quadrant of altitude so that its graduated edge may pass through both places, and the point marked 0 may be on one of them. Then the point of the quadrant which is over the other place will show the distance between the two places in degrees, which may be reduced to miles by multiplying them by 69, because 69 miles make nearly one degree.

Examples.

1. Find the distance of Liverpool from New York.
   Ans. 3600 miles.
2. Find the distance of Jeddo from San Francisco. *Ans.*

3. Find the distance of Melbourne from San Francisco. *Ans.*

55. *To find the Antipodes of a given Place.* — Bring the given place to the wooden horizon, and the opposite point of the horizon will indicate the antipodes. The one place will be as far from the north point of the wooden horizon as the other is from the south point.

Examples.

1. Find the antipodes of Cape Horn. *Ans.* Irkutsk.
2. Find the antipodes of London. *Ans.*
3. Find the antipodes of the Sandwich Islands. *Ans.*

56. *Given the Hour of the Day at any Place, to find the Hour at any other Place.*—Bring the place at which the time is given to the brass meridian, and set the hour index to the given time. Turn the globe till the other place comes to the meridian, and the index will point to the required time.

Examples.

1. When it is 10 A.M. in New York, what is the hour in San Francisco? *Ans.* $6\frac{3}{4}$ A.M.
2. When it is 5 P.M. in London, what is the hour in New York? *Ans.*
3. When it is noon in New York, what is the hour at Canton? *Ans.*

CHAPTER II.

INSTRUMENTS FOR OBSERVATION. — THE CLOCK. — TRANSIT INSTRUMENT. — MURAL CIRCLE. — ALTITUDE AND AZIMUTH INSTRUMENT. — THE SEXTANT.

57. *Why Observations are chiefly made in the Meridian.*— Whenever circumstances allow an astronomer to select his own time of observation, almost all his observations of the heavenly bodies are made when they are upon the meridian, because a large instrument can be more accurately and permanently adjusted to describe a *vertical* plane than any plane oblique to the horizon; and there is no other vertical plane which combines so many advantages as the meridian. The places of the heavenly bodies are most conveniently expressed by right ascension and declination, and the right ascension is simply the time of passing the meridian, as shown by a sidereal clock. Moreover, when a heavenly body is at its upper culmination, its refraction and parallax are the least possible, and in this position refraction and parallax do not affect the right ascension of the body, but simply its declination; while for every position out of the meridian they affect both right ascension and declination.

58. *The Astronomical Clock.*—The capital instruments of an astronomical observatory are the clock, the transit instrument, and the mural circle.

In a stationary observatory, a pendulum clock is used for measuring time. The pendulum should be so constructed that its length may not be affected by changes of temperature; and the clock should rest upon a stone pier having a firm foundation, and not connected with the floor of the observatory. It should be so regulated that, if a star be observed upon the meridian at the instant when the hands point to 0h. 0m. 0s., they will point to 0h. 0m. 0s. when the same star is next seen on the meridian. This interval is called a *sidereal day*, and is divided into 24 sidereal hours. If the pendulum were perfectly adjusted, it would make 86,400 vibrations in the interval between two successive returns of the same star to the meridian. But no clock is perfect, and it therefore becomes necessary to determine its *error* and *rate* daily, and, in reducing our observations, to make an allowance for the error of the clock.

The *error* of a sidereal clock at any instant is its difference from true sidereal time. The *rate* of a clock is the *change* of its error in 24 hours. Thus if, on the 8th of January, when Aldebaran passed the meridian, the clock was found to be 30.84s. slow, and on the 9th of January, when the same star passed the meridian, the clock was 31.66s. slow, the clock lost 0.82s. per day. In other words, the error of the clock, Jan. 9th, was −31.66s., and its daily rate −0.82s.

The error of a clock is found from day to day by observing the time of transit of some star whose place has been accurately determined, and comparing the observed time with the star's right ascension. Where great accuracy is required, the transits of several standard stars should be observed. To facilitate these observations, the apparent places of over a hundred stars are given in the Nautical Almanac.

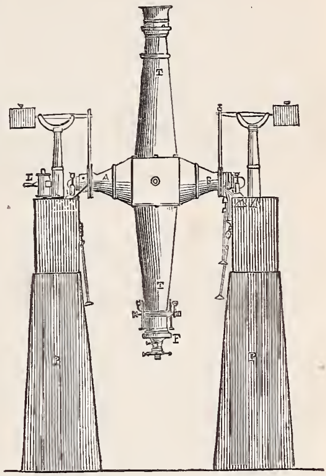
59. *The Transit Instrument.*—Most of the observations of the heavenly bodies are made when they are upon the celestial meridian, and in many cases the sole business of the observer is to determine the exact instant when the object is brought to the meridian by the apparent diurnal motion of the firmament. The passage of a heavenly body over the meridian is called a *transit*, and an instrument mounted in such a manner as to enable an observer, supplied with a suitable clock, to determine the exact time of transit, is called a *transit instrument.*

60. *Transit Instrument described.*—A transit instrument consists of a telescope, TT, mounted upon an axis, AB, at right angles to the tube, which axis occupies a horizontal position, and points east and west. The tube of the telescope, when horizontal, will therefore be directed north and south; and if the telescope be revolved on its axis through

180 degrees, the central line of the tube will move in the plane of the meridian, and may be directed to any point on the celestial meridian.

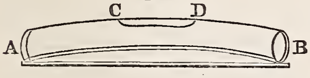
A small transit instrument is usually mounted upon a solid stand of cast iron, which can be easily moved from place to place. A large transit instrument is mounted upon two stone piers, P,P, Fig. 19, which should have a solid foundation, and should stand on an east and west line. On the top of each of the piers is secured a metallic support in the form of the letter Y, to receive the extremities of the axis of the telescope. At the left end of the axis there is a screw, by which the Y of that extremity may be raised or lowered a little, in order that the axis may be made perfectly horizontal. At the right end of the axis is a screw, by which the Y of that extremity may be moved backward or forward, so as to enable us to bring the telescope into the plane of the meridian.

Fig. 19.



61. *The Spirit Level.*—When the transit instrument is properly adjusted, its axis will be horizontal, and directed due east and west. If the axis be not exactly horizontal, its deviation may be ascertained by placing upon it a *spirit level.* This consists of a glass tube, AB, nearly filled with alcohol or ether. The tube forms a portion of a ring having a very large radius, and when it is placed horizontally, with its convexity upward, the bubble, CD, will occupy the highest position in the middle of its length. A graduated scale is attached to the tube, by which we may measure any deviation of the bubble from the middle of the tube.

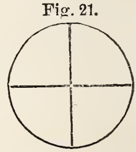
Fig. 20.



To ascertain whether the axis of the telescope is horizontal, apply the level to it, and see if the bubble occupies the middle of the tube. If it does not, one end of the axis must be elevated or depressed by turning the screw which moves one of the Y's in a vertical direction (Art. 60). The level must now be taken up, and reversed end for end, when the bubble should still occupy the middle of the tube. If it does not, it indicates that the two legs of the level are not of equal length, and the error must be corrected by turning the adjusting screw of the spirit level. This operation of reversing the level must be repeated until the bubble rests in the middle of the tube in both positions of the level.

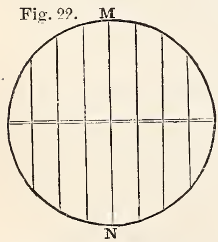
62. *The Reticle.*—In order to furnish within the field of view of the telescope a fixed point of reference, a system of wires or fibres is attached to a frame, and secured in the focus of the eye-glass of the telescope, so that when seen through the eye-glass they appear like fine lines drawn across the field of view. Such an apparatus is called a *reticle.* In a theodolite there are generally two wires intersecting at right angles at the centre of the field of view, and dividing it into quadrants, as shown in Fig. 21.

Fig. 21.



In the focus of the eye-piece of the transit instrument is secured a small frame to which are attached several parallel and equidistant wires, crossed by one or two others at right angles, Fig. 22. The latter should be made horizontal, when the former wires will of course be vertical. When the reticle and the telescope have been properly adjusted, the middle wire, MN, will be in the plane of the meridian, and when an object is seen upon it, the object will be on the celestial meridian.

Fig. 22.



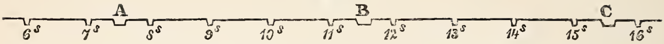
63. *Method of observing Transits.*—The fixed stars appear in the telescope as bright points of light without sensible magnitude, and by the diurnal motion of the heavens a star is carried successively over each of the wires of the transit instrument. The observer, just before the star enters the field of view, writes down the hour and minute indicated by the clock, and proceeds to count the seconds by listening to the beats of the clock, while his eye is looking through the telescope. He observes the instant at which the star crosses each of the wires, estimating the time to the nearest tenth of a second; and by taking a mean of all these observations, he obtains with great precision the instant at which the star passed the middle wire, and this is regarded as the true time of the transit. The mean of the observations over several wires is considered more reliable than an observation over a single wire.

During the day, the wires of the reticle are visible as fine black lines stretched across the field of view. At night they are rendered visible by a lamp, L, Fig. 19, whose light passes through a perforation in the axis of the transit instrument, and is reflected to the eye-glass by a mirror placed diagonally at the junction of the axis and telescope. The field of view may thus be illumined more or less at pleasure.

When we observe the sun or any object which has a sensible disk, the time of transit is the instant at which the centre of the disk crosses the middle wire. This time is obtained by observing the instants at which the eastern and western edges of the disk touch each of the wires in succession, and taking the mean of all the observations. When the visible disk is not circular, special methods of reduction are employed.

64. *The Electro-chronograph.*—In many observatories it is now customary to employ the electric circuit to record transit observations. An electro-magnetic recording apparatus is connected with the pendulum of an astronomical clock in such a manner that the circuit is broken at each vibration of the pendulum, and the seconds of the clock are denoted by a series of equally distant breaks in a line traced upon a sheet of paper to which an equable motion is given by machinery. At the instant a star is seen to pass one of the wires of the transit, the observer presses his finger upon a key, and a break is made in one of the short lines representing seconds, as shown at A, B, and C, in Fig. 23. In this

Fig. 23.



way observations can be made with much greater accuracy than by the old method, and a greater number of observations can be made in a given time.

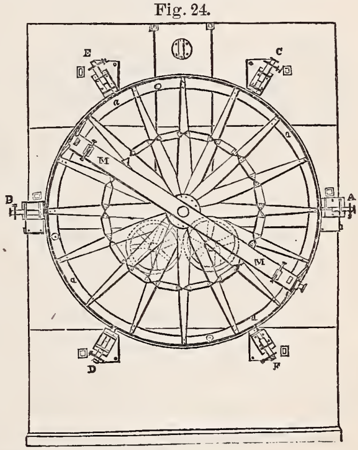
65. *Rate of the Diurnal Motion.* — Since the celestial sphere revolves at the rate of 15 degrees per hour, or 15 seconds of arc in one second of time, the space passed over between two successive beats of the pendulum will be 15 seconds of arc. When the sun is on the equator, and its apparent diameter is 32 minutes of arc, the interval between the contacts of the east and west limbs with the middle wire of the transit instrument will be 2m. 8s.

66. *To adjust a Transit Instrument to the Meridian.*—A transit instrument may be adjusted to describe the plane of the meridian by observations of the pole star. Direct the telescope to the pole star at the instant of its crossing the meridian, as near as the time can be ascertained; the transit will then be *nearly* in the plane of the meridian. The pole star is on the meridian when it attains its greatest or least altitude. It is now desirable to set the clock to indicate sidereal time, which may be done as follows: Having leveled the axis, turn the telescope to a star about to cross the meridian near the zenith. Since every vertical circle intersects the meridian at the zenith, a zenith star will cross the field of the telescope at the same time, whether the plane of the transit coincide with the meridian or not. At the moment when the star crosses the central wire, set the clock to the star's right ascension as given by the Nautical Almanac, and the clock will henceforth indicate nearly sidereal time. The times of the upper and lower culminations of the pole star will now be known pretty accurately. Observe the pole star at one of its culminations, following its motion until the clock indicates its right ascension, or its right ascension plus 12 hours. By means of the azimuth screw bring the middle wire of the telescope to coincide with the star, and the adjustment will be nearly complete.

67. *Final Verification.*—The axis being supposed perfectly horizontal, if the middle wire of the telescope is exactly in the meridian, it will bisect the circle which the pole star describes round the pole in 24 sidereal hours. If, then, the interval between the upper and lower culminations is exactly equal to the interval between the lower and upper, the adjustment is perfect. But if the time elapsed while the star is traversing the eastern semicircle is greater than that of traversing the western, the plane in which the telescope moves is westward of the true meridian on the north horizon, and *vice versa* if the western interval is greatest. This error of position must be corrected by turning the azimuth screw. The adjustment must then be verified by further observations until the instrument is fixed in the meridian with all attainable accuracy.

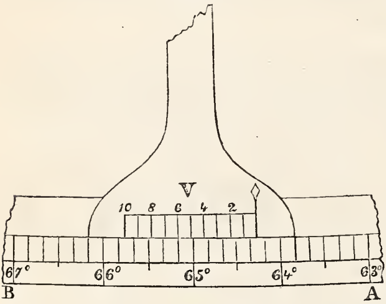
68. *The Mural Circle.*—The mural circle is an instrument used to measure the altitude of a heavenly body at the instant when it crosses the meridian. It consists of a large graduated circle, *aaaa*, Fig. 24, firmly attached at right angles to a horizontal axis upon which it turns. This axis is supported by a stone pier or wall, whose face is accurately adjusted to the plane of the meridian. To the circle is attached a telescope, MM, so that the entire instrument, including the telescope, turns in the plane of the meridian. The circle is divided into degrees, and subdivided into spaces of five minutes, and sometimes of two minutes, the divisions being numbered from 0 to 360 degrees round the entire circle. The smallest spaces on the limb are further subdivided to single seconds, sometimes by a *vernier*, but generally by a *reading microscope.*

Fig. 24.



69. *The Vernier.*—A vernier is a scale of small extent, graduated in such a manner that, being moved by the side of a fixed scale, we are enabled to measure minute portions of this scale. The length of this movable scale is equal to a certain number of parts of that to be subdivided; but it is divided into parts either one more or one less than those of the primary scale taken for the length of the vernier. Thus, if a circle is graduated to sixths of a degree, or 10 minutes, and we wish to measure single minutes by the vernier, we take an arc equal to 9 divisions upon the limb, and divide it into 10 equal parts. Then each division of the vernier will be equal to $\frac{9}{60}$ of a degree, while each division of the scale is $\frac{10}{60}$ of a degree; that is, each space on the limb exceeds one upon the vernier by one minute.

Fig. 25.



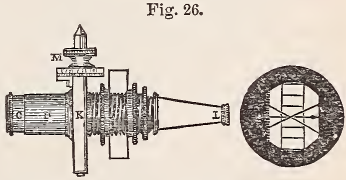
Thus, let AB represent a portion of the limb of a circle divided into degrees and 10′ spaces, and let V represent the vernier, which may be moved entirely round the circle, and having 10 of its divisions equal to 9 divisions of the circle; that is, to $\frac{9}{6}$ of a degree. Therefore one division of the circle exceeds one division of the vernier by $\frac{1}{60}$ of a degree. Now, as the sixth division of the vernier (in the figure) coincides with a division of the circle, the fifth division of the vernier will be 1′ beyond the nearest division of the circle; the fourth division, 2′; and the zero of the vernier will be 6′ beyond the next lower division of the circle; *i. e.*, the zero of the vernier coincides with 64° 16′ upon the circle.

In order, therefore, to read an angle for any position of the vernier, we observe what division of the vernier coincides with a division of the circle. The number of this line from the zero point indicates the minutes which are to be added to the degrees and minutes taken from the graduated circle.

By increasing the number of subdivisions of the vernier, much smaller quantities than one minute may be measured. With a circle of 8 inches' radius, we may easily read angles to 10 seconds, and with a circle of 2 feet radius we may measure angles as small as 1 or 2 seconds.

70. *The Reading Microscope.*—The reading microscope is a compound microscope firmly attached to the pier which supports the circle, and having in its focus cross-wires which are moved laterally by a fine-threaded micrometer screw. The figure on the right shows the field of view, with the magnified divisions of the circle as seen through the microscope. When the microscope is properly adjusted, the image of the divided limb and the micrometer wires are distinctly visible together. If the circle is divided into spaces of 5′, then five revolutions of the screw must exactly measure one of these spaces. One revolution of the head of the screw will therefore carry the wires over a space of one minute. The circumference of the circle attached to the head, M, is divided into 60 equal parts, so that the motion of the head through one of these divisions advances the wires through a space of one second. There are six of these microscopes, A, B, C, D, E, F, placed at equal distances round the circle, Fig. 24, and firmly attached to the pier.

Fig. 26.



71. *To determine the Horizontal Point upon the Limb of the Circle.*—Direct the telescope upon any star which is about crossing the meridian, and bring its image to coincide with the horizontal wire which passes through the centre of the field of the telescope. Then read the graduation by each of the fixed microscopes. On the next night, place a basin containing mercury in such a position that, by directing the telescope of the circle toward it, the same star may be seen reflected from the surface of the mercury, and bring the reflected image to coincide with the horizontal wire of the telescope. Then read the graduation as before. Now, by a law of optics, the reflected image will appear as much depressed below the horizon as the star is elevated above it; therefore half the sum of the two readings, at either of the microscopes, will be the reading at the same microscope when the telescope is horizontal.

72. *To measure the Altitude of a Heavenly Body.*—Having determined the reading of each of the microscopes when the telescope is directed to the horizon, if we wish to measure the altitude of a star, direct the telescope upon it so that it may be seen on the horizontal wire as the star passes the meridian, and read off the angle from the several microscopes. The difference between the last reading and the reading when the telescope is horizontal is the altitude required.

The zenith distance of a star is found by subtracting its altitude from 90°.

To measure the altitude of the sun or any object which has a sensible disk, measure the altitude of the upper and lower limbs, and take half their sum for the altitude of the centre; or measure the altitude of the lower limb, and add the apparent semi-diameter taken from the Nautical Almanac.

73. *To determine the Declination of a Heavenly Body.*—The pole star crosses the meridian above and below the pole at intervals of 12 hours sidereal time, and the true position of the pole is exactly midway between the two points where the star crosses the meridian; therefore half the sum of the altitudes of these points will be the altitude of the pole itself.

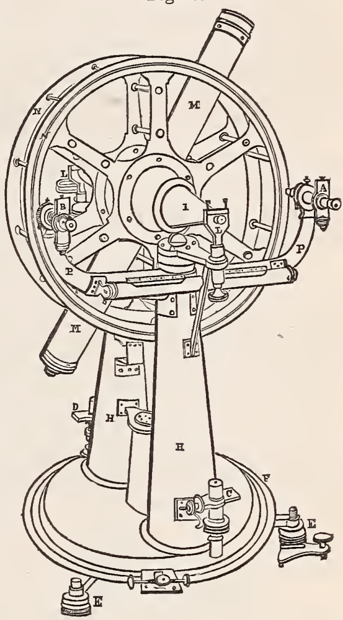
The altitude of the pole being determined, that of the equator is also known, since the equator is 90 degrees from the pole.

Having determined the position of the celestial equator, the declination of any star is easily determined, since its declination is simply its distance from the equator. Art. 31.

74. *The Meridian Circle.*—Since the mural circle has a short axis, its position in the meridian is unstable, and therefore it can not be relied upon to give the right ascension of stars with great accuracy. The meridian circle is a combination of the transit instrument and mural circle, being simply a transit instrument with a large graduated circle attached to its axis. It is sometimes called a *transit circle*, and is now in common use at most of the large observatories.

75. *Altitude and Azimuth Instrument.*—This instrument has one graduated circle, E F, confined to a horizontal plane; a second graduated circle, N, perpendicular to the former, and capable of being turned to any azimuth; and a telescope, MM, firmly fastened to the second circle, and turning with it about a horizontal axis. The appearance of the instrument will be learned from Fig. 27.

Fig. 27.

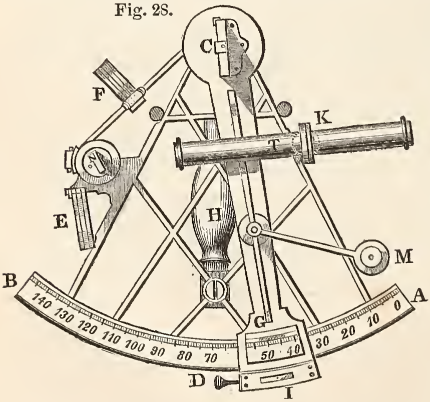


76. *Adjustments of this Instrument.* — Before commencing observations with this instrument, the horizontal circle must be leveled, and also the axis of the telescope. The meridional point on the azimuth circle is its reading when the telescope is pointed north or south, and may be determined by observing a star at equal altitudes east and west of the meridian, and finding the point midway between the two observed azimuths. The horizontal point of the altitude circle is its reading when the axis of the telescope is horizontal, and may be found in the manner described for the mural circle, Art. 71.

This instrument has the advantage over the meridian circle in being able to determine the place of a star in any part of the visible heavens; but we ordinarily prefer the place of a star to be given in right ascension and declination instead of altitude and azimuth, and to deduce the one from the other requires a laborious computation. Hence the altitude and azimuth instrument is but little used for astronomical observations, except for special purposes, as, for example, to investigate the laws of refraction.

77. *The Sextant.*—The sextant is much used at sea for the determination of latitude and longitude, and is also frequently useful on land when only portable instruments can be obtained. It has a triangular frame, ABC, made of brass, with a wooden handle, H. It has a graduated limb, AB, comprising 60 or 70 degrees of the circle, but it is graduated into 120 or more degrees, and each degree is divided into six equal parts of 10′ each, while the vernier gives angles to 10″. The divisions are also continued a short distance on the other side of zero toward A, forming what is called the arc of excess. The microscope, M, is used to read off the divisions on the graduated limb. At I is a screw for clamping the index to the limb; and D is a tangent screw for giving the index, CG, a small motion, and thus securing an accurate contact of the images. Attached to the index bar, CG, the silvered index glass, C, is fixed perpendicular to the plane of the instrument. To the frame at N is attached a second glass, called the horizon glass, the lower half of which only is silvered. This is also perpendicular to the plane of the instrument, and is parallel to the plane of the index glass, C, when the vernier is set to zero on the limb AB.

Fig. 28.



The telescope, T, is supported in a ring, K; and in the focus of the object glass are placed two wires parallel to each other, and equidistant from the axis of the telescope. At E and

F are colored glasses of different shades, to diminish the intensity of the light when a bright object, as the sun, is observed.

78. *To measure the Distance between two Objects.*—Hold the sextant in the right hand by the handle, so that its plane may pass through both objects. Point the telescope upon one of the objects, and with the left hand move the index until the reflected image of the other object is brought to the centre of the field of the telescope, into apparent contact with the object seen directly. The angle is then read off from the limb by the aid of the microscope.

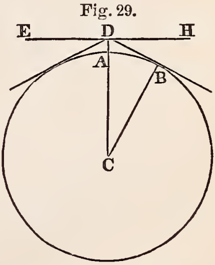
79. *To measure the Altitude of a Heavenly Body.*—For an artificial horizon, place a shallow vessel containing a small quantity of mercury in a position convenient for observation. Measure the angle between the body and its image reflected from the mercury as if this image were a real object. Half this angle will be the altitude of the body.

In obtaining the altitude of a body at sea, its altitude above the visible horizon is measured by bringing the reflected image into contact with the horizon.

80. *Dip of the Horizon.*—The visible horizon which we employ in measuring altitudes at sea is depressed below the true horizontal plane.

Let AC represent the radius of the earth, AD the height of the eye above the level of the sea, EDH a horizontal plane passing through the place of the observer; then HDB will represent the depression of the horizon, and is commonly called the *dip of the horizon.* This angle may be computed as follows:

Fig. 29.



The angle BDH is equal to the angle BCD; and in the right-angled triangle BCD we know BC, the radius of the earth, and CD, the radius of the earth plus the height of the observer. Hence, by Trigonometry, we can compute the angle BCD.

For an elevation of 25 feet the dip of the horizon amounts to nearly five minutes, and for an elevation of 100 feet it amounts to nearly 10 minutes. For an elevation of 3000 feet the dip amounts to about one degree, and for an elevation of 12,000 feet it amounts to about two degrees.

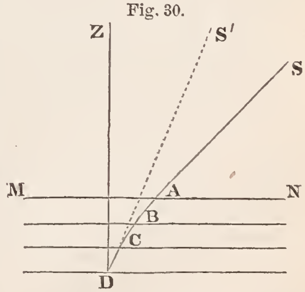
CHAPTER III.

ATMOSPHERIC REFRACTION.—TWILIGHT.

81. The air which surrounds the earth gradually decreases in density as we ascend from the surface. At the height of 4 miles its density is only about half as great as at the earth's surface; at the height of 8 miles, about one fourth as great; at the height of 12 miles, about one eighth as great, and so on. From this law it follows that at the height of 50 miles its density must be extremely small, so as to be nearly or quite insensible to ordinary tests. The phenomena of shooting stars and the Aurora Borealis, however, indicate that a very feeble atmosphere extends to a height of 500 miles.

82. *Path of a Ray of Light.*—According to a law of optics, when a ray of light passes obliquely from a rarer to a denser medium, it is bent toward the perpendicular to the refracting surface. Hence the light which comes from a star to the earth is refracted toward a vertical line. We may conceive the atmosphere to consist of an infinite number of strata increasing in density from the top downward.

Fig. 30.



Let SA be a ray of light coming from a distant object, S, and falling obliquely upon the atmospheric strata. The ray SA, passing into the first layer, will be deflected in the direction AB, toward a perpendicular to the surface MN. Passing into the next layer, it will be again deflected in the direction BC, more toward the perpendicular; and, passing through the lowest layer, it will be still more deflected, and will enter the eye at D, in the direction of CD; and since every object appears in the direction from which the visual ray enters the eye, the object S will be seen in the direction DS′, instead of its true direction AS.

Since the density of the earth's atmosphere increases gradually from its upper surface to the earth, the path of a ray of light from a heavenly body is not a broken line, as we have here supposed, but a curve line concave toward the earth. Since the density of the upper part of the atmosphere is very small, the curve at first deviates very little from a straight line, but the deviation increases as the ray approaches the earth. Both the straight and curved parts of the ray lie in the same vertical plane, for this plane is perpendicular to all the strata of the atmosphere, and therefore the ray will continue in this plane in passing from one stratum to another. The refraction of the atmosphere therefore makes a star appear to be nearer the zenith than it really is, but its azimuth remains unchanged.

In the zenith the refraction is zero, since the ray of light falls perpendicularly upon all the strata of the atmosphere. The refraction increases with the zenith distance; for, the greater the zenith distance of a star, the more obliquely do the rays from it fall upon the different strata, and therefore, according to the principles of optics, the greater is the refraction. The refraction of a star is therefore greatest at the horizon.

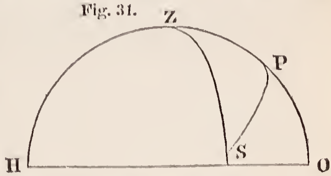
83. *How the Refraction may be determined by Observation.*—In latitudes greater than 45°, a star which passes through the zenith of the place may also be observed when it passes the meridian below the pole. Let the polar distance of such a star be measured both at the upper and lower culminations. In the former case there will be no refraction; the difference between the two observed polar distances will therefore be the amount of refraction for the altitude at the lower culmination; because, if there were no refraction, the apparent diurnal path of the star would be a circle, with the celestial pole for its centre.

This method is strictly applicable only in latitudes greater than 45°, and by observations at one station we can only determine the refraction corresponding to a single altitude; but by combining observations at different stations from latitude 45° to 70°, we may determine the refraction for any altitude from zero to 50 degrees.

84. *A general Method of determining Refraction.*—When the latitude of a place and the polar distance of a star which passes the meridian near the zenith have been determined, the refraction may be found for all altitudes from observations at a single station.

In Fig. 31, let PZH represent the meridian of the place of observation, P the pole, Z the zenith, and S the true place of the star. Let ZS be a vertical circle passing through the star, and PS an hour circle passing through the star. Then, in the triangle ZPS, PZ is the complement of the latitude, which is supposed to be known; PS is the polar distance of the star, which is also known. If, then, we knew also the angle ZPS, we could compute ZS, which represents the true zenith distance of the star. The difference between the computed value of ZS and its observed value will be the refraction corresponding to this altitude. Now the angle ZPS is the angular distance of the star from the meridian, or the difference between the time when the star was at S and the time when it crosses the meridian.

Fig. 31.



If we commence our observations when the star is near the horizon, and continue them at short intervals until it reaches the meridian, measuring the apparent altitude, and noting the time of observation by the clock, we may determine the amount of refraction for all altitudes from zero to 90 degrees.

The average value of refraction at the horizon is about 35′, or a little more than half a degree; at an altitude of 10° it is only 5′; at 25° it is 2′; at 45° it is 1′; at 62° it is only 30″; and in the zenith it is zero.

85. *Corrections for Temperature and Pressure.*—The amount of refraction at a given altitude is not always the same, but depends upon the temperature and the pressure of the air. Tables have been constructed, partly from observation and partly from theory, by which we may readily obtain the mean refraction for any altitude; and rules are given by which the proper correction may be made for the height of the barometer and thermometer.

86. *Effect of Refraction upon the Time of Sunrise.*—Since refraction increases the altitudes of the heavenly bodies, it must accelerate their rising and retard their setting, and thus render them longer visible. The amount of refraction at the horizon is about 35′, which being a little more than the apparent diameters of the sun and moon, it follows that, when the lower limb of one of these bodies appears just to touch the horizon, if there were no refraction it would be wholly invisible.

87. *Effect of Refraction upon the Figure of the Sun's Disk.*—When the sun is near the horizon, the lower limb, having the least altitude, is most affected by refraction, and therefore more elevated than the upper limb, and thus the vertical diameter is shortened, while the horizontal diameter remains sensibly the same. This effect is greatest near the horizon, because there the refraction changes most rapidly for a given change of altitude. The difference between the vertical and horizontal diameters may amount to one fifth of the whole diameter. The disk thus assumes an elliptical form, with its longer axis horizontal.

88. *Enlargement of the Sun near the Horizon.*—The apparent enlargement of the sun and moon near the horizon is not due to refraction, but is an illusion of the judgment. If we measure the apparent diameters of these bodies with any suitable instrument, we shall find that, when near the horizon, they subtend a *less* angle than when seen near the zenith. This is owing to their greater distance from us in the former instance than in the latter, as explained in Art. 127. It is, then, through an error of judgment that they seem to us larger near the horizon.

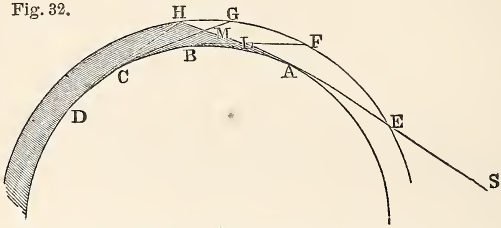
Our judgment of the absolute magnitude of a body is based upon our estimate of its distance. If two objects at unequal distances subtend the same angle, the more distant one must be the larger. Now the sun and moon, when near the horizon, appear to us more distant than when they are high in the heavens. They seem more distant in the former position, partly from the number of intervening objects, and partly from their diminished brightness. When the moon is near the horizon a variety of intervening objects shows us that the distance of the moon must be considerable; but when the moon is high up in the sky no such objects intervene, and the moon appears quite near. For the same reason, the vault of heaven does not present the appearance of a hemisphere, but appears flattened toward the zenith, and spread out at the horizon.

Our estimate of the distance of objects is also influenced by their clearness or obscurity. Thus a distant mountain, seen through a perfectly clear atmosphere, appears much nearer than when seen through a hazy atmosphere. The disks of the sun and moon, when near the horizon, appear much less brilliant than they do when high up in the heavens, and on this account we assign to them a greater distance.

89. *Cause of Twilight.*—After the sun has set, its rays continue for some time to illumine the upper strata of the air, and are thence reflected to the earth, producing considerable light. As the sun descends farther below the horizon, a less part of the visible atmosphere receives his direct light—less light is reflected to the surface of the earth—until at length all reflection ceases, and night begins. Before sunrise in the morning, the same phenomena are exhibited in the reverse order. The illumination thus produced is called the *twilight*.

Let ABCD, Fig. 32, represent a portion of the earth's surface; let EFGH be the limit of the atmosphere, or at least of that part which reflects light visibly; and let SAH be a ray of light from the sun, just grazing the earth at A, and leaving the atmosphere at the point H. The point A is illumined by the whole reflective atmosphere HGFE. The point B, to which the sun has set, receives no direct solar light, nor any light reflected from that part of the atmosphere which is below ALH; but it receives a twilight from the portion HLF, which lies above the visible horizon BF. The point C receives a twilight only from the small portion

Fig. 32.



of the atmosphere HMG, while at D the twilight has ceased altogether.

The limit of twilight is generally understood to be the instant when stars of the sixth magnitude begin to be visible in the zenith at evening, or disappear in the morning. This generally happens when the sun is about 18 degrees below the horizon.

90. *Duration of Twilight at the Equator.*—The duration of twilight depends upon the latitude of the place and the sun's declination. At the equator, where the circles of diurnal motion are perpendicular to the horizon, when the sun is in the celestial equator it descends through 18 degrees in an hour and twelve minutes ($\frac{18}{15}=1\frac{1}{5}$ hours); that is, twilight lasts 1h. and 12m. When the sun is not in the equator the duration of twilight is slightly increased.

91. *Duration of Twilight at the Poles.*—At the north pole, since the horizon coincides with the celestial equator, there is continued day as long as the sun is north of the equator; that is, for a period of six months. Then succeeds a period of twilight, which lasts about 50 days, until the sun attains a distance of 18 degrees south of the equator. Then succeeds a period of about eighty days without twilight, when the sun again reaches a south declination of 18 degrees. Twilight now commences, and continues for about 50 days, and is succeeded by another long day of six months.

92. *Duration of Twilight in Middle Latitudes.*—At intermediate latitudes the duration of twilight may vary from 1h. 12m. to 50 days. The summer twilights are longer than those of winter, and the longest twilight occurs at the summer solstice, while the shortest occurs when the sun has a small southern declination. In latitude 40°, twilight varies from an hour and a half to a little over two hours.

In latitude 50°, where the north pole is elevated 50 degrees above the horizon, the point which is on the meridian 18 degrees below the north point of the horizon is 68° distant from the north pole, and therefore 22 degrees distant from the equator. Now, during the entire month of June, the distance of the sun from the equator exceeds 22 degrees; that is, in latitude 50°, there is continued twilight from sunset to sunrise during a period of more than a month.

In latitude 60°, the period of the year during which twilight lasts through the entire night is about four months.

93. *Consequences if there were no Atmosphere.*—If there were no atmosphere, none of the sun's rays could reach us after his actual setting or before his rising; that is, the darkness of midnight would instantly succeed the setting of the sun, and it would continue thus until the instant of the sun's rising. During the day the illumination would also be much less than it is at present, for the sun's light could only penetrate apartments which were accessible to his direct rays, or into which it was reflected from the surface of natural objects. On the summits of mountains, where the atmosphere is very rare, the sky assumes the color of the deepest blue, approaching to blackness, and stars become visible in the daytime.

CHAPTER IV.

THE EARTH'S ANNUAL MOTION.—SIDEREAL AND SOLAR TIME. — EQUATION OF TIME. — THE CALENDAR. — PARALLAX. — PROBLEMS ON THE GLOBES.

94. *Sun's apparent Motion in Right Ascension.*—The sun appears to move toward the east among the stars; for if, on any evening soon after sunset, we notice the distance of any star from the western horizon, we shall find in a few evenings that this distance has grown less, and, since the stars themselves all maintain the same position with respect to each other, we conclude that the sun has moved toward the east.

If we determine the sun's right ascension from day to day with the transit instrument, we shall find that the right ascension increases each day about one degree, or four minutes of time; so that in a year the sun makes a complete circuit round the heavens, moving continually among the stars from west to east. This daily motion in right ascension is not uniform, but varies from 215s. to 266s., the average motion being about 236s., or 3m. 56s.

95. *Sun's apparent Motion in Declination.*—If we observe daily with the mural circle the point at which the sun's centre crosses the meridian, we shall find that its position changes continually from day to day. Its declination is zero on the 20th of March, from which time its north declination increases until the 21st of June, when it is 23° 27′. It then decreases until the 22d of September, when the sun's centre is again upon the equator. Its south declination then increases until the 21st of December, when it is 23° 27′, after which it decreases until the sun's centre returns to the equator on the 20th of March.

If we combine these two motions in right ascension and declination, and trace upon a celestial globe the course of the sun from day to day through the year, we shall find that its path is a great circle of the heavens, whose plane makes an angle of 23° 27′ with the plane of the celestial equator. This circle is called the *ecliptic*, because solar and lunar eclipses can only take place when the moon is very near this plane.

96. *The Equinoxes and Solstices.*—The ecliptic intersects the celestial equator at two points diametrically opposite to each other. These are called the *equinoctial points*, because when the sun is at these points it is for an equal time above and below the horizon, and the days and nights are therefore equal.

That one of these points which the sun passes in the spring is called the *vernal* equinoctial point, and the other, which is passed in the autumn, is called the *autumnal* equinoctial point. The *times* at which the sun's centre is found at these points are called the vernal and autumnal *equinoxes*. The vernal equinox therefore occurs on the 20th of March, and the autumnal on the 22d of September.

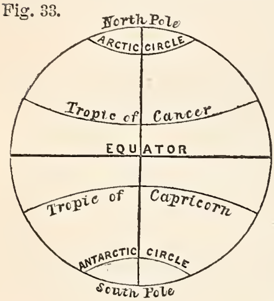
Those points of the ecliptic which are midway between the equinoctial points are the most distant from the celestial equator, and are called the *solstitial* points; and the times at which the sun's centre passes these points are called the *solstices*. That which occurs in the summer is called the *summer solstice*, and the other the *winter solstice*. The summer solstice takes place about the 21st of June, and the winter solstice about the 21st of December.

The distance of either solstitial point from the celestial equator is 23° 27′. The more distant the sun is from the celestial equator, the more unequal will be the days and nights; and therefore the longest day of the year will be the day of the summer solstice, and the shortest that of the winter solstice. In southern latitudes the seasons will be reversed.

97. *The Colures.*—The equinoctial colure is the hour circle which passes through the equinoctial points. The solstitial colure is the hour circle which passes through the solstitial points. The solstitial colure is at right angles both to the ecliptic and to the equator, for it passes through the pole of each of these circles.

98. *Tropics and Polar Circles.*—The tropics are two small circles parallel to the equator, and passing through the solstices. That which is on the north side of the equator is called the *Tropic of Cancer*, and the other the *Tropic of Capricorn.*

Fig. 33.



The polar circles are two small circles parallel to the equator, and distant 23° 27′ from the poles. The one about the north pole is called the *Arctic circle;* the other, about the south pole, is called the *Antarctic circle.*

99. *The Zodiac.*—The zodiac is a zone of the heavens extending eight degrees on each side of the ecliptic. The sun, the moon, and all the larger planets have their motions within the limits of the zodiac.

The ecliptic and zodiac are divided into twelve equal parts called *signs*, each of which contains 30 degrees. Beginning at the vernal equinox, and following round from west to east, the signs of the zodiac, with the symbols by which they are designated, are as follows:

Sign.	Symbol.	Sign.	Symbol.
I. Aries..........	♈	VII. Libra	♎
II. Taurus	♉	VIII. Scorpio	♏
III. Gemini	♊	IX. Sagittarius..	♐
IV. Cancer	♋	X. Capricornus....	♑
V. Leo	♌	XI. Aquarius	♒
VI. Virgo	♍	XII. Pisces.........	♓

The first six are called northern signs, being north of the celestial equator; the others are called southern signs.

The vernal equinox corresponds to the first point of Aries, and the autumnal equinox to the first point of Libra. The summer solstice corresponds to the first point of Cancer, and the winter solstice to the first point of Capricorn.

100. *Celestial Latitude and Longitude.*—A *circle of latitude* is a great circle of the celestial sphere which passes through the poles of the ecliptic, and therefore cuts this circle at right angles.

The *latitude* of a heavenly body is its distance from the ecliptic measured on a circle of latitude. It may be north or south, and is counted from zero to 90 degrees.

The *longitude* of a heavenly body is the distance from the vernal equinox to the circle of latitude which passes through the centre of the body, and is measured on the ecliptic toward the east, or in the order of the signs. Longitude is counted from zero to 360 degrees.

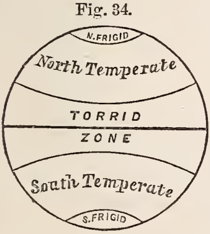
The position of a heavenly body is designated by means of its longitude and latitude, as well as by its right ascension and declination, Art. 31. The former refer to the vernal equinox and the ecliptic, the latter to the vernal equinox and the equator.

101. *Division of the Earth into Zones.*—The earth is naturally divided into five zones, depending on the appearance of the diurnal path of the sun. These zones are,

1st. The *torrid* zone, extending from the Tropic of Cancer to the Tropic of Capricorn. Throughout this zone the sun every year passes through the zenith of the observer, when the sun's declination is equal to the latitude of the place.

2d. The two *frigid* zones, included within the polar circles. Within these zones there are several days of the year, near the winter solstice, during which the sun does not rise above the horizon, and near the summer solstice there are several days during which the sun does not sink below the horizon. At the summer solstice, on the arctic circle, the sun's distance from the north pole is just equal to the latitude of the place, and the sun's diurnal path just touches the horizon at the north point.

Fig. 34.



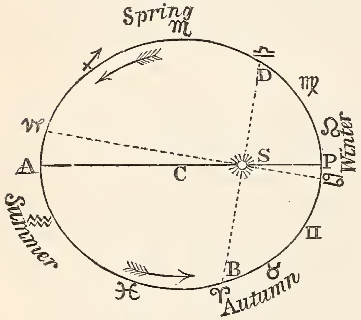
3d. The north and south *temperate* zones, extending from the tropics to the polar circles. Within these zones the sun is never seen in the zenith, and it rises and sets every day.

102. *Appearances produced by the Earth's Annual Motion.* —The apparent annual motion of the sun may be explained either by supposing a real revolution of the sun around the earth, or a revolution of the earth around the sun. But we conclude, from the principles of Mechanics, that the earth and sun must both revolve around their common centre of gravity, and this point is very near the centre of the sun, Art. 147.

If the earth could be observed by a spectator upon the sun, it would appear among the fixed stars in the point of the sky opposite to that in which the sun appears as viewed from the earth.

In Fig. 35, let S represent the sun, and ABPD the orbit of the earth. To a spectator upon the earth, the sun will appear projected among the fixed stars in the point of the sky opposite to that occupied by the earth; and, while the earth moves from A to B and P, the sun will appear to move among the stars from P to D and A, and in the course of the year will trace out in the sky the plane of the ecliptic. When the earth is in Libra, we see the sun in the opposite sign, Aries; and while the earth moves from Libra to Scorpio, the sun appears to move from Aries to Taurus, and so on through the ecliptic.

Fig. 35.



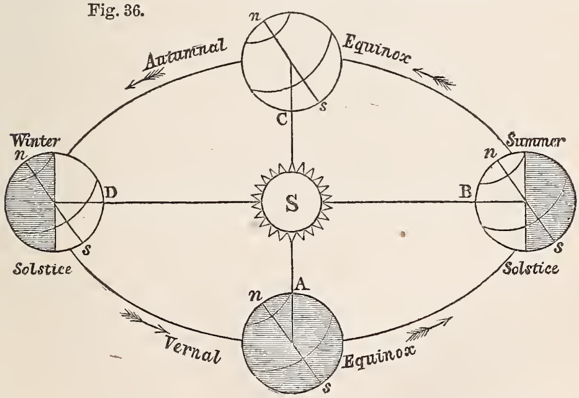
103. *Cause of the Change of Seasons.*—The annual revolution of the earth around the sun, combined with its diurnal rotation upon its axis, enables us to explain not only the alternations of day and night, but also the succession of seasons. While the earth revolves annually round the sun, it has a motion of rotation upon an axis which is inclined 23° 27′ from a perpendicular to the ecliptic; and this axis continually points *in the same direction.*

In June, when the north pole of the earth inclines toward the sun, the greater portion of the northern hemisphere is enlightened, and the greater portion of the southern hemisphere is dark. The days are therefore longer than the nights in the northern hemisphere, while the reverse is true in the southern hemisphere. Upon the equator, however, the days and nights are equal. In December, when the south pole inclines toward the sun, the days are longer than the nights in the southern hemisphere, and the nights are longer than the days in the northern hemisphere.

In March and September, when the earth's axis is perpendicular to the direction of the sun, the circle which separates the enlightened from the unenlightened hemisphere passes through the poles, and the days and nights are equal all over the globe.

These different cases are illustrated by Fig. 36. Let S represent the position of the sun, and ABCD different positions of the earth in its orbit, the axis, *ns*, always pointing toward the same fixed star. At A and C (the equinoxes) the sun illumines from *n* to *s*, and as the globe turns upon its axis the sun will appear to describe the equator, and the days and nights will be equal in all parts of the globe. When the earth is at B (the summer solstice) the sun illumines $23\frac{1}{2}$

Fig. 36.



degrees beyond the north pole, *n*, and falls the same distance short of the south pole, *s*. When the earth is at D (the winter solstice) the sun illumines $23\frac{1}{2}$ degrees beyond the south pole, *s*, and falls the same distance short of the north pole, *n*.

104. *In what Case would there have been no Change of Seasons.*—If the earth's axis had been perpendicular to the plane of its orbit, the equator would have coincided with the ecliptic, day and night would have been of equal duration throughout the year, and there would have been no diversity of seasons.

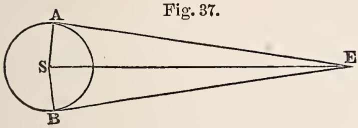
105. *In what Case would the Change of Seasons have been greater than it now is?*—If the inclination of the equator to the ecliptic had been greater than it is, the sun would have receded farther from the equator on the north side in summer, and on the south side in winter, and the heat of summer, as well as the cold of winter, would have been more intense; that is, the diversity of the seasons would have been greater than it is at present. If the equator were at right angles to the ecliptic, the poles of the equator would be situated in the ecliptic; and at the summer solstice the sun would appear at the north pole of the celestial sphere, while at the winter solstice it would be at the south pole of the celestial sphere. To an observer in the middle latitudes the sun would therefore, for a considerable part of summer, be within the circle of perpetual apparition, and for several weeks be constantly above the horizon. So also for a considerable part of winter he would be within the circle of perpetual occultation, and for several weeks be constantly below the horizon. The great vicissitudes of heat and cold resulting from such a movement of the sun would be extremely unfavorable to both animal and vegetable life.

106. *To Determine the Obliquity of the Ecliptic.*—The obliquity of the ecliptic, that is, the inclination of the equator to the ecliptic, is equal to the greatest declination of the sun. It may therefore be determined by measuring with a mural circle the sun's declination at the summer or at the winter solstice. The mean value of the obliquity in Jan., 1868, was $23° 27' 23''$. The obliquity is diminishing at the rate of about half a second annually.

107. *To determine the Form of the Earth's Orbit.*—The form of the earth's orbit could be determined if we knew the direction of the sun from the earth for each day of the year, and also his daily distances from the earth either absolute or relative. Now the direction of the sun is indicated by his longitude, which can be determined by observation.

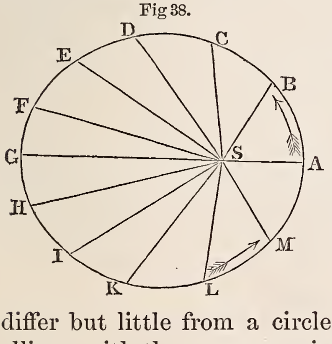
To determine the sun's absolute distance from us requires a knowledge of his parallax, which will be explained hereafter, Art. 145 ; but his relative distances from day to day are indicated by his apparent diameters, since the apparent diameter of the sun at different distances from the earth varies inversely as the distance. Thus, if AB represents the sun

Fig. 37.



seen from the earth at E, it is evident that, the greater the distance, the less will be the angle AE B. By measuring with a micrometer the sun's apparent diameter from day to day throughout the year, we have a measure of the relative distances; and if we also observe the sun's longitude for every day of the year, by combining the two series of observations we may determine the form of the earth's orbit. If the sun's longitude be increased by 180 degrees, it will represent the direction of the earth as seen from the sun, Art. 102. We then construct a figure by drawing lines SA, SB, etc., to

Fig 38.



represent the direction of the earth from the sun for each day of the year, and set off the distances SA, SB, etc., equal to the relative distances already determined by the observations. Then, connecting the points A, B, C, D, etc., by a curve line, we have a figure which represents the earth's orbit. This orbit is found to differ but little from a circle, but more accurately it is an ellipse, with the sun occupying one of the foci.

108. *To find the Eccentricity of the Earth's Orbit.*—The eccentricity of an ellipse measures its deviation from the form of a circle. It is the distance between the two foci divided by the major axis. Its value can be deduced from the greatest and least apparent diameters of the sun, since these furnish a measure of the relative distances. The greatest and least apparent diameters are 32′.61 and 31′.53. The distances SG and SA are in the ratio of the same numbers. Their sum is 64′.14, and their difference 1′.08. Hence the eccentricity of the ellipse is $\frac{108}{6414}$, or $\frac{1}{60}$ very nearly. This quantity is so small that if a diagram were drawn representing the earth's orbit with perfect accuracy, we could not, without careful measurement, discern any deviation from an exact circle.

The point A of the orbit where the earth is nearest the sun is called the *perihelion*, and the earth passes this point on the 1st of January. The point G, most distant from the sun, is called the *aphelion*, and the earth passes this point on the 1st of July; that is, the earth is more distant from the sun in summer than in winter by one thirtieth of the mean distance.

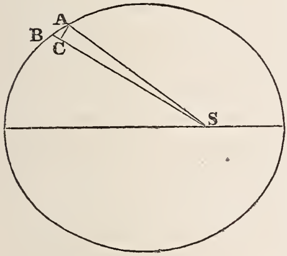
109. *Why the greatest Heat and Cold do not occur at the Solstices.*—The influence of the sun in heating the earth's surface depends upon its altitude at noon, and upon the length of time during which it continues above the horizon. Both these causes conspire to produce the increased heat of summer and the diminished heat of winter. If the temperature at any place depended simply upon the direct momentary influence of the sun, the hottest day would occur at the summer solstice when the sun rises highest and the days are the longest; but during the most of summer the heat received from the sun during the day is greater than the loss by radiation during the night, and the maximum occurs when the loss by night is just equal to the gain by day. At most places in the northern hemisphere this occurs some time in July or August.

For the same reason, the greatest cold does not occur at the winter solstice, but some time in January or February, when the gain of heat by day is just equal to the loss by night.

The variation in the distance of the sun from the earth exerts no appreciable influence upon the difference of seasons, because, when this distance is least, the angular velocity of the earth about the sun is greatest; and hence, in that half of the orbit which is most remote from the sun, we receive the same amount of heat as in the half of the orbit which is nearest the sun.

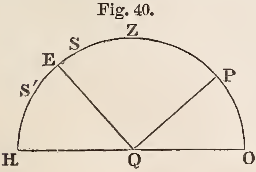
110. *The Radius Vector of the Earth's Orbit describes equal Areas in equal Times.*—The straight line drawn from the centre of the sun to the centre of the earth is called the radius vector of the earth's orbit. If we suppose S to represent the place of the sun, and A and B to represent the places of the earth at noon on two successive days, then the figure ASB will be the area described by the radius vector of the earth in one day. Knowing the relative distances of AS, BS, and also the angle ASB, as explained in Art. 107, we can compute the area of the triangular space ASB. If, in like manner, we suppose lines to be drawn from the sun to the places occupied by the earth at noon for each day of the year, the triangular spaces thus formed will all be found to be equal to each other. Hence it is established by observation that the radius vector of the earth's orbit describes equal areas in equal times.

Fig. 39.



111. *To find the Latitude of any Place.*—The latitude of a place may be determined by measuring the altitude of any circumpolar star, both at its upper and lower culminations, as explained in Art. 72. It may also be determined by measuring a single meridian altitude of any celestial body whose declination is known. Let HO represent the horizon of a place, Z the zenith, P the elevated pole, and EQ the

Fig. 40.



equator. Let S or S′ be a star upon the meridian; then SE or S′E will represent its declination. Measure SH, the altitude of the star, and correct the altitude for the effect of refraction. Then

$$EH = SH - SE = S'H + S'E.$$

Hence EH, which is the altitude of the equator, becomes known; and hence PO, the latitude of the place, is known, since PO is the complement of EH. The declinations of all the brighter stars have been determined with great accuracy, and are recorded in catalogues of the stars.

112. *To find the Latitude at Sea.*—At sea the latitude is usually determined by measuring with a sextant the greatest altitude of the sun's lower limb above the sea horizon at noon. The observations should be commenced about half an hour before noon, and the altitude of the sun be repeatedly measured until the altitude ceases to increase. This greatest altitude is considered to be the sun's altitude when on the meridian. To this altitude we must add the sun's semidiameter in order to obtain the altitude of the sun's centre, and this result must be corrected for refraction. To this result we must add the declination of the sun when it is south of the equator, or subtract it when north, and we shall obtain the elevation of the equator, which is the complement of the latitude. The sun's declination for every day in the year is given annually in the Nautical Almanac.

113. *Sidereal Time.*—Sidereal time is time reckoned in sidereal days, hours, etc. A sidereal day is the interval between two successive returns of the vernal equinox to the same meridian. This interval represents the time of the earth's rotation upon its axis, and is not only invariable from one month to another, but has not changed so much as the hundredth part of a second in two thousand years.

114. *Solar Time.*—Solar time is time reckoned in solar days, hours, etc. A solar day is the interval between two successive returns of the sun to the same meridian.

The sun moves through 360 degrees of longitude in one tropical year, or 365 days, 5 hours, 48 minutes, and 47 seconds. Hence the sun's mean daily motion in longitude is found by the proportion

One year : one day :: 360° : 59′ 8″ = the daily motion.

This motion is not uniform, but is most rapid when the sun is nearest to the earth. Hence the solar days are unequal; and to avoid the inconvenience which would result from this fact, astronomers employ a *mean* solar day, whose length is equal to the mean or average of all the apparent solar days in a year.

115. *Sidereal and Solar Time compared.*—The length of the mean solar day is greater than that of the sidereal, because when, in its diurnal motion, the mean sun returns to a given meridian, it is 59′ 8″ eastward (with respect to the fixed stars) of its position on the preceding day.

Hence, in a mean solar day, an arc of the equator equal to 360° 59′ 8″ passes over the meridian, while only 360° pass in a sidereal day. The excess of the solar day above the sidereal day will then be given by the proportion

360° : 59′ 8″ :: one day : 3m. 56s.

Hence 24 hours of mean solar time are equivalent to 24h. 3m. 56s. of sidereal time; and 24 hours of sidereal time are equivalent to 23h. 56m. 4s. of mean solar time, omitting, for convenience, the fractions of a second.

116. *Civil Day and Astronomical Day.*—The civil day begins at midnight, and consists of two periods of 12 hours each; but modern astronomers number the hours continuously up to 24, and commence the day at noon, because this date is marked by a phenomenon which can be easily observed, viz. the passage of the sun over the meridian; and because, since observations are chiefly made at night, it is inconvenient to have a change of date at midnight. The astronomical day commences 12 hours later than the civil day. Thus, July 4th, 9 A.M., civil time, corresponds to July 3d, 21 hours of astronomical time.

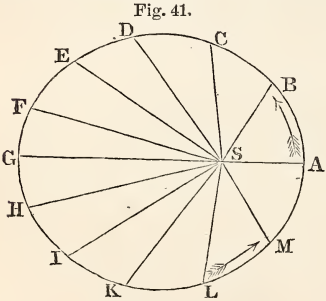
117. *Apparent Time and Mean Time.*—An apparent solar day is the interval between two successive transits of the sun's centre over the same meridian. Apparent time is time reckoned in apparent solar days, while mean time is time reckoned in mean solar days. The difference between apparent solar time and mean solar time is called the *equation of time.*

If a clock were required to indicate apparent solar time, it would be necessary that its rate should change from day to day, according to a very complicated law. It has been found in practice so difficult to accomplish this, that clocks are now generally regulated to indicate mean solar time. Such a clock will not, therefore, generally indicate exactly 12 hours when the sun is on the meridian, but will sometimes indicate a few minutes more than 12 hours, and sometimes a few minutes less than 12 hours; the difference being equal to the equation of time.

118. *First Cause of the Inequality of the Solar Days.*—The inequality of the solar days depends on two causes, the unequal motion of the earth in its orbit, and the inclination of the equator to the ecliptic.

While the earth is revolving round the sun in an elliptic orbit, its motion is most rapid when it is nearest to the sun, and slowest when it is most distant. Let ADGK represent the elliptic orbit of the earth, with the sun in one of its foci at S, and let the direction of motion be from A toward B.

Fig. 41.

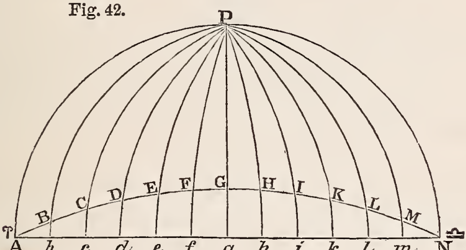


We have found that the sun's mean daily motion as seen from the earth, or the earth's mean daily motion as seen from the sun, is 59′ 8.″ But when the earth is nearest the sun at A, its daily motion is 61′ 10″, while at G, when most remote from the sun, it is only 57′ 12″. While moving, therefore, from A to G, the earth will be in advance of its mean place; but at G, having completed a half revolution, the true and the mean places will coincide. For a like reason, in going from G to A, the earth will be behind its mean place; but at A the true and the mean places will again coincide. The point A in the diagram corresponds to about the 1st of January.

So far, then, as it depends upon the unequal motion of the earth in its orbit, the difference between apparent time and mean time will be zero on the 1st of January; but after this, mean time will be in advance of apparent time, and the difference will go on increasing for about three months, when it amounts to a little more than 8 minutes. From this time the difference will diminish until about the 1st of July, when it becomes zero; after this, apparent time will be in advance of mean time, and the difference will go on increasing for about three months, when it amounts to a little more than 8 minutes, from which time the difference will diminish until the 1st of January, when apparent time and mean time again coincide.

119. *Second Cause for the Inequality of the Solar Days.*— Even if the earth's motion in its orbit were perfectly uniform, the apparent solar days would be unequal, because the ecliptic is inclined to the equator. Let A*g*N represent half

Fig. 42.



the equator, and AGN the northern half of the ecliptic. Let the ecliptic be divided into equal portions, AB, BC, etc., supposed to be described by the sun in equal portions of time; and through the points B, C, D, etc., let hour circles be drawn cutting the equator in the points *b*, *c*, *d*, etc. Then AB, BC, etc., represent arcs of longitude, while A*b*, *bc*, etc., represent the corresponding arcs of right ascension. The arc AGN is equal to the arc A*g*N, for all great circles bisect each other; and therefore AG, the half of AGN, is equal to A*g*, the half of A*g*N. Now, since AB*b* is a right-angled triangle, AB is greater than A*b*; for the same reason, AC is greater than Ac, etc. But FG is *less* than *fg*; that is, A*g* is divided into *unequal* portions at the points *b*, *c*, *d*, etc.

Thus we see that if the daily motion in longitude were uniform, the daily motion in right ascension would not be uniform, but would be least near the equinoxes, where the arc of longitude is most inclined to the arc of right ascension, and greatest near the solstices, where the two arcs become parallel to each other.

Suppose, then, that a fictitious sun (which we will call the mean sun) moves uniformly along the equator, while the real sun moves uniformly along the ecliptic, and let them start together at the vernal equinox. From the vernal equinox to the summer solstice the right ascension of the mean sun will be greater than that of the real sun, but at the summer solstice the difference will vanish. In the second quadrant the mean sun will precede the true sun, but at the autumnal equinox they will again coincide. From the autumnal equinox to the winter solstice the true sun will precede the mean, while from the winter solstice to the vernal equinox the mean sun will precede the true.

The amount of the equation of time depending upon the obliquity of the ecliptic varies from zero to nearly 10 minutes. It is negative for three months, then positive for three months; then negative for three months, and then positive for another three months.

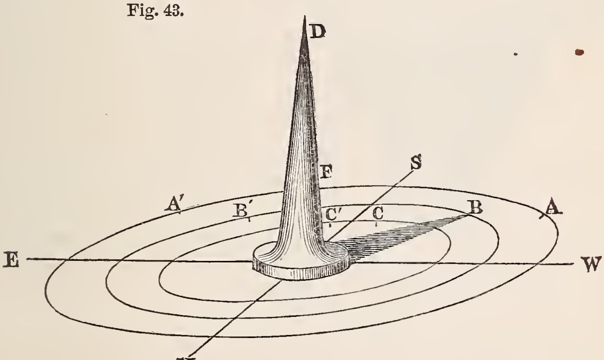
The actual value of the equation of time will be found by taking the algebraic sum of the effects due to these two separate causes. The result is that there are four periods of the year when the equation is zero, and the equation, when greatest, amounts to 16 minutes. The equation of time for each day of the year is given in the Nautical Almanac, and it is also stated approximately upon most celestial globes.

120. *To find the Time at any Place.*—The time of apparent noon is the time of the sun's meridian passage, and is most conveniently found by means of a transit instrument adjusted to the meridian. Mean time may be derived from apparent time by applying the equation of time with its proper sign.

The time of apparent noon may also be found by noting the times when the sun has equal altitudes before and after noon, and bisecting the interval between them. When great accuracy is required, the result obtained by this method requires a slight correction, since the sun's declination changes in the interval between the observations.

121. *To trace a Meridian Line.*—At the instant of noon, the shadow cast by a vertical rod upon a horizontal plane is the shortest, and the line marked at that instant by the shadow is a meridian line. Since, however, near the time of noon, the length of the shadow changes very slowly, this method is not susceptible of much precision. The following method is more accurate:

Fig. 43.

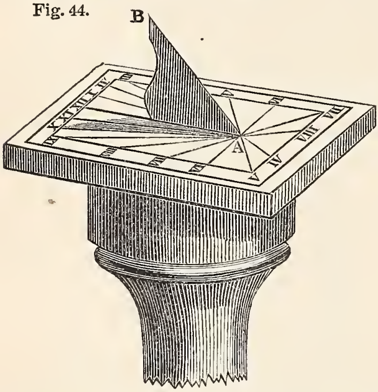


Upon a horizontal plane draw a series of concentric circles, and at the centre of the circles erect a vertical rod of wood or brass. During the forenoon, observe the instant when the vertex of the shadow of the rod falls upon the outer circle, and mark the point A. Mark also the point B, where the vertex of the shadow crosses the second circle, the point C, where it crosses the third circle, etc. In the afternoon, mark in like manner the points C′, B′, A′, where the vertex of the shadow crosses the same circles. Bisect the arcs AA′, BB′, CC′, etc.; the line NS, passing through the points of bisection, will be a meridian line.

Having established a meridian line, the time of apparent noon will be indicated by the passage of the shadow of the rod over this line.

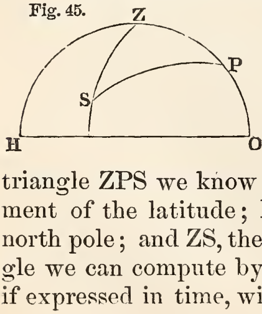
122. *A Sun-dial.*—If we draw a line, AB, parallel to the axis of the earth, the plane passing through the sun and this line will advance uniformly 15 degrees each hour. If the line here supposed be a slender metallic rod, its shadow will advance each hour 15 degrees about a circle perpendicular to the axis of the earth; and this shadow, cast upon a horizontal plane, will have the same direction at any given hour at all seasons of the year. If, then, we graduate this horizontal plane in a suitable manner, and mark the lines with the hours of the day, we may determine the apparent time whenever the sun shines upon the rod. Such an instrument is called a *sun-dial*, and for many centuries this was the principal means relied upon for the determination of time. This instrument will always indicate *apparent* time; but *mean* time may be deduced from it by applying the equation of time.

Fig. 44.



123. *To find the Time by a single Altitude of the Sun.*—The time may also be computed from an altitude of the sun measured at any hour of the day, provided we know the latitude of the place and the sun's declination.

Fig. 45.



Let PZH represent the meridian of the place of observation, P the pole, Z the zenith, and S the place of the sun. Measure the sun's zenith distance ZS, and correct it for refraction. Then in the spherical triangle ZPS we know the three sides, viz., PZ, the complement of the latitude; PS, the distance of the sun from the north pole; and ZS, the sun's zenith distance. In this triangle we can compute by trigonometry the angle ZPS, which, if expressed in time, will be the interval between noon and the moment of observation. This observation can be made at sea with a sextant, and this is the method of determining time which is commonly practiced by navigators.

124. *The Julian Calendar.*—The interval between two successive returns of the sun to the vernal equinox is called a *tropical year.* Its average length, expressed in mean solar time, is 365d. 5h. 48m. 48s. But in reckoning time for the common purposes of life, it is convenient to make the year consist of a certain number of *entire* days. In the calendar established by Julius Cæsar, and hence called the Julian Calendar, three successive years were made to consist of 365 days each, and the fourth of 366 days. The year which contained 366 days was called a *bissextile* year, because the 6th of the kalends of March was twice counted. Such a year is now commonly called leap year, and the others are called common years. The odd day inserted in a bissextile year is called the *intercalary* day.

The reckoning by the Julian calendar supposes the length of the year to be 365¼ days. A Julian year therefore exceeds the tropical year by 11m. 12s. This difference amounts to a little more than three days in the course of 400 years.

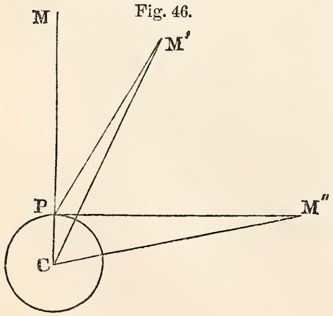
125. *The Gregorian Calendar.*—At the time of the Council of Nice, in the year 325, the Julian calendar was adopted by the Church, and at that time the vernal equinox fell on the 21st of March; but in the year 1582 the error of the Julian calendar had accumulated to nearly 10 days, and the vernal equinox fell on the 11th of March. If this erroneous reckoning had continued for several thousand years, spring would have commenced in September, and summer in December. It was therefore resolved to reform the calendar, which was done by Pope Gregory XIII., and the first step was to correct the loss of the ten days by counting the day succeeding the 4th of October, 1582, the 15th of the month instead of the 5th. In order to prevent the recurrence of the like error in future, it was decided that three intercalary days should be omitted every four hundred years. It was also decided that the omission of the intercalary days should take place in those years which are divisible by 100, but not by 400. Thus the years 1700, 1800, and 1900, which in the Julian calendar are bissextile, in the Gregorian calendar are common years of 365 days. The error of the Gregorian calendar amounts to less than one day in 3000 years.

126. *Adoption of the Gregorian Calendar.*—The Gregorian Calendar was immediately adopted at Rome, and soon afterward in all Catholic countries. In Protestant countries the reform was not so readily adopted, and in England and her colonies it was not introduced till the year 1752. At this time there was a difference of 11 days between the Julian and Gregorian calendars, in consequence of the suppression in the latter of the intercalary day in 1700. It was therefore decided that 11 days should be struck out of the month of September, 1752, by calling the day succeeding the 2d of the month the 14th instead of the 3d.

The Julian and Gregorian calendars are frequently designated by the terms *old style* and *new style.* In consequence of the suppression of the intercalary day in the year 1800, the difference between the two calendars now amounts to 12 days. Russia, and the Greek Church generally, still adhere to the old style, consequently their dates are thus expressed: 1868, $\frac{\text{June 22.}}{\text{July 4.}}$

127. *Diurnal Parallax explained.* — The direction in which a celestial body would be seen if viewed from the centre of the earth is called its *true* place, and the direction in which it is seen from any point on the surface is called its *apparent* place. The arc of the heavens intercepted between the true and apparent places, that is, the apparent displacement which would be produced by the transfer of the observer from the centre to the surface of the earth, is called the *diurnal parallax.*

Fig. 46.



Let C denote the centre of the earth, P the place of an observer on its surface, M an object (as the moon) seen in the zenith at P, M′ the same object seen at the zenith distance MPM′, and M″ the same object seen in the horizon.

It is evident that M will appear in the same direction, whether it be viewed from P or C. Hence in the zenith there is no diurnal parallax, and there the apparent place of an object is its true place.

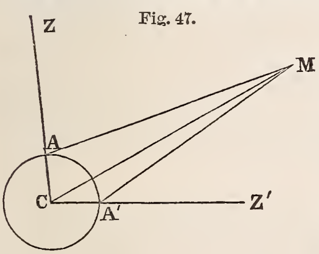
If the object be at M′, its apparent direction is PM′ while its true direction is CM′, and the parallax corresponding to the zenith distance MPM′ will be PM′C.

As the distance of the object from the zenith increases, the parallax increases; and when the object is in the horizon as at M″, the diurnal parallax becomes greatest, and is called the *horizontal parallax*. It is the angle which the earth's radius subtends to an observer supposed to be stationed upon the object.

It is evident that parallax increases the zenith distance, and consequently diminishes the apparent altitude. Hence, to obtain the true zenith distance from the apparent, the parallax must be *subtracted;* and to obtain the apparent zenith distance from the true, the parallax must be *added.* The azimuth of a heavenly body is not affected by parallax.

128. *To determine the Parallax of a Heavenly Body by Observation.* — Let A, A′ be two places on the earth situated under the same meridian, and at a great distance from each other, one in the northern hemisphere, and the other in the southern; let C be the centre of the earth, and M the body to be observed (the moon, for example). Let an observer at each of the stations measure the zenith distance of the moon when on the meridian, and correct the measured distance for the effect of refraction. This will furnish the angles ZAM and Z′A′M. But the angle ZCZ′ is the sum of the latitudes of the two stations, which are supposed to be known. Hence we can obtain the angle AMA′, which is the sum of the par-

Fig. 47.



allaxes at the two stations, and from this we can compute what would be the parallax if the object were seen in the horizon; that is, we can deduce the horizontal parallax.

It is not essential that the two observers should be exactly on the same meridian; for if the meridian zenith distances of the body be observed from day to day, its daily variation will become known. Then, knowing the difference of longitude of the two places, we may reduce the zenith distance observed at one of the stations to what it would have been if the observations had been made in the same latitude on the meridian of the other station.

129. *Results obtained by this Method.*—By combining observations made at the Cape of Good Hope with those made at European observatories, the moon's parallax has been determined with great precision. This parallax varies considerably from one day to another. The horizontal parallax, when greatest, is about 61′, and when least 53′, the average value being about 57′, or a little less than one degree.

The parallax of the sun and planets can be determined in the same manner; but these parallaxes are very small, and there are other methods by which they can be more accurately determined.

When we know the earth's radius and the horizontal parallax of a heavenly body, we can compute its distance. For (Fig. 46),

$$\sin. PM''C : PC :: \text{radius} : CM'',$$

or the distance of a heavenly body from the centre of the earth is equal to the radius of the earth divided by the sine of the horizontal parallax.

ADDITIONAL PROBLEMS ON THE TERRESTRIAL GLOBE.

130. *To find the Sun's Longitude for any given Day.*—Find the given month and day on the wooden horizon, and the sign and degree corresponding to it in the circle of signs will show the sun's place in the ecliptic; find this place on the ecliptic, and the number of degrees between it and the first point of Aries, counting toward the east, will be the sun's longitude.

Ex. 1. What is the sun's longitude Feb. 22d? *Ans.* 333°.

Ex. 2. What is the sun's longitude July 4th? *Ans.* 102°.
Ex. 3. What is the sun's longitude Oct. 25th? *Ans.* 212°.

131. *To find the Sun's right Ascension and Declination for any given Day.*—Bring the sun's place in the ecliptic to the graduated edge of the brass meridian; then the degree of the equator under the brass meridian will be the right ascension, and the degree of the meridian directly over the place will be the declination.

Ex. 1. What is the sun's right ascension July 4th?
Ans. 104°, or 6h. 56m.

Ex. 2. What is the sun's right ascension Feb. 22d?
Ans. 335°, or 22h. 20m.

Ex. 3. What is the sun's declination July 4th?
Ans. 23° N.

Ex. 4. What is the sun's declination Feb. 22d?
Ans. 10 °S.

The right ascension, declination, longitude and latitude of the sun, moon, and principal planets, are given in the Nautical Almanac for each day of the year.

132. *To find the Sun's Meridian Altitude for any Day of the Year.*—Make the elevation of the pole above the wooden horizon equal to the latitude of the place, so that the wooden horizon may represent the horizon of that place. Bring the sun's place in the ecliptic to the brass meridian, and the number of degrees on the meridian from the sun's place to the horizon will be the meridian altitude.

Ex. 1. Find the sun's meridian altitude at New York Feb. 22d. *Ans.* 39°.

Ex. 2. Find the sun's meridian altitude at London July 4th. *Ans.* $61\frac{1}{2}$°.

Ex. 3. Find the sun's meridian altitude at Ceylon Oct. 25th. *Ans.* 70°.

133. *To find the Sun's Amplitude at any Place and for any Day of the Year.*—Elevate the pole to the latitude of the place, then bring the sun's place in the ecliptic to the eastern or western edge of the horizon, and the number of degrees on the horizon from the east or west point will be the amplitude.

Ex. 1. Find the sun's amplitude at New York July 4th.
Ans. 31° N.

Ex. 2. Find the sun's amplitude at London Feb. 22d.
Ans. 16° S.

Ex. 3. Find the sun's amplitude at Ceylon Oct. 25th.
Ans. 13° S.

134. *To find the Sun's Altitude and Azimuth at any Place for any Day and Hour.*—Elevate the pole to the latitude of the place; then bring the sun's place in the ecliptic to the brass meridian, and set the hour index to XII. Then turn the globe eastward or westward, according as the time is before or after noon, until the index points to the given hour. Screw the quadrant of altitude over the zenith of the globe, and bring its graduated edge over the sun's place in the ecliptic; the number of degrees on the quadrant from the sun's place to the horizon will be the altitude, and the number of degrees on the horizon from the meridian to the edge of the quadrant will be the azimuth.

Ex. 1. Find the altitude and azimuth of the sun at New York, Feb. 22d, at 9 A.M.
Ans. Altitude 26°; Azimuth S. 49° E.

Ex. 2. At London, July 4th, at 7 A.M.
Ans. Altitude 28°; Azimuth N. 86° E.

Ex. 3. At Ceylon, October 25th, at 3½ P.M.
Ans. Altitude 33°; Azimuth S. 72° W.

135. *To find at what Places the Sun is Vertical at Noon on any Day of the Year.*—When the sun's declination is equal to the latitude of the place, the sun at noon will appear in the zenith. Therefore, find the sun's declination, and note the degree upon the brass meridian; revolve the globe, and all places which pass under that point will have the sun vertical at noon.

If we wish to know on what two days of the year the sun is vertical at any place in the torrid zone, revolve the globe, and observe what two points of the ecliptic pass under that degree of the brass meridian which corresponds to the latitude of the place; the days which correspond to these points on the circle of signs will be the days required.

Ex. 1. At what places is the sun vertical April 15th?
Ans. All places in lat. 10° N.

Ex. 2. At what places is the sun vertical Nov. 21st?
Ans. All places in lat. 20° S.

Ex. 3. On what two days of the year is the sun vertical at Madras? *Ans.* April 24 and Aug. 18.

136. *To find the Time of the Sun's Rising and Setting at a given Place on a given Day, and also the Length of the Day and of the Night.*—Elevate the pole to the latitude of the place; find the sun's place in the ecliptic; bring it to the meridian, and set the hour index to XII. Turn the globe till the sun's place is brought down to the eastern horizon; the hour index will show the time of the sun's rising. Turn the globe till the sun's place comes to the western horizon; the hour index will show the time of the sun's setting.

Double the time of its setting will be the length of the day, and double the time of rising will be the length of the night.

Ex. 1. At what time does the sun rise and set at Washington Aug. 18th? *Ans.* Sun rises at 5¼h., and sets at 6¾h.

Ex. 2. At what time does the sun rise and set at Berlin July 4th? *Ans.* Sun rises at 3⅔h., and sets at 8⅓h.

At any place in the northern hemisphere not within the polar circle, the longest day will be at the time of the summer solstice, and the shortest day at the time of the winter solstice.

Ex. 3. What is the length of the longest day at Berlin, and what is the length of the shortest day?

Ans. Longest day 16h. 50m.; shortest day 7h. 10m.

The following table shows the length of the longest days in different latitudes from the equator to the poles:

Latitude.	Longest Day.	Latitude.	Longest Day.
0° 0′ (Equator)	12 hours.	65° 48′........	22 hours.
30° 48′........	14 "	66° 32′........	24 "
49° 2′........	16 "	69° 51′........	2 months.
58° 27′........	18 "	78° 11′........	4 "
63° 23′........	20 "	90° 0′ (Pole)...	6 "

137. *To find the Beginning, End, and Duration of con-*

stant Day at any Place within the Polar Circles.—At any place in the northern hemisphere, the sun at midnight will just graze the northern horizon when the sun's north declination is equal to the distance of the place from the north pole. Therefore note on the brass meridian that degree of north declination which is equal to the polar distance of the place; revolve the globe, and the two points of the ecliptic which pass under that degree will be the sun's places at the beginning and end of constant day. The month and day corresponding to each of these places will be the times required. The interval between these dates will be the duration of constant day.

Ex. Find the beginning and end of constant day in lat. 75° N. *Ans.* Begins April 30th and ends Aug. 11th.

138. *To find the Time of the Beginning and End of Twilight.*—Elevate the pole to the latitude of the place; find the sun's place and bring it to the meridian, and set the hour index at XII. Screw the quadrant of altitude over the zenith of the globe, and bring the sun's place below the eastern horizon until it coincides with the 18th degree on the quadrant. The hour index will then mark the beginning of twilight. The end of twilight may be found in the same manner by bringing the sun's place below the western horizon. The difference between the time of sunrise and the beginning of morning twilight will be the duration of twilight.

Ex. 1. What is the beginning and duration of morning twilight at Boston July 1st?

Ans. Begins 2h. 12m.; duration 2h. 15m.

Ex. 2. What is the end and duration of evening twilight at Berlin Aug. 1st? *Ans.* Ends at 10h. 45m.; duration 3h.

PROBLEMS ON THE CELESTIAL GLOBE.

139. *To find the right Ascension and Declination of a Star.*—Bring the star to the brass meridian; the degree of the meridian directly over the star will be its declination, and the degree on the equinoctial under the brass meridian will be its right ascension. Right ascension is sometimes expressed in hours and minutes of time, and sometimes in degrees and minutes of arc.

Verify the following by the globe:

	R. A.	Dec.		R. A.	Dec.
Aldebaran...	4h. 28m.	16° 14′ N.	Regulus......	10h. 1m.	12° 36′ N.
Sirius.........	6h. 39m.	16° 32′ S.	Arcturus.....	14h. 9m.	19° 52′ N.

140. *The Right Ascension and Declination of a Star being given, to find the Star upon the Globe.*—Bring the degree of the equator which marks the right ascension to the brass meridian; then under the given declination marked on the meridian will be the star required.

Ex. 1. What star is in R. A. 5h. 6m., and Dec. 45° 51′ N.?
Ans. Capella.

Ex. 2. What star is in R. A. 18h. 32m., and Dec. 38° 39′ N?
Ans. Vega.

Ex. 3. What star is in R. A. 16h. 21m., and Dec. 26° 8′ S.?
Ans. Antares.

141. *To find the Distance between two Stars.*—Place the quadrant of altitude so that its graduated edge may pass through both stars, and the point marked 0 may be on one of them. Then the point of the quadrant which is over the other star will show the distance between the two stars.

Ex. 1. Find the distance of Aldebaran from Sirius.
Ans. 46 degrees.

Ex. 2. Find the distance of Sirius from Regulus.
Ans. 58 degrees.

Ex. 3. Find the distance of Arcturus from Vega.
Ans. 59 degrees.

142. *To find the Appearance of the Heavens at any Place at a given Day and Hour.*—Set the globe so that the brass meridian shall coincide with the meridian of the place; elevate the pole to the latitude of the place; bring the sun's place in the ecliptic to the meridian, and set the hour index at XII.; then turn the globe westward until the index points to the given hour. The constellations will then have the same appearance to an eye situated at the centre of the globe as they have at that moment in the heavens. The altitude and azimuth of any star at that instant can thus be measured on the globe.

Ex. 1. Required the appearance of the heavens at New Haven, lat. 41° 18′, July 4th, at 10 o'clock P.M.

Ex. 2. What star is rising near the east at 8 P.M. on the 20th of October at New York? *Ans.* Aldebaran.

143. *To determine the Time of Rising, Setting, and Culmination of a Star for a given Day and Place.*—Elevate the pole to the latitude of the place; bring the sun's place in the ecliptic to the meridian, and set the hour index at XII. Turn the globe until the star comes to the eastern horizon, and the hour shown by the index will be the time of the star's rising. Bring the star to the brass meridian, and the index will show the time of the star's culmination. Turn the globe until the star comes to the western horizon, and the index will show the time of the star's setting.

Ex. Required the time when Aldebaran rises, culminates, and sets at Cincinnati, October 10th.

144. *To determine the Position of the Moon or a Planet in the Heavens at any given Time and Place.*—Find the right ascension and declination of the body for the given day from the Nautical Almanac, and mark its place upon the globe; then adjust the globe as in Art. 142, and the position of the body upon the globe will correspond to its position in the heavens. We may then determine the time of its rising and setting, as in Art. 143. The time of rising and setting of a comet may be determined in the same manner.

CHAPTER V.

THE SUN—ITS PHYSICAL CONSTITUTION.

145. *Distance of the Sun.*—The distance of the sun from the earth can be computed when we know its horizontal parallax and the radius of the earth, Art. 129. There is some uncertainty respecting the exact value of the sun's parallax, but its mean value is very near 8″.9; and the equatorial radius of the earth is 3963 miles.

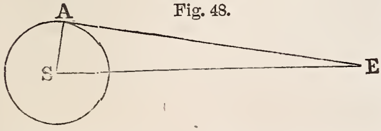
Hence, sin. 8″.9 : 1 :: 3963 : 92,000,000 miles,
which is the distance of the sun from the earth.

146. *Velocity of the Earth's Motion in its Orbit.*—Since the earth makes the entire circuit around the sun in one year, its daily motion may be found by dividing the circumference of its orbit by 365¼, and thence we may find the motion for one hour, minute, or second. The circumference of the earth's orbit is 577,000,000 miles; whence we find that the earth moves 1,580,000 miles per day; 65,800 miles per hour; 1097 miles per minute; and 18 miles per second.

By the diurnal rotation, a point on the earth's equator is carried round at the rate of 1037 miles per hour; hence the motion in the orbit is 63 times as rapid as the diurnal motion at the equator.

147. *The Diameter of the Sun.*—The sun's absolute diameter can be computed when we know his distance and apparent diameter. The apparent diameter at the mean distance is 32′ 4″. Hence we have the proportion,

Fig. 48.



1 : sin. 16′ 2″ :: 92 millions (ES) : 428,000 miles,
which is the sun's radius. Hence his diameter is 856,000 miles.

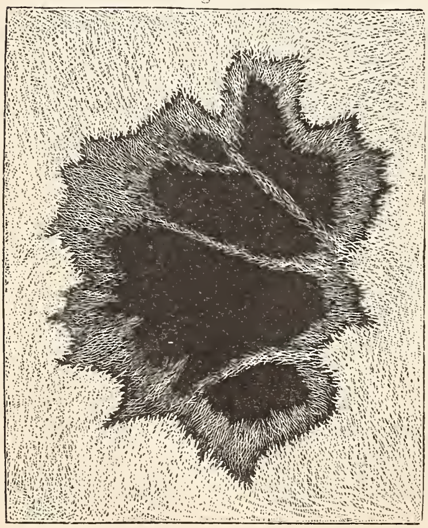
The diameter of the sun is therefore 108 times that of the earth; and, since spheres are as the cubes of their diameters, the volume of the sun is about 1,260,000 times that of the earth.

The density of the sun is about one quarter that of the earth, and therefore his mass, which is equal to the product of his volume by his density, is found to be 355,000 times that of the earth.

148. *Force of Gravity on the Sun.*—Since the attraction of a sphere is proportional to its mass directly, and the square of the distance from the centre inversely, we can compute the ratio of the force of gravity on the surface of the sun to that on the earth, and we find the ratio to be 27 to 1; that is, one pound of terrestrial matter at the sun's surface would exert a pressure equal to what 27 such pounds would do at the surface of the earth.

At the surface of the earth, a body falls through 16 feet in one second; but a body on the sun would fall through 16×27, or 440 feet in one second.

Fig. 49.



149. *Solar Spots.*—When we examine the sun with a good telescope, we often perceive upon his disc black spots of irregular form, sometimes extremely minute, and at other times of vast extent. Their appearance is usually that of an intensely black, irregularly-shaped patch, called the *nucleus*, surrounded by a fringe which is less dark, and is called the *penumbra.* The form of this border is generally similar to that of the inclosed black spot; but sometimes several dark spots are included within the same penumbra.

Black spots have occasionally been seen without any penumbra, and sometimes a large penumbra has been seen without any central black spot; but generally both the nucleus and penumbra are combined.

The spots usually appear in clusters of from two or three up to fifty or more. In one instance upward of 200 single spots and points were counted in a large group of spots.

150. *Magnitude of the Spots.*—Solar spots are sometimes of immense magnitude, so that they have been repeatedly visible to the naked eye. Not unfrequently they subtend an angle of one minute, which indicates a diameter of 26,000 miles. In 1843 a solar spot appeared which had a diameter of 74,000 miles, and remained for a whole week visible to the naked eye. A group of spots, with the penumbra surrounding it, has been observed, having a diameter of 147,000 miles.

151. *Changes of the Spots.*—The spots change their form from day to day, and sometimes from hour to hour. They usually commence from a point of insensible magnitude, grow very rapidly at first, and often attain their full size in less than a day. Then they remain nearly stationary, with a well-defined penumbra, and sometimes continue for weeks or even months. Then the nucleus usually becomes divided by a luminous line, which sends out numerous branches, until the entire nucleus is covered by the penumbra.

Decided changes have been detected in the appearance of a spot within the interval of a single hour, indicating a motion upon the sun's surface of at least 1000 miles per hour.

The duration of the spots is very variable. A spot has appeared and vanished in less than 24 hours, while in another instance a spot remained for eight months.

152. *Periodicity of the Spots.*—The number of spots seen on the sun's disc varies greatly in different years. Sometimes the disc is entirely free from them, and continues thus for weeks or even months together; at other times a large portion of the sun's disc is covered with spots, and some years the sun's disc is *never* seen entirely free from them. From a long series of observations, it appears that the spots are subject to a certain periodicity. The number of the spots increases during 5 or 6 years, and then decreases during about an equal period of time, the interval between two consecutive maxima being from 10 to 12 years. The last year of minimum was 1867.

153. *Faculæ.*—Frequently we observe upon the sun's disc curved lines, or branching streaks of light, more luminous than the general body of the sun. These are called faculæ. They generally appear in the neighborhood of the black spots. They are sometimes 40,000 miles in length, and 1000 to 4000 miles in breadth.

The faculæ are ridges or masses of luminous matter elevated above the general level of the sun's surface. A bright streak of unusual size has been observed at the very edge of the sun's disc, and it was seen to project beyond the circular contour of the disc, like a range of mountains. Their actual height could not have been less than 500 miles, and was probably over 1000 miles.

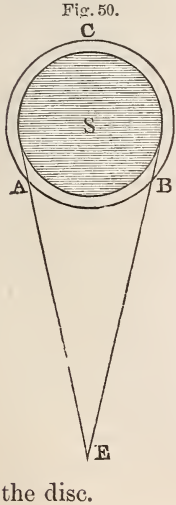
154. *General Appearance of the Sun's Disc.*—Independently of the dark spots, the luminous part of the sun's disc is not of uniform brightness. It exhibits inequalities of light, which present a coarsely mottled appearance. We often notice minute dark dots which appear to be in a state of change; and we also notice the appearance of bright granules scattered irregularly over the entire disc of the sun, giving the disc a resemblance to the skin of an orange. Some observers have reported the sun's surface to be formed all over of long narrow filaments resembling *willow leaves.*

155. *Apparent Motion of the Spots.*—When a spot is observed from day to day, it is found to change its apparent position on the sun's surface, moving from east to west. Occasionally a spot may be seen near the eastern limb of the sun; it advances gradually toward the centre, passes beyond it, and disappears near the western limb after an interval of about 14 days. After the lapse of another fortnight, if it remain as before, it will reappear upon the eastern limb in nearly the same position as at first, and again cross the sun's disc as before, having taken 27d. 7h. in the entire revolution.

To account for these phenomena, it is necessary to admit that the sun has a motion of rotation from west to east around an axis nearly perpendicular to the plane of the ecliptic, and that the spots are upon the surface of the sun. This supposition explains the changes which take place in the form of the more permanent spots during their passage across the disc. When a spot is first seen at the eastern limb, it appears as a narrow streak; as it advances toward the middle of the disc, its diameter from east to west increases; and it again becomes reduced to a narrow line as it approaches the western limb.

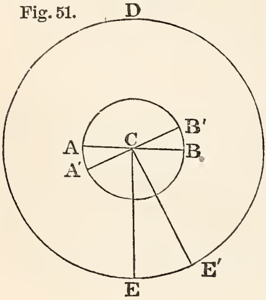
156. *The Solar Spots are not Planetary Bodies.*—Soon after the discovery of the solar spots, it was maintained that they were small planets revolving round the sun. It is evident, however, that they are *at the surface* of the sun, for if they were bodies revolving at some distance from it, the time during which they would be seen on the sun's disc would be *less* than that occupied in the remainder of their revolution. Thus, let S represent the sun, E the earth, and let ABC represent the path of an opaque body revolving about the sun. Then AB represents that part of the orbit in which the body would appear projected upon the sun's disc, and this is less than half the entire circumference; whereas the spot reappears on the opposite limb of the sun after an interval nearly equal to that required to pass across the disc.

Fig. 50.



157. *To determine the Time of the Sun's Rotation.*—It is found that a spot employs about $27\frac{1}{4}$ days in passing from one limb of the sun around to the same limb again, and it is inferred that this apparent motion is caused by a rotation of the sun upon his axis. This is not, however, the precise period of the sun's rotation; for during this interval the earth has advanced nearly 30 degrees in its orbit. Let AA′B represent the sun, and EE′D the orbit of the earth.

Fig. 51.



When the earth is at E, the visible disc of the sun is AA′B; and if the earth was stationary at E, then the time required for a spot to move from the limb B round to the same point again would be the time of the sun's rotation. But while the spot has been performing its apparent revolution, the earth has advanced in her orbit from E to E′, and now the visible disc of the sun is A′B′, so that the spot has performed more than a complete revolution during the time it has taken to move from the western limb to the western limb again. Since an apparent rotation of the sun takes place in $27\frac{1}{4}$ days, the number of apparent rotations in a year will be $\frac{365\frac{1}{4}}{27\frac{1}{4}}$, or 13.4.

But, in consequence of the motion of the earth about the sun, if the sun had no real rotation, it would in one year make an *apparent* rotation in a direction contrary to the motion of the earth. Hence, in one year, there must be 14.4 real rotations of the sun, and the time of one real rotation is $\frac{365\frac{1}{4}}{14.4}$, or 25.3 days, which is nearly two days less than the time of an apparent rotation.

158. *Absolute Motion of the Solar Spots.*—The apparent motion of the spots can not be wholly explained by supposing a rotation of the sun upon his axis, for the apparent time of revolution of some of the spots is much greater than that of others. In one instance, the time of the sun's rotation, as deduced from observations of a solar spot, was only 24d. 7h., while in another case it amounted to 26d. 6h. This difference can only be explained by admitting that the spots have a motion of their own relative to the sun's surface, just as our clouds have a motion relative to the earth's surface.

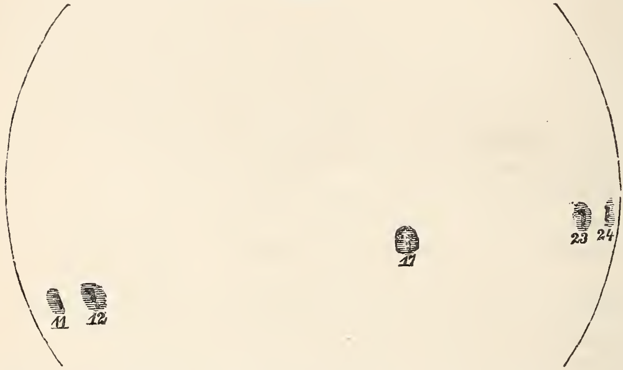
The motion of the solar spots in latitude is very small, and this motion is sometimes directed *toward* the equator, but generally *from* the equator. The motion of the spots in longitude is more decided. Spots near the sun's equator have an apparent movement of rotation more rapid than those at a distance from the equator. While at the equator the daily angular velocity of rotation is 865′ (indicating a rotation in 25 days), in lat. 20° the velocity is only 840′, and in lat. 30° it is 816′ (corresponding to a complete rotation in 26½ days).

159. *Position of the Sun's Equator.*—Besides the time of rotation, observations of the solar spots enable us to ascertain the position of the sun's equator with reference to the ecliptic. The inclination of the sun's equator to the ecliptic has been determined to be about 7 degrees. About the first weeks of June and December, the spots, in traversing the sun's disc, appear to us to describe straight lines, but at other periods of the year the apparent paths of the spots are somewhat curved, and they present the greatest curvature about the first weeks of March and September.

160. *Region of the Spots.*—The spots do not appear with equal frequency upon every part of the sun's disc. With very few exceptions they are confined to a zone extending from 30° of N. latitude to 30° of S. latitude, measured from the sun's equator. There are only three cases on record in which spots have been seen as far as 45° from the sun's equator. Moreover, spots are seldom seen directly upon the sun's equator. They are most abundant near the parallel of 18 degrees in either hemisphere.

161. *The dark Spots are Depressions below the luminous Surface of the Sun.*—This was first proved by an observation made by Dr. Wilson, of Glasgow, in 1769. He noticed that as a large spot came near the western limb, the penumbra on the eastern side, that is, on the side toward the centre of the disc, contracted and disappeared, while on the other side the penumbra underwent but little change. This is shown indistinctly in Fig. 52, and more distinctly in Fig. 53.

Fig. 52.



When the spot first reappeared on the sun's eastern limb, there was no penumbra on the western side, which was now the side toward the centre of the disc, although the penumbra was distinctly seen on the remaining sides. As the spot advanced upon the disc, the penumbra came into view on the western side, though narrower than on the other sides. As the spot approached the middle of the disc, the penumbra appeared of equal extent on every side of the nucleus. These observations prove that both the black nucleus and penumbra were below the luminous surface of the sun. Dr. Wilson estimated the depth of the spot to be nearly 4000 miles.

Fig. 53.

Similar observations have repeatedly been made by more recent astronomers.

162. *The Sun is not a solid Body.*—That the outer envelope of the sun is not solid is proved by the rapid changes which take place upon its surface. We can hardly suppose a liquid body to move with a velocity of 1000 miles per hour, a rate of motion which has been observed in solar spots, Art. 151. We conclude, therefore, that the luminous matter which envelops the sun must be gaseous, or of the nature of a precipitate suspended in a gaseous medium, in a manner analogous to the clouds which are suspended in our own atmosphere.

A comparison of the dark lines in the solar spectrum has shown that the most refractory substances, such as iron and nickel, exist upon the sun in a state of elastic vapor. The vast amount of heat received by the earth from the sun, at the distance of 92 millions of miles, proves that the heat of the sun must be very intense. These two considerations combined leave but little doubt that the heat of the sun far exceeds that of terrestrial volcanoes, a degree of heat which is sufficient to melt any substance upon the earth. We can not, therefore, well suppose that any large part of the sun's mass is in the condition of a solid, or even a liquid body; but it is probable that the principal part, if not the entire mass of the sun, consists of matter in the gaseous condition, or of matter in a state of minute subdivision suspended in a gaseous medium.

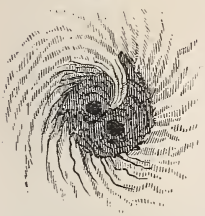
163. *Nature of the Sun's Photosphere.*—The bright envelope of the sun, which is the great source of the sun's light, is called the *photosphere* of the sun. This photosphere consists of matter in a state analogous to that of aqueous vapor in terrestrial clouds; that is, in the condition of a precipitate suspended in a transparent atmosphere. By observations with the spectroscope, it is considered to be proved that the following substances (and probably many others) exist in the sun's photosphere, viz., iron, copper, zinc, nickel, sodium, magnesium, calcium, chromium, and barium. The sun's atmosphere consists of the vapors of these substances, and the visible matter of the photosphere probably consists of particles of these substances precipitated in consequence of their loss of heat by radiation. This does not imply that the photosphere is not intensely hot, but simply that its heat is less than that of the interior of the sun.

The sun's gaseous envelope extends far beyond the photosphere. During total eclipses we observe vast masses of a delicate light rising to a height of 80,000 miles above the surface of the sun, which indicates the existence of bodies analogous to clouds floating at great elevations in an atmosphere, and it is not improbable that the solar atmosphere extends to more than a million of miles beyond his surface.

164. *Nature of the Penumbra.*—The penumbra of a solar spot appears to be formed of filaments of photospheric light converging toward the centre of the nucleus, each of the filaments having the same light as the photosphere, and the sombre tint results from the dark interstices (which are of the same nature as the dark nucleus) between the luminous streaks. The dark nucleus is simply a portion of the sun's gaseous mass not containing any sensible portion of the luminous precipitate, and therefore emitting but a very feeble light. The convergence of the luminous streaks of the penumbra toward the centre of the spot indicates the existence of currents flowing toward the centre. These converging currents probably meet an ascending current of the heated atmosphere, by contact with which the matter of the photosphere is dissolved and becomes non-luminous.

165. *Origin of the Sun's Spots.*—The sun's spots exhibit a remarkable periodicity, and the principal period varies from 9 to 13 years, averaging a little more than 11 years. As this period corresponds to the time of one revolution of Jupiter, it is inferred that Jupiter has the power of sensibly disturbing the sun's photosphere. A careful discussion of all the reliable observations of the spots which have been recorded has shown that Saturn and Venus also exert an appreciable influence upon the sun's photosphere. Such an effect can scarcely be ascribed to that force of attraction of the planets by which they are held in their orbits, but it is probably of a magnetic or electric origin. We may suppose that the matter of the sun's photosphere is in a magnetized state, and that the action of the planets excites electric currents in that region of the sun which is most directly exposed to their influence; and that these electric currents set in motion the solar atmosphere, causing movements analogous to the winds which prevail upon the earth. Observations frequently indicate a tendency of the solar atmosphere toward particular points. Such a movement must develop a tendency to revolve around this central point, for the same reason that terrestrial storms sometimes rotate about a vertical axis. A rotary motion of the solar spots has been repeatedly indicated by observation. Moreover, solar spots have sometimes exhibited a spiral structure such as might be supposed to result from rotation about a vertical axis. See Fig. 54.

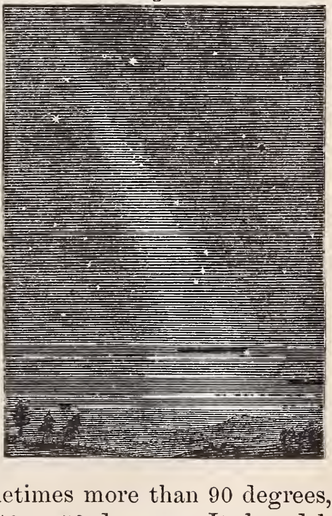
Fig. 54.



The faculæ are ascribed to commotions in the photosphere, by which the thickness of the phosphorescent stratum is rendered greater in some places than in others, and the surface appears brightest at those points where the luminous envelope is the thickest.

166. *Zodiacal Light.*—The zodiacal light is a faint light, somewhat resembling that of the Milky Way, which is seen at certain seasons of the year in the west after the close of evening twilight, or in the east before the commencement of the morning twilight. Its apparent form is nearly triangular, with its base toward the sun, and its axis is situated nearly in the plane of the ecliptic. The season most favorable for observing this phenomenon is when its direction, or the direction of the ecliptic, is most nearly perpendicular to the horizon. In northern latitudes this occurs in February and March for the evening, and in October and November for the morning.

Fig. 55.



The distance to which the zodiacal light extends from the sun varies with the season of the year and the state of the atmosphere. It is sometimes more than 90 degrees, but ordinarily not more than 40 or 50 degrees. Its breadth at its base perpendicularly to its length varies from 8 to 30 degrees. It is brightest in the parts nearest the sun, and in its upper part its light fades away by insensible degrees, so that different observers at the same time and place assign to it different limits. In tropical regions the zodiacal light has been seen at all hours of the night to extend entirely across the heavens, from the eastern to the western horizon, in the form of a pale luminous arch, having a breadth of 30 degrees.

167. *Cause of the Zodiacal Light.*—The zodiacal light is probably caused by an immense collection of extremely minute bodies circulating round the sun in orbits like the planets or comets. These bodies are too minute to be separately visible even in our telescopes, but their number is so immense that their joint light is sufficient to produce a strong impression upon the eye. These bodies are crowded together most closely in the neighborhood of the sun, but they extend beyond the orbits of Mercury and Venus, and in diminished numbers even beyond the orbit of the earth. It is probable that shooting stars are but individuals of this group of bodies which the earth encounters in its annual motion around the sun. If the sun could be viewed from one of the other stars, it would probably appear to be surrounded by a nebulosity similar to that in which some of the fixed stars appear to be enveloped, as seen from the earth.

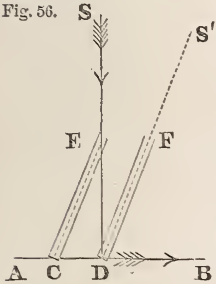
CHAPTER VI.

ABERRATION.—PRECESSION OF THE EQUINOXES.—NUTATION.

168. *Aberration of Light.*—The motion of the earth in its orbit about the sun, combined with the progressive motion of light, causes the stars to appear in a direction different from their true direction. This apparent displacement of the star is called the aberration of the star. The nature of this phenomenon may be understood from the following illustration.

Let us suppose a shower of rain to fall during a perfect calm, in which the drops descend in vertical lines. If the observer, standing still, hold in his hand a tube in a vertical position, a drop of rain may pass through the tube without touching the side. But if the observer move forward, the rain will strike against his face; and in order that a drop of rain may descend through the tube without touching the side, the upper end of the tube must be inclined forward.

Fig. 56.



Suppose, while a rain-drop is falling from E to D with a uniform velocity, the observer moves from C to D, and carries the tube inclined in the direction EC. A drop of rain entering the tube at E, when the tube has the position EC, would reach the ground at D when the tube has come into the position FD; and if the observer were unconscious of his own motion (as might happen upon a vessel at sea), the drop of rain would appear to fall in the oblique direction of the tube.

Now, in the triangle CED,

$$\text{tang. CED} = \frac{\text{CD}}{\text{ED}};$$

that is, the tangent of the apparent deflection of the rain-drop = the velocity of the observer divided by the velocity of the falling drop.

169. *Aberration of Light determined.*—In like manner, the aberration of light is produced by the motion of the observer combined with the motion of light. Let AB represent a small portion of the earth's orbit about the sun, and let S be the position of a star. Let CD be the distance through which the earth moves in one second, and ED the distance traversed by light in the same time. Suppose that CE is the position of the axis of a telescope when the earth is at C, and that, as the earth moves from C to D, the tube remains parallel to itself, a ray of light from the star S, in moving from E to D, will pass along the axis of the tube, and will arrive at D when the earth reaches the same point. The star will appear in the direction of the axis of the telescope; that is, the star appears in the direction S′D, instead of its true direction, SD; and the angle CED is the aberration of the star. Now the velocity of the earth in its orbit is about 18 miles per second, while the velocity of light is 185,000 miles per second, and

$$\text{tang. CED} = \frac{18}{185,000}.$$

Hence CED $= 20''$; that is, the aberration of a star which is $90°$ from the direction in which the earth is moving, amounts to $20''$.

170. *Annual Curve of Aberration.*—The effect of aberration at any one time is to displace the star by a small amount directly toward that point of the ecliptic toward which the earth is moving. The position of this point varies with the season of the year, and in the course of a year this point will move entirely round the ecliptic; that is, in consequence of aberration, a star appears to describe in the heavens a small curve around its true position. If the star be situated at the pole of the ecliptic, it will appear annually to describe about its true place a small circle whose radius is $20''$.

If the star be situated in the plane of the ecliptic, then once during a year the earth and the light of the star will be moving in the same direction, and once during the year they will be moving in opposite directions, in both of which cases there will be no aberration. The aberration during the year will be alternately $20''$ upon one side of the true position of the star, and 20″ upon the opposite side, but the star will always appear in the plane of the ecliptic.

If the star be situated any where between the ecliptic and its poles, it will appear annually to describe an ellipse whose centre is the true place of the star. The major axis of the ellipse will be 40″, but its minor axis will increase with its distance from the plane of the ecliptic.

171. *Fixed Position of the Ecliptic.*—By comparing recent catalogues of stars with those formed centuries ago, we find that the *latitudes* of the stars continue very nearly the same. Now the latitude of a star is its angular distance from the ecliptic; and since this distance is well-nigh invariable, it follows that the plane of the ecliptic remains fixed, or nearly so, with reference to the fixed stars.

172. *Precession of the Equinoxes.* It is found that the *longitudes* of all the stars increase at the same mean rate of about 50″ in a year. Since this increase of longitude is common to all the stars, and is nearly the same for each star, we can not ascribe it to motions in the stars themselves. It follows, therefore, that the vernal equinox, the point from which longitude is reckoned, has an annual motion of about 50″ along the ecliptic, in a direction contrary to the order of the signs, or from east to west. The autumnal equinox, being always distant 180° from the vernal, must have the same motion. This motion of the equinoctial points is called the *precession of the equinoxes*, because the place of the equinox among the stars each year *precedes* (with reference to the diurnal motion) the place which it had the previous year.

The amount of precession is 50″ annually. If we divide the number of seconds in the circumference of a circle by 50, we shall find the number of years required for a complete revolution of the equinoctial points. This time is about 25,000 years.

173. *Progressive Motion of the Pole of the Equator.*—Since the ecliptic is stationary, it is evident that the earth's equator must change its position with reference to the stars, otherwise there would be no motion of the equinoctial points.

Now a motion of the equator implies a motion of the poles of the equator; and since it appears from observation that the inclination of the equator to the ecliptic remains nearly constant, the distance from the pole of the equator to the pole of the ecliptic must remain nearly constant. Hence it appears that the pole of the equator has a motion about the pole of the ecliptic in a small circle whose radius is equal to the obliquity of the ecliptic, or about 23½ degrees. Its rate of motion must be the same as that of the equinox, or 50″ annually, and the pole of the equator will accomplish a complete revolution in 25,000 years.

174. *Change of the Pole Star.*—The pole of the equator, in its revolution about the pole of the ecliptic, must pass successively by different stars. At the time the first catalogue of the stars was formed (about 2000 years ago), the north pole was nearly 12 degrees distant from the present pole star, while its distance is now less than 1½ degrees. The pole will continue to approach this star till the distance between them is about half a degree, after which it will begin to recede from it. After the lapse of about 12,000 years, the pole will have arrived within about five degrees of the brightest star in the northern hemisphere, a star in the constellation Lyra.

165. *Effect of Precession on the Length of the Year.*—The time occupied by the sun in moving from the vernal equinox to the vernal equinox again is called a *tropical* year. The time occupied by the sun in moving from one fixed star to the same fixed star again is called a *sidereal* year.

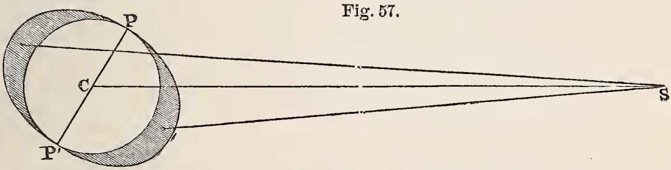
On account of the precession of the equinoxes, the tropical year is less than the sidereal year, the vernal equinox having gone westward so as to meet the sun. The tropical year is less than the sidereal year by the time that the sun takes to move through 50″ of its orbit. This amounts to 20m. 22s.

Since the mean length of a tropical year expressed in mean solar time is 365d. 5h. 48m. 48s., the length of the sidereal year is 365d. 6h. 9m. 10s.

176. *Signs of the Zodiac and Constellations of the Zodiac.*—At the time of the formation of the first catalogue of stars (140 years before Christ), the signs of the ecliptic corresponded very nearly to the constellations of the zodiac bearing the same names. But in the interval of 2000 years since that period, the vernal equinox has retrograded about 28 degrees, so that now the vernal equinox is near the beginning of the constellation Pisces; the sign Taurus corresponds nearly with the constellation Aries; the sign Gemini with the constellation Taurus, and so for the others.

177. *Cause of the Precession of the Equinoxes.*—The precession of the equinoxes is caused by the action of the sun and moon upon that portion of the matter of the earth which lies on the outside of a sphere conceived to be described about the earth's axis. The earth may be considered as a

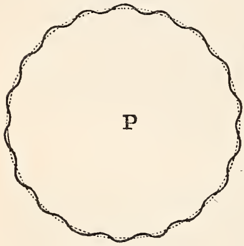
Fig. 57.



sphere surrounded by a spheroidal shell, thickest at the equator, Art. 43. The matter of this shell may be regarded as forming around the earth a ring, situated in the plane of the equator. Now the tendency of the sun's action on this ring, except at the time of the equinoxes, is always to make it turn round the line of the equinoxes toward the plane of the ecliptic, and the plane of the equator would ultimately coincide with that of the ecliptic were it not for the rotation of the earth upon its axis. The result of these two motions is that the axis of the earth is continually displaced, describing nearly the circumference of a circle about the pole of the ecliptic.

178. *Nutation.*—The effect of the action of the sun and moon upon the earth's equatorial ring depends upon their position with regard to the equator, the effect being greatest when the distance of the body from the equator is greatest. Twice a year, therefore, the effect of the sun to produce precession is nothing, and twice a year it attains its maximum. The precession of the equinoxes, as well as the obliquity of the ecliptic, is therefore subject to a small semi-annual variation, which is called the *solar nutation*. There is also a small inequality depending upon the position of the moon, which is called *lunar nutation*. In consequence of this oscillatory motion of the equator, its pole, in revolving about the pole of the ecliptic, does not move strictly in a circle, but in a waving curve, as represented in Fig. 58.

Fig. 58.



CHAPTER VII.

THE MOON—ITS MOTION.—PHASES.—TELESCOPIC APPEARANCE.

179. *Definitions.*—Two heavenly bodies are said to be in *conjunction* when their longitudes are the same; they are said to be in *opposition* when their longitudes differ by 180 degrees; and they are said to be in *quadrature* when their longitudes differ 90 degrees or 270 degrees. The term *syzygy* is used to denote either conjunction or opposition. The *octants* are the four points midway between the syzygies and quadratures.

The *nodes* of the moon's orbit or of a planet's orbit are the two points in which the orbit cuts the plane of the ecliptic. The node at which the body passes from the south to the north side of the ecliptic is called the *ascending* node, and the other is called the *descending* node.

180. *Distance of the Moon.*—The distance of the moon from the earth can be computed when we know its horizontal parallax. This parallax changes not only during one revolution, but also from one revolution to another, varying from 53′ to 61′. Its mean value at the equator is 57′ 2″. Hence the mean distance will be found by the proportion

$$\sin. 57' 2'' : 1 :: 3963 : 239{,}000 \text{ miles},$$

which is the average distance of the moon from the earth. This distance is, however, sometimes as great as 253,000 miles, and sometimes as small as 221,000 miles.

181. *Diameter of the Moon.*—The moon's absolute diameter can be computed when we know its distance and apparent diameter. The apparent diameter varies from 29′ to 33′; at the mean distance the apparent diameter is 31′ 7″. Hence the radius of the moon will be found by the proportion

$$1 : \sin. 15' 33'' :: 239{,}000 : 1081 \text{ miles}.$$

The moon's diameter is therefore 2162 miles.

Since spheres are as the cubes of their diameters, the *volume* of the moon is $\frac{1}{49}$th that of the earth. Its *density* is about $\frac{3}{5}$ths the density of the earth, and therefore its *mass* (which is the product of the volume by the density) is about $\frac{1}{80}$th of the mass of the earth.

182. *Revolution of the Moon.*—If we observe the situation of the moon on successive nights, we shall find that it changes its position rapidly among the stars, moving among them from west to east; that is, in a direction opposite to that of the diurnal motion. It thus makes a complete circuit of the heavens in about 27 days. Hence either the moon revolves around the earth, or the earth round the moon; or rather, according to the principles of Mechanics, we conclude that each must revolve about their common centre of gravity. This is a point in the line joining their centres, situated at an average distance of 2950 miles from the centre of the earth, or about 1000 miles beneath the surface of the earth.

183. *Sidereal and Synodic Revolutions.*—A complete revolution of the moon about the earth occupies 27d. 7h. 43m., which is the time intervening between her departure from a fixed star and her return to it again. This is called the *sidereal* revolution.

If we divide 360 degrees by the number of days in one revolution of the moon, we shall obtain the mean daily motion, which is thus found to be a little more than 13 degrees.

The *synodical* revolution of the moon is the interval between two consecutive conjunctions or oppositions. The synodical revolution of the moon is more than two days longer than the sidereal, for this is the time required by the moon to describe the arc traversed by the sun since the preceding conjunction. The synodical period is thus found to consist of 29d. 12h. 44m.

184. *How the Synodical Period is determined.*—The mean synodical period may be determined with great accuracy by comparing recent observations of eclipses with those made in ancient times. The middle of an eclipse of the moon is near the instant of opposition, and from the observations of the eclipse the exact time of opposition may be computed. Now eclipses have been very long observed, and we have the records of several which were observed before the commencement of the Christian era. By comparing the time of opposition deduced from these ancient observations with that of an opposition observed in modern times, and dividing this period by the number of intervening revolutions, we obtain the mean synodic period with great accuracy. When the synodic period has been determined, the sidereal period can be easily deduced from it.

185. *Form and Position of the Moon's Orbit.*—By observing the moon from day to day when she passes the meridian, we find that her path does not coincide with the ecliptic, but is inclined to it at an angle a little greater than 5 degrees, and intersects the ecliptic in two opposite points, which are called the moon's nodes.

It can be proved in a manner similar to that employed for the sun, Arts. 107 and 110, that the moon, in her motion around the earth, obeys the following laws:

1st. The moon's path is an ellipse, of which the earth occupies one of the foci.

2d. The radius vector of the moon describes equal areas in equal times.

That point in the moon's orbit which is nearest to the earth is called her *perigee*, and the point farthest from the earth her *apogee.* The line which joins the perigee and apogee is called the line of the *apsides.*

The eccentricity of the moon's orbit may be determined by observing the moon's greatest and least apparent diameters, in the same manner as was done in the case of the sun, Art. 108. This eccentricity is more than three times as great as that of the earth's orbit, amounting to about $\frac{1}{18}$th.

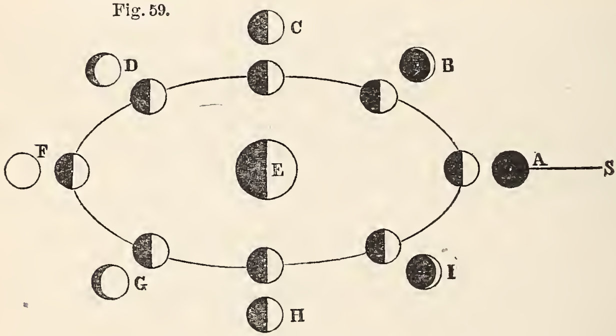
186. *Interval of Moon's Transits.* — The moon's mean daily motion in right ascension is about 12 degrees greater than that of the sun. Hence if, on any given day, the moon should be on the meridian at the same instant with the sun, on the next day she will not arrive at the meridian till 51m.

after the sun; that is, the interval between two successive meridian passages of the moon averages 24h. 51m. This interval, however, varies from 24h. 38m. to 25h. 6m.

187. *Phases of the Moon.*—The different forms which the moon's visible disc presents during a synodic revolution are called the phases of the moon. These phases are readily accounted for if we admit that the moon is an opaque globular body, rendered visible by reflecting the light received from the sun.

Let E represent the earth, ABCDH the orbit of the moon,

Fig. 59.



and let the sun be supposed to be situated at a great distance in the direction AS. Since the distance of the sun from the earth is about 400 times the distance of the moon, lines drawn from the sun to the different parts of the moon's orbit will be nearly parallel to each other. The moon being an opaque globular body, that hemisphere which is turned toward the sun will be continually illuminated, and the other will be dark. When the moon is in conjunction at A, the enlightened half is turned entirely away from the earth, and it is invisible. It is then said to be *new moon.*

Soon after conjunction, a portion of the moon on the right begins to be seen, presenting the appearance of a *crescent,* with the horns turned from the sun, as represented at B. As the moon advances the crescent enlarges, and when the moon is in quadrature at C, one half of her illumined surface is turned toward the earth, and her enlightened disc appears as a semicircle. She is then said to be in her *first quarter.*

Soon after the first quarter, more than half the moon's disc becomes visible, as represented at D, and the moon is said to be *gibbous*. As the moon advances toward opposition, the visible disc enlarges, and in opposition at F the whole of her illumined surface is turned toward the earth, and she appears as a full circle of light. It is then said to be *full moon*.

From opposition to conjunction, the western limb will pass in the inverse order through the same variety of forms as the eastern limb in the interval between conjunction and opposition. When the moon is again in quadrature at H, one half of her illumined surface being turned toward the earth, she again appears as a semicircle. She is then said to be at her *last quarter*. These phases prove conclusively that the moon shines by light borrowed from the sun.

The interval from one new moon to the next new moon is called a *lunation*, or *lunar month*. It is evidently the same as a synodical revolution of the moon.

188. *Obscure Part of the Moon's Disc.*—When, after conjunction, the new moon first becomes visible, her entire disc is quite perceptible, the part which is not fully illumined appearing with a faint light. As the moon advances, the obscure part becomes more faint, and before full moon it entirely disappears. This phenomenon depends on light of the sun reflected to the moon from the earth.

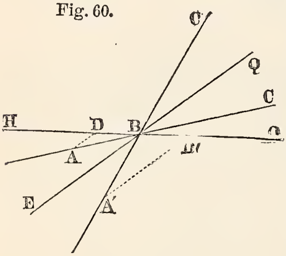
When the moon is near to A, she receives light from nearly an entire hemisphere of the earth, and this light renders that portion of the moon's disc which is not directly illumined by the sun faintly visible to us. As the moon advances toward opposition at F, the amount of light she receives from the earth decreases; and its effect in rendering the obscure part visible is farther diminished by the increased light of that part which is directly illuminated by the sun's rays.

It is obvious, therefore, that the earth, as viewed from the moon, goes through the same phases, in the course of a lunar month, as the moon does to an inhabitant of the earth; but its apparent diameter is more than three times as great.

189. *Harvest Moon.*—Since the moon moves eastward from the sun about 12 degrees a day, it will rise (at a mean) about 50 minutes later each succeeding night; but in the latitude of New York this interval varies in the course of a year from 23 minutes to 1h. 17m. This retardation of the moon's rising attracts most attention when it occurs at the time of full moon. When the retardation is least, near the time of full moon, the moon for several successive evenings rises soon after sunset, before twilight is passed; whereas, when the retardation is greatest, the moon in two or three days ceases to be seen in the early part of the evening.

The reason of these variations is, that the arc (12°) through which the moon moves away from the sun in a day has very different inclinations to the horizon at different seasons of the year. In lat. 40°, this inclination varies from 21° to 79°; and the interval of time employed in rising above the horizon will vary accordingly. Let HO represent the horizon, EQ the equator, and let AC, A′C′ represent two positions of the moon's orbit having the greatest and least inclinations to the horizon. Take BA, BA′, each equal to 12°. The point A, by the diurnal motion, will be brought to the horizon after describing the arc AD parallel to the equator, which may require less than 30 minutes, while the point A′ must describe the arc A′D′, which may require over 60 minutes. For the full moon this arc of 12° rises in the shortest time near the autumnal equinox. As this is about the period of the English harvest, this moon is hence called the *Harvest Moon.*

Fig. 60.



190. *Moon's Rotation upon an Axis.*—The moon always presents nearly the same hemisphere toward the earth, for the same spots always occupy nearly the same positions upon the disc. It follows, therefore, that the moon makes one rotation upon an axis in the same direction, and in the same time, in which she makes a revolution in her orbit. If the moon had no motion of rotation, then in opposite parts of her orbit she would present opposite sides to the earth.

191. *Librations of the Moon.*—Although the spots on the moon's disc constantly occupy nearly the same situations with respect to the visible disc, they are not exactly stationary, but alternately approach to and recede from the edge of the disc. Those that are very near the edge sometimes disappear, and afterward become visible again. This oscillatory motion of the moon's spots is called *libration.*

Libration in Longitude.—While the moon's motion of rotation is perfectly uniform throughout the month, its angular velocity in its orbit is not uniform, being most rapid when nearest the earth. Hence small portions near the eastern and western edges of the moon alternately come into view and disappear. The periodical oscillation of the spots in an east and west direction is called the libration in longitude.

Libration in Latitude.—The moon's axis is not exactly perpendicular to the plane of her orbit, but makes an angle with it of 83½ degrees, and remains continually parallel to itself. Hence the northern and southern poles of the moon incline 6½ degrees alternately to and from the earth. When the north pole leans toward the earth, we see beyond the north pole of the moon; and when it leans the contrary way, we see beyond the south pole. This periodical oscillation of the spots in a north and south direction is called the libration in latitude.

Diurnal Libration.—By the diurnal motion of the earth, we are carried with it round its axis; and if the moon continually presented the same hemisphere toward the earth's centre, the hemisphere visible to us when the moon is near the eastern horizon would be different from that which would be visible to us when the moon is near the western horizon. This is another cause of a variation in the edges of the moon's disc, and is called the diurnal libration.

In consequence of all these librations, we have an opportunity to observe somewhat more than half of the surface of the moon; yet there remains about three sevenths of its surface which is always hidden from our view.

192. *Telescopic Appearance of the Moon.*—When the moon is viewed with a telescope, especially if near quadrature, the bounding line between the illumined and dark portions of the moon's surface is seen to be very irregular and serrated. On the dark part of the face, near the illumined surface, we often notice insulated bright spots; and on the illumined portion we also find dark spots. These appearances change sensibly in a few hours. As the light of the sun advances upon the moon, the dark spots become bright; and at full moon they all disappear, except that certain regions appear somewhat less luminous than others. It is hence inferred that the moon's surface is diversified by mountains and valleys. Fig. 61 is a representation of a small portion of the moon's surface, as seen with a powerful telescope near the time of first quarter.

Fig. 61.

193. *Particular Phenomena described.*—Near the bounding line between the illumined and dark portions of the moon's surface we frequently observe the following phenomena: A bright ring nearly circular; within it, on the side next the sun, a black circular segment; and without it, on the side opposite to the sun, a black region with a boundary quite jagged. Near the centre of the circle we sometimes notice a bright spot, and a black stripe extending from it opposite to the sun. After a few hours, the black portions are found to have contracted in extent, and in a day or two entirely disappear.

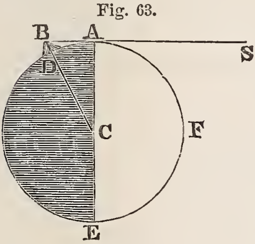
After about two weeks these dark portions reappear, but on the side opposite to that on which they were before seen;

Fig. 62.

and they increase in length until they pass entirely within the dark portion of the moon. These appearances indicate the existence of a circular wall, rising above the general level of the moon's surface, and inclosing a large basin, from the middle of which rises a conical peak. Fig. 62 gives a magnified representation of the annular mountain Cassini.

194. *Height of the Lunar Mountains.*—The height of a lunar mountain may be determined by measuring with a micrometer the length of its shadow, or the distance of its summit, when first illuminated, from the enlightened part of the disc.

Fig. 63.



Let AFE be the illuminated hemisphere of the moon, SA a ray of the sun touching the moon at A, and let BD be a mountain so elevated that its summit just reaches to the ray SAB, and is illumined, while the intervening space AB is dark. Let us suppose the earth to be in the direction of the diameter AE produced. Let the angle which AB subtends at the earth be measured with a micrometer; then, since the distance of the moon from the earth is known, the absolute length of AB can be computed. Then, in the right-angled triangle ABC, AC, the radius of the moon, is known, whence BC can be computed; and subtracting AC from BC gives BD, the height of the mountain.

If the earth is so situated that the line AB is not seen perpendicularly, since we know the relative positions of the sun and moon, we can determine the inclination at which AB is seen, and hence the absolute length of AB.

The greatest elevation of any lunar mountain which has been observed is 23,800 feet, and ten different mountains have been observed having elevations of 18,000 feet and upward. The altitude of these mountains has probably been determined as accurately as those of the highest mountains on the earth.

195. *Has the Moon an Atmosphere?*—That there is no considerable atmosphere surrounding the moon is proved by the absence of any appreciable twilight. Upon the earth, twilight continues until the sun is 18 degrees below the horizon; that is, day and night are separated by a belt 1200 miles in breadth, in which the transition from light to darkness is not sudden, but gradual—the light fading away into the darkness by imperceptible gradations. This twilight results from the reflection of light by our atmosphere; and if the moon had an atmosphere, we should notice a gradual transition from the bright to the dark portions of the moon's surface. Such, however, is not the case. The boundary between the light and darkness, though irregular, is extremely well defined and sudden. Close to this boundary, the unillumined portion of the moon appears well-nigh, if not entirely, as dark as any portion of the moon's unillumined surface.

196. *Argument from the Absence of Refraction.*—The absence of an appreciable atmosphere is also proved by the absence of refraction when the moon passes between us and the distant stars; for when a star suffers occultation from the interposition of the moon between it and the observer, the duration of the occultation is the same as is computed without making any allowance for the refraction of a lunar atmosphere.

Many thousand occultations of stars by the moon have been observed, and no appreciable effect of refraction has ever been detected, from which it is inferred that this refraction can not be as large a quantity as 4″ of arc. Now the earth's atmosphere, in like circumstances, would change the direction of a ray of light over 4000″; whence it is inferred that if the moon have an atmosphere, its density can not exceed one thousandth part of the density of our own. Such an atmosphere is more rare than that which remains under the receiver of the best air-pump when it has reached its limit of exhaustion.

Certain phenomena have, however, been observed, which are thought to indicate the presence of a limited atmosphere upon the moon's surface. A faint light has sometimes been perceived extending from the horns of the new moon a little distance into the dark part of the moon's disc. This is considered to be the moon's twilight, and indicates the existence of an atmosphere, which, however, we can not suppose to be sufficient to support a column of mercury more than $\frac{3}{100}$ths of an inch in height.

197. *Is there Water upon the Moon?*—There are upon the moon certain dusky and apparently level regions which were formerly supposed to be extensive sheets of water, but when the boundary of light and darkness falls upon these regions we detect with a good telescope black shadows, indicating the existence of permanent inequalities, which could not exist on a liquid surface. These regions are therefore concluded to be extensive plains, with only moderate elevations and depressions. These level regions occupy about one third of the visible surface of the moon. There are therefore no seas nor other bodies of water upon the surface of the moon. Moreover, if there were any water (even the smallest quantity) on the moon's surface, a portion of it would rise in vapor, and form an atmosphere which would have an elastic force far exceeding $\frac{3}{100}$ths of an inch of mercury. This argument also proves that there is no water on that side of the moon which we have never had an opportunity to observe.

198. *The Moon's Mountain Forms.*—The mountainous formations of the moon may be divided into three classes.

A. *Isolated peaks*, or sugar-loaf mountains, rising suddenly from plains nearly level, sometimes to a height of 4 or 5 miles. Such peaks also frequently occur in the centres of circular plains.

B. *Ranges of mountains*, extending in length two or three hundred miles, and sometimes rising to the height of from 18,000 to 20,000 feet. Sometimes they run nearly in a straight line, and sometimes they form fragments of a ring.

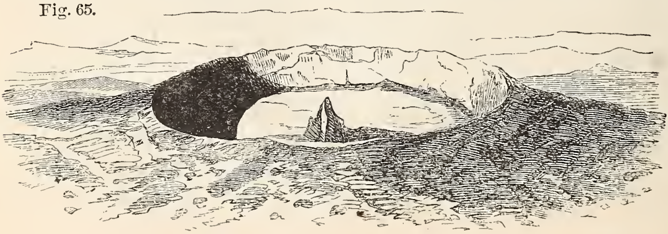
C. *Circular formations*, or mountain ranges approaching nearly to the form of circles, constitute the characteristic feature of the moon's surface, not less than three fifths of the moon's surface being studded with them. They have been subdivided into bulwark plains, ring mountains, and craters.

Fig. 64.

Bulwark plains are circular areas varying from 40 to 120 miles in diameter, inclosed by a ring of mountain ridges, or several concentric ridges. The inclosed area is generally a plain, from which rise mountains of less height.

Ring mountains vary from 10 to 50 miles in diameter, and

Fig. 65.



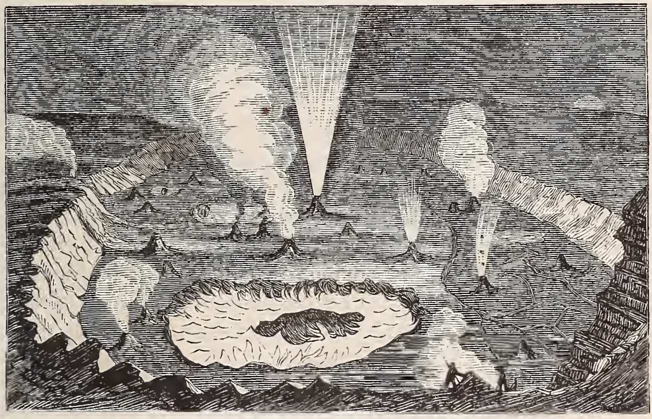
are generally more nearly circular in their form. Their inner declivity is always steep, and the inclosed area often includes a central mountain.

Craters are still smaller, and inclose a small area, containing generally a central mound or peak.

Fig. 64 gives a general view of the mountainous region in the southwest part of the moon's disc; and Fig. 65 gives a magnified representation of one of these ring mountains.

199. *Comparison with Terrestrial Volcanoes.*—The circular mountains of the moon bear an obvious analogy to the volcanic craters upon the earth. Figure 66 represents the

Fig. 66.



crater of Kilauea on one of the Sandwich Islands, which presents a basin three miles in diameter and 1000 feet deep. The volcanoes Vesuvius, Ætna, Teneriffe, and others, bear so strong a resemblance to the circular mountains of the moon, that it is now generally admitted that the lunar mountains are of volcanic origin. They differ, however, from terrestrial volcanoes in their enormous dimensions and immense number. This difference may be ascribed in part to the feeble attraction of the moon, since objects on the moon's surface weigh only one sixth what they would on the earth; and partly to the continued action of rain and frost, by which the older volcanic craters upon the earth have been disintegrated and leveled, while upon the moon, where there are no such agencies, the oldest volcanoes have preserved their outlines as sharp as the more recent ones.

200. *Are the Lunar Volcanoes extinct?*—It is certain that most of the lunar volcanoes are entirely extinct; and it is doubted whether any signs of eruption have ever been noticed. Herschel observed on the dark portion of the moon three bright points, which he ascribed to volcanic fires; but the same lights may be seen every month, and they are probably to be ascribed to mountain peaks, which have an unusual power of reflecting the feeble light which is emitted by the earth. Two astronomers, who have studied the moon's surface with greater care than any one else, assert that they have never seen any thing that could authorize the conclusion that there are in the moon volcanoes now in a state of ignition.

In 1866 it was announced that a small crater called Linnè, 5 miles in diameter, had suddenly disappeared, and that its place was occupied by an ill-defined white spot. Since that time, however, the crater has been distinctly seen, and it is now claimed that the cloudy appearance was due to the disturbing effect of our atmosphere, which effect is specially noticeable over this spot, on account of the absence of well-defined points upon which the eye can rest.

CHAPTER VIII.

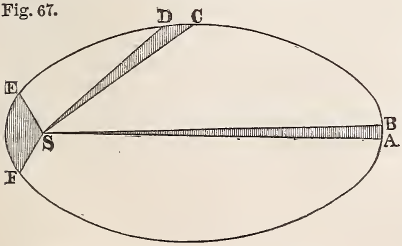
CENTRAL FORCES.—LAW OF GRAVITATION.

201. *Curvilinear Motion.*—If a body at rest receive an impulse in any direction, and is not acted upon by any other force, it will move in the direction of that impulse; that is, in a straight line, and with a uniform rate of motion. A body must therefore continue forever in a state of rest, or in a state of uniform and rectilinear motion, if not disturbed by the action of an external force. Hence, if a body move in a curve line, there must be some force which at each instant deflects it from the rectilinear course which it tends to pursue in virtue of its inertia. We may then consider this motion in a curve line to arise from two forces: one a primitive impulse given to the body, which alone would have caused it to describe a straight line; the other a deflecting force, which continually urges the body toward some point out of the original line of motion.

202. *Kepler's Laws.*—Before Newton's discovery of the law of universal gravitation, the paths in which the planets revolve about the sun had been ascertained by observation; and the following laws, discovered by Kepler, and generally called *Kepler's laws*, were known to be true:

(1.) *The radius vector of every planet describes about the sun equal areas in equal times.*

Fig. 67.



Thus, if ACF represent the orbit of a planet about the sun, S, and if AB, CD, EF, etc., are the arcs described by the planet in equal times, as, for example, one day, then the areas SAB, SCD, SEF, etc., will all be equal to each other.

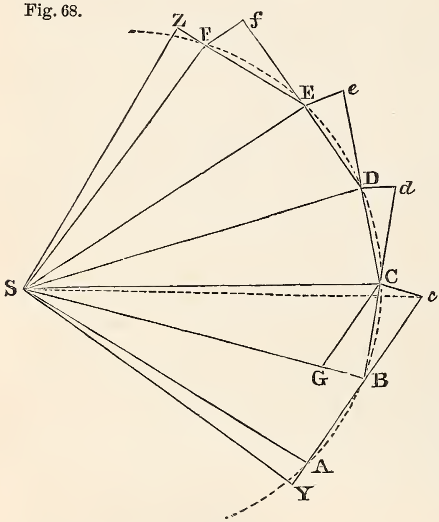
(2.) *The orbit of every planet is an ellipse, of which the sun occupies one of the foci.*

(3.) *The squares of the times of revolution of the planets are as the cubes of their mean distances from the sun, or of the semi-major axes of their orbits.*

From these facts, discovered by an examination of observations, we may deduce the law of attractive force upon which they depend.

203. *When a body moves in a curve, acted on by a force tending to a fixed point, the areas which it describes by radii drawn to the centre of force are in a constant plane, and are proportional to the times.*

Fig. 68.



Let S be a fixed point, which is the centre of attraction; let the time be divided into short and equal portions, and in the first portion of time let the body describe AB. In the second portion of time, if no new force were to act upon the body, it would proceed to *c* in the same straight line, describing B*c* equal to AB. But when the body has arrived at B, let a force tending to the centre, S, act on it by a single instantaneous impulse, and compel the body to continue its motion along the line BC. Draw C*c* parallel to BS, and at the end of the second portion of time the body will be found in C, in the same plane with the triangle ASB. Join SC; and because SB and C*c* are parallel, the triangle SBC will be equal to the triangle SB*c*, and therefore also to the triangle SAB, because B*c* is equal to AB.

In like manner, if a centripetal force toward S act impulsively at C, D, E, etc., at the end of equal successive portions of time, causing the body to describe the straight lines CD, DE, EF, etc., these lines will all lie in the same plane, and the triangles SCD, SDE, SEF will each be equal to SAB and SBC. Therefore these triangles will be described in equal times, and will be in a constant plane; and we shall have

polygon SADS : polygon SAFS :: time in AD : time in AF.

Let now the number of the portions of time in AD, AF be augmented, and their magnitude be diminished *in infinitum*, the perimeter ABCDEF ultimately becomes a curve line, and the force which acted impulsively at B, C, D, E, etc., becomes a force which acts continually at all points. Therefore, in this case also, we have

the curvilinear area SADS : the curvilinear area SAFS
:: the time in AD : the time in AF.

Conversely, it may be proved in a similar manner that if a body moves in a curve line in a constant plane in such a manner that the areas described by the radius vector about a fixed point are proportional to the times, it is urged by an incessant force constantly directed toward that point.

Now, by Kepler's first law, the radius vector of each planet describes about the sun equal areas in equal times; hence it follows that each planet is acted upon by a force which urges it continually toward the centre of the sun. We say therefore that the planets *gravitate* toward the sun, and the force which urges each planet toward the sun is called its gravity toward the sun.

204. *Law of Variation of Gravity.*—It is proved in treatises on Mechanics that if a body describe an ellipse, being continually urged by a force directed toward the focus, the force by which it is urged must vary inversely as the square of the distance. But by Kepler's second law the planets describe ellipses, having the sun at one of their foci, and by the preceding article each planet is acted upon by a force which urges it continually toward the sun; hence it follows that the force of gravity of each planet toward the sun varies inversely as the square of its distance from the sun's centre.

205. *Gravity operates on all the Planets alike.*—It is proved in treatises on Mechanics that when several bodies revolve in ellipses about the same centre of force, if the squares of the periodic times vary as the cubes of the major axes, the force by which they are all drawn toward the centre must vary inversely as the square of the distance. Hence we conclude that the planets are solicited by a force of gravitation toward the sun, which varies from one planet to another inversely as the square of their distance. It is therefore one and the same force, modified only by distance from the sun, which causes all the planets to gravitate toward him, and retains them in their orbits. This force is conceived to be an attraction of the matter of the sun for the matter of the planets, and is called the solar attraction. This force extends infinitely in every direction, varying inversely as the square of the distance.

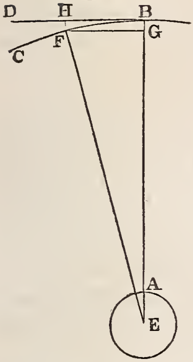
206. *The Planets endowed with an attractive Force.*—The motions of the satellites about their primary planets are found to be in conformity with Kepler's laws; hence the planets which have satellites are endowed with an attractive force, which extends indefinitely, and varies inversely as the square of the distance. It is evident also that the satellites gravitate toward the sun in the same manner as their planets, for their relative motions about their primaries are the same as if the planets were at rest.

The planets which have no satellites are endowed with a similar attractive force, as is proved by the disturbances which they cause in the motion of the other planets.

207. The force that causes bodies to fall near the earth's surface, being diminished in proportion to the square of the distance from the earth's centre, is found at the distance of the moon to be exactly equal to the force which retains the moon in her orbit.

Let E be the centre of the earth, A a point on its surface, and BC a part of the moon's orbit assumed to be circular. When the moon is at any point, B, in her orbit, she would move on in the direction of the line BD, a tangent to the orbit at B, if she was not acted upon by some deflecting force.

Fig. 69.



Let F be her place in her orbit one second of time after she was at B, and let FG be drawn parallel to BD, and FH parallel to EB. The line FH, or its equal BG, is the distance the moon has been drawn, during one second, from the tangent toward the earth at E. If we divide the circumference of the moon's orbit by the number of seconds in the time of one revolution, we shall have the length of the arc BF. Hence, by the principles of Geometry, we can compute BG, which is found to be $\frac{1}{19}$th of an inch.

Now at the earth's surface a body falls through 192 inches in the first second; and the distance of the moon is 60 times the earth's radius. At the distance of the moon, the force of the earth's attraction will be found by the proportion

$$60^2 : 1^2 :: 192 : \tfrac{1}{19}\text{th inch},$$

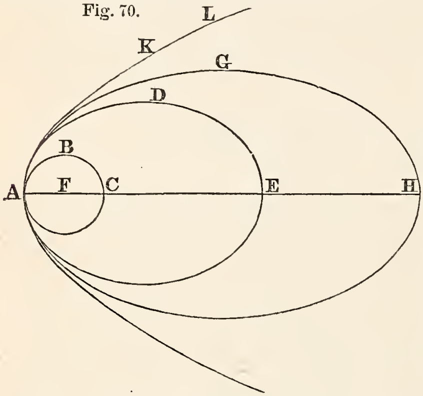
which agrees with the distance above computed.

208. *The component Particles of the Planets attract each other.*—The force of attraction of one body for another arises from the attraction of its individual particles. A large planet may be regarded as a collection of numerous smaller planets, and the attraction of the whole must be the result of the attraction of the component parts. Thus the gravitation of the earth toward the sun is the sum of the gravitation of each of its particles, and hence the force of gravity of each of the planets is proportional to the matter which it contains—that is, to its mass. Moreover, since the attraction of the planets varies inversely as the square of the distance, the force of every particle must also vary inversely as the square of the distance of the particles.

209. *Theory of Universal Gravitation.*—It follows, then, as a necessary consequence from the general facts or laws discovered by Kepler, that all bodies mutually attract each other with forces varying directly as their quantities of matter, and inversely as the squares of their distances. This principle is called the law of universal gravitation. It was first distinctly promulgated by Sir Isaac Newton, and hence is frequently called Newton's theory of universal gravitation.

210. *All the Bodies of the Solar System move in Conic Sections.*—It was demonstrated by Newton that if a body (a planet, for instance) is impelled by a projectile force, and is continually drawn toward the sun's centre by a force varying inversely as the square of the distance, and no other forces act upon the body, the body will move in one of the following curves—a circle, an ellipse, a parabola, or an hyperbola. The particular form of the orbit will depend upon the direction and intensity of the projectile force.

Fig. 70.



If we conceive F to be the centre of an attractive force, and a body at A to be projected in a direction perpendicular to the line AF, then there is a certain velocity of projection which would cause the body to describe the circle ABC; a greater velocity would cause it to describe the ellipse ADE, or the more eccentric ellipse AGH; and if the velocity of projection be sufficient, the body will describe the semi-parabola AKL. If the velocity of projection be still greater, the body will describe an hyperbola. The curve can not be a circle unless the body be projected in a direction perpendicular to AF, and also the velocity of projection must be neither greater nor less than one particular velocity, determined by the distance AF and the mass of the central body. If it differs but little from this precise velocity (either greater or less), the body will move in an ellipse; but if the velocity be much greater, the body will move in a parabola or an hyperbola.

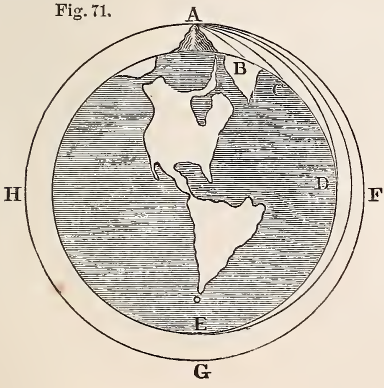
If the body be projected in a direction oblique to AF, and the velocity of projection be small, the body will move in an ellipse; if the velocity be great, it may move in a parabola or an hyperbola, but not in a circle.

If the body describe a circle, the sun will be in the centre of the circle. If it describe an ellipse, the sun will be, not in the centre of the ellipse, but in one of the foci. If the body describe a parabola or an hyperbola, the sun will be in the focus.

The planets describe about the sun ellipses which differ but little from circles. A few of the comets describe very elongated ellipses; and nearly all the others whose orbits have been computed move in curves which can not be distinguished from parabolas. There are two or three comets which are thought to move in hyperbolas.

211. *Motions of Projectiles.*—The motions of projectiles are governed by the same laws as the motions of the planets. If a body be projected from the top of a mountain in a horizontal direction, it is deflected by the attraction of the earth from the rectilinear path which it would otherwise have pursued, and made to describe a curve line which at length brings it to the earth's surface; and the greater the velocity of projection, the farther it will go before it reaches the earth's surface. We may therefore suppose the velocity to be so increased that it shall pass entirely round the earth without touching it.

Fig. 71.



Let BCD represent the surface of the earth; AB, AC, AD the curve lines which a body would describe if projected horizontally from the top of a high mountain, with successively greater and greater velocities. If there were no air to offer resistance, and the velocity were sufficiently great, the body would pass entirely round the earth, and return to the point from which it was projected. Such a body would be a satellite revolving round the earth in an orbit whose radius is but little greater than the radius of the earth, and the time of one revolution would be one hour and twenty-five minutes.

212. *Modification of Kepler's Third Law.*—Kepler's third law is strictly true only in the case of planets whose quantity of matter is inappreciable in comparison with that of the central body. In consequence of the action of the planets upon the sun, the time of revolution depends upon the masses of the planets as well as their distances from the sun. Consequently, in comparing the orbits described by different planets round the sun, we must suppose the central force to be the attraction of a mass equal to the sum of the sun and planet. With this modification Kepler's third law becomes rigorously true.

CHAPTER IX.

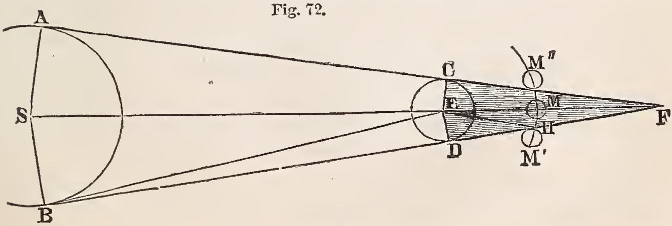
ECLIPSES OF THE MOON.—ECLIPSES OF THE SUN.

213. *Cause of Eclipses.*—An eclipse of the sun is caused by the interposition of the moon between the sun and the earth. It can therefore only occur when the moon is in conjunction with the sun—that is, at the time of new moon. An eclipse of the moon is caused by the interposition of the earth between the sun and moon. It can therefore only occur when the moon is in opposition—that is, at the time of full moon.

214. *Why Eclipses do not occur every Month.*—If the moon's orbit coincided with the plane of the ecliptic, there would be a solar eclipse at every new moon, since the moon would pass directly between the sun and earth; and there would be a lunar eclipse at every full moon, since the earth would be directly between the sun and moon. But since the moon's orbit is inclined to the ecliptic about five degrees, an eclipse can only occur when the moon, at the time of new or full, is at one of its nodes, or very near it. At other times, the moon is too far north or south of the ecliptic to cause an eclipse of the sun, or to be itself eclipsed.

215. *Form of the Earth's Shadow.*—Since the sun is much larger than the earth, and both bodies are nearly spherical, the shadow of the earth must have the form of a cone, whose vertex lies in a direction opposite to that of the sun. Let AB

Fig. 72.



represent the sun, and CD the earth, and let the tangent lines AC, BD, be drawn and produced to meet in F. The triangular space CFD will represent a section of the earth's shadow, and EF will be the axis of the shadow. If the triangle AFS be supposed to revolve about the axis SF, the tangent CF will describe the convex surface of a cone within which the light of the sun is wholly intercepted by the earth.

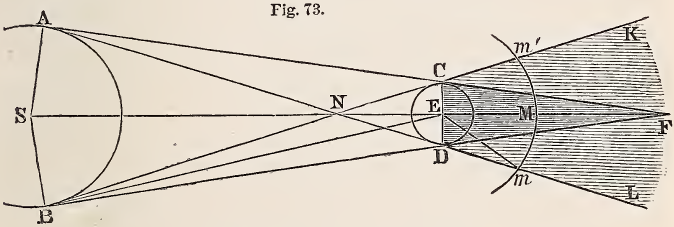
216. *To find the Length of the Earth's Shadow.*—In Fig. 72, EFC or EFD represents half the angle of the cone of the earth's shadow. Now, by Geometry, B. I., Prop. 27, SEB=EFB+EBF; that is, EFB=SEB−EBF; or half the angle of the cone of the earth's shadow is equal to the sun's apparent semi-diameter minus his horizontal parallax. Thus the angle EFD becomes known; and in the right-angled triangle EFD, we know the side ED, the radius of the earth, and all the angles. Hence we can compute EF, the length of the earth's shadow. The length varies according to the distance of the sun from the earth; but its mean length is 856,000 miles, which is more than three times the distance of the moon from the earth.

217. *Breadth of the Earth's Shadow.*—In order to determine the duration of an eclipse, we must know the breadth of the earth's shadow at the point where the moon crosses it. Let M′M″ represent a portion of the moon's orbit. The angle MEH represents the apparent semi-diameter of the earth's shadow at the distance of the moon. Now, by Geometry, B. I., Prop. 27, EHD=MEH+HFE; that is, MEH =EHD−HFE. But EHD represents the moon's horizontal parallax, and HFE is the sun's semi-diameter minus his horizontal parallax, Art. 216. Therefore half the angle subtended by the section of the shadow is equal to the sum of the parallaxes of the sun and moon minus the sun's semi-diameter. The diameter of the shadow can therefore be computed, and we find it to be about three times the moon's diameter. The moon may therefore be totally eclipsed for as long a time as she requires to describe about twice her own diameter, or nearly two hours. The eclipse will begin when the moon's disc at M′ touches the earth's shadow, and the eclipse will end when the moon's disc touches the earth's shadow at M″.

218. *Different kinds of Lunar Eclipses.*—When a part, but not the whole of the moon, enters the earth's shadow, the eclipse is said to be *partial;* when the entire disc of the moon enters into the earth's shadow, the eclipse is said to be *total;* and if the moon's centre should pass through the centre of the shadow, it would be called a *central* eclipse. It is probable, however, that a strictly central eclipse of the moon has never occurred. When the moon just touches the earth's shadow, but passes by it without entering it, the circumstance is called an *appulse.*

219. *The Earth's Penumbra.*—Long before the moon enters the cone of the earth's total shadow, the earth begins to intercept from it a portion of the sun's light, so that the light of the moon's surface experiences a gradual diminution. This partial shadow is called the earth's *penumbra.* Its limits are determined by the tangent lines AD, BC pro-

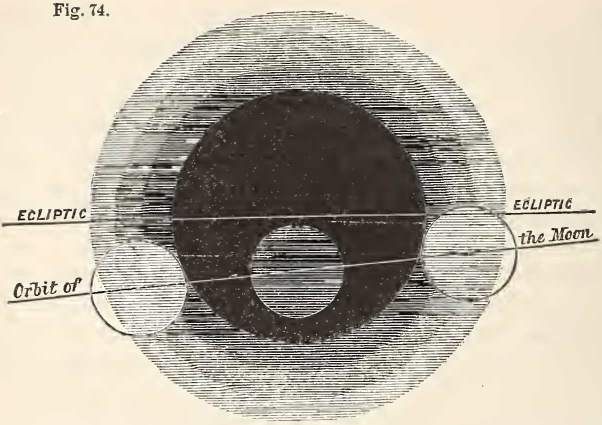
Fig. 73.



duced. Throughout the space included between the lines CK and DL, light will be received from only a portion of the sun's disc. If a spectator were placed at L, he would see the entire disc of the sun; but between L and the line DF he would see only a portion of the sun's surface, and the portion of the sun which was hidden would increase until he reached the line DF, while within the space DFC the sun would be entirely hidden from view.

Fig. 74 represents the dark shadow of the earth, surrounded by the penumbra, and the moon is represented in

Fig. 74.



three different positions, viz., at the beginning, middle, and end of the eclipse.

220. *Effect of the Earth's Atmosphere.*—We have hitherto supposed the cone of the earth's shadow to be determined by lines drawn from the edge of the sun, and touching the earth's surface. It is, however, found by observation that the duration of an eclipse always exceeds the duration computed on this hypothesis. This fact is accounted for in part by supposing that those rays of the sun which pass near the surface of the earth are absorbed by the lower strata of the atmosphere; but we must also admit that those rays of the sun which enter the earth's atmosphere at such a distance from the surface as not to be absorbed are refracted toward the axis of the shadow, and are spread over the entire extent of the geometrical shadow, thereby diminishing the darkness, but increasing the diameter of the shadow, and, consequently, the duration of the eclipse.

In consequence of the gradual diminution of the moon's light as it enters the penumbra, it is difficult to determine with accuracy the instant when the moon enters the dark shadow; and astronomers have differed as to the amount of correction which should be made for the effect of the earth's atmosphere. It is the practice, however, to increase the computed diameter of the shadow by $\frac{1}{60}$th part, which amounts to the same thing as increasing the earth's radius by 66 miles.

221. *Moon visible in the Earth's Shadow.* — When the moon is totally immersed in the earth's shadow, she does not, unless on some rare occasions, become wholly invisible, but appears of a dull reddish hue, somewhat of the color of tarnished copper. This phenomenon results from the refraction of the sun's rays in passing through the earth's atmosphere, as explained in Art. 220. Those rays from the sun which enter the earth's atmosphere, and are so far from the surface as not to be absorbed, are bent toward the axis of the shadow, and fall upon the moon, producing sufficient illumination to render the disc distinctly visible.

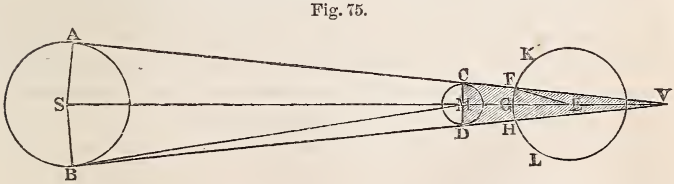
ECLIPSES OF THE SUN.

222. *Moon's Shadow cast upon the Earth.*—We may regard an eclipse of the sun as caused by the moon's shadow falling upon the earth. Wherever the dark shadow falls there will be a total eclipse, and wherever the penumbra falls there will be a partial eclipse. In order to discover the extent of the earth's surface over which an eclipse may occur, we must ascertain the length of the moon's shadow.

223. *Length of the Moon's Shadow.* — We will suppose the moon to be in conjunction, and also at one of her nodes. Her centre will then be in the plane of the ecliptic, and in the straight line passing through the centres of the sun and earth.

Let ASB be a section of the sun, KFL that of the earth,

Fig. 75.



and CMD that of the moon interposed directly between them. Draw AC, BD, tangents to the sun and moon, and produce these lines to meet in V. Then V is the vertex of the moon's shadow, and CVD represents the outline of a cone whose base is CD. Now, by Geometry, B. I., Prop. 27,

$$SMB = MVB + MBV;$$

hence

$$MVB = SMB - MBV.$$

But SMB, which is the sun's semi-diameter as seen from the moon, is $\frac{1}{400}$th greater than the sun's semi-diameter as seen from the earth, because the distance of the moon from the earth is $\frac{1}{400}$th of its distance from the sun; and therefore the value of SMB is easily determined. Also MBV, the angle which the moon's radius subtends at the sun, is to the angle which the earth's radius subtends at the sun (which is the sun's horizontal parallax) as the moon's radius to the earth's radius; and thus the value of MBV can be determined.

We thus obtain the angle MVB, which is half the angle of the cone of the moon's shadow; and, knowing also the moon's diameter, we can compute MV, the length of the shadow. We thus find that when the moon is at her mean distance from the earth, her shadow will not quite reach to the earth's surface. But when the moon is nearest to us, and her shadow is the longest, the shadow extends 14,000 miles beyond the earth's centre; and there must be a total eclipse of the sun at all places within this shadow.

224. *Breadth of the Moon's Shadow at the Earth.*—Having found the greatest length of the moon's shadow, its breadth at the surface of the earth is easily computed.

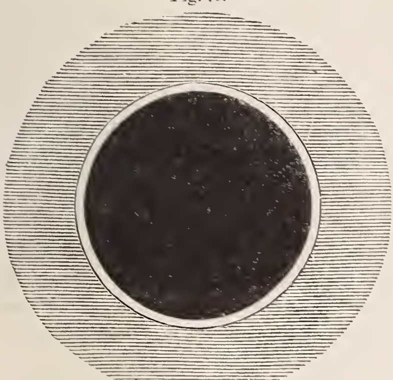
In the triangle FEV, we know two sides, FE and EV, and the angle FVE; we can therefore compute VFE. But the angle FEG = VFE + FVE. Hence we know the arc FG, and of course FH; and allowing 69 miles to a degree, we have the value of FH in miles. We thus find that the greatest breadth of the moon's shadow at the surface of the earth, when it falls perpendicularly on the surface, is 166 miles.

225. *Path of the Moon's Shadow.*—The moon's shadow cast upon the earth is at each instant nearly a circle whose diameter may have any value from zero up to 166 miles; but, on account of the rapid motion of the moon, this shadow will travel along the earth's surface with a velocity of about

2000 miles per hour, and will pass entirely across the earth in somewhat less than four hours. The path of the moon's shadow will therefore be a zone of several thousand miles in length, and only a few miles in breadth. The penumbra, or partial shadow of the moon, may have a breadth of nearly 5000 miles.

226. *Different Kinds of Eclipses of the Sun.*—A *partial* eclipse of the sun is one in which a part, but not the whole of the sun, is obscured. A *total* eclipse is one in which the entire disc of the sun is obscured. It must occur at all those places on which the moon's total shadow falls. A *central* eclipse is one in which the axis of the moon's shadow, or the axis produced, passes through a given place. An *annular* eclipse is one in which the entire disc of the sun is obscured, except a narrow ring or annulus round the moon's dark body.

Fig. 76.



The apparent discs of the sun and moon, though nearly equal, are subject to small variations, corresponding to their variations of distance, in consequence of which the disc of the moon sometimes appears a little greater, and sometimes a little less than that of the sun. If the centres of the sun and moon coincide, and the disc of the moon be less than that of the sun, the moon will cover the central portion of the sun, but will leave uncovered a narrow ring, which appears like an illuminated border round the body of the moon, as shown in Fig. 76. This is called an annular eclipse.

227. *Duration of Eclipses.*—A total eclipse of the sun can not last at any one place more than eight minutes; and it seldom lasts more than four or five minutes. An annular eclipse can not last at any one place more than twelve and a half minutes, and it seldom lasts more than six minutes. The entire duration of an eclipse at one place may exceed three hours.

Since the apparent directions of the centres of the sun and moon vary with the position of the observer on the earth's surface, an eclipse which is total at one place may be partial at another, while at other places no eclipse whatever may occur.

228. *Number of Eclipses in a Year.*—There can not be less than two eclipses in a year, nor more than seven. The most usual number is four, and it is rare to have more than six. When there are seven eclipses in a year, five are of the sun and two of the moon; when there are but two, they are both of the sun. In the year 1868 there were but two eclipses, while in 1823 there were seven. In 1869, August 7th, the sun will be totally eclipsed in Illinois, Kentucky, and North Carolina.

Although the absolute number of solar eclipses is greater than that of lunar eclipses, yet at any given place more lunar than solar eclipses are seen, because a lunar eclipse is visible to an entire hemisphere of the earth, while a solar is only visible to a part.

229. *Darkness attending a Total Eclipse of the Sun.*—During a total eclipse the darkness is somewhat less than that which prevails at night in presence of a full moon, but the darkness appears much greater than this, on account of the sudden transition from day to night. This darkness is attended by an unnatural gloom, which is tinged with unusual colors, such as a light olive, purple, or violet.

230. *The Corona.*—When the body of the sun is concealed from view, the disc of the moon appears surrounded by a ring of light called the corona. It is brightest next to the moon's limb, and gradually decreases in lustre until it becomes undistinguishable from the general light of the sky. Its apparent breadth is generally about one third of the

Fig. 77.

moon's diameter, but sometimes is equal to the entire diameter of the moon. Its color is sometimes white, sometimes of a pale yellow, and sometimes of a rosy tint. The intensity of its light is about equal to that of the moon.

The corona generally presents somewhat of a radiated appearance. Sometimes these rays are very strongly marked, and extend to a distance greater than the diameter of the sun.

231. *Rose-colored Protuberances.*—Immediately after the commencement of the total obscuration, red protuberances, resembling flames, are seen to issue from behind the moon's disc. They have various forms, sometimes resembling the tops of an irregular range of hills; sometimes they appear entirely detached from the moon's limb, and frequently they extend in irregular forms far beyond the support of the base.

Sometimes they rise to a height of 80,000 miles; while others have every intermediate elevation down to the smallest visible object. They are generally tinged with red light, but sometimes appear nearly white, and sometimes they are so conspicuous as to be seen without a telescope.

232. *These Protuberances emanate from the Sun.*—That these protuberances emanate from the sun, and not from the moon, is proved by the following observations. In the progress of a total eclipse, the protuberances seen on the eastern limb continually decrease in their apparent dimensions, while those on the western limb continually increase in their dimensions, indicating that the moon covers more and more the protuberances on the eastern side, and gradually exposes more and more those on the western side. The protuberances retain a fixed position with reference to the sun during the entire eclipse, and only change their form as the moon, by passing over them, shuts them off on the eastern side, while fresh ones become visible on the western.

Fig. 78 is a representation of the solar eclipse of 1860, taken one minute after the commencement of total obscuration; and Fig. 79 is a representation of the same eclipse,

Fig. 78.

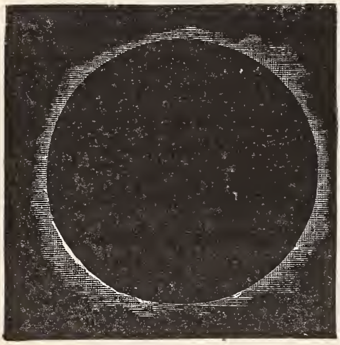
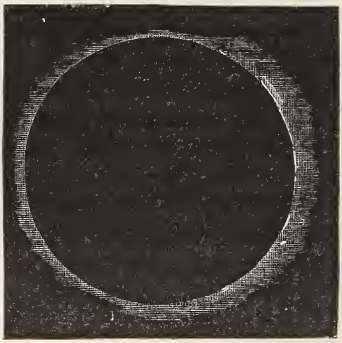


Fig. 79.



taken just previous to the reappearance of the sun. In the first figure the luminous protuberances are chiefly on the left-hand side of the sun's disc, while in the second figure they are chiefly on the right-hand side.

233. *Nature of these Protuberances.*—That these protuberances are not solid bodies like mountains is proved by their forms, as they sometimes appear without any visible support; and the same consideration proves that they are not liquid bodies. They seem to be analogous to the clouds which float at great elevations in our own atmosphere; and we are led to infer that the sun is surrounded by a transparent atmosphere, rising to a height of a million of miles or more; and in this atmosphere there are frequently found cloudy masses of extreme tenuity floating at various elevations, and sometimes rising to the height of 80,000 miles above the photosphere of the sun.

234. *Cause of the Corona.*—The corona is probably due to the solar atmosphere reflecting a portion of the sun's light. Its radiated appearance may result from a partial interception of the sun's light by clouds floating in his atmosphere. These clouds, whose existence was shown in Art. 233, would intercept a portion of the sun's light, and the space behind these would appear less bright than that portion of space which is illumined by the unobstructed rays of the sun.

235. *Occultations.*—When the moon passes between the earth and a star or planet, she must render that body invisible to some parts of the earth. This phenomenon is called an occultation of the star or planet. The moon in her monthly course occults every star which is included in a zone extending a quarter of a degree on each side of the apparent path of her centre. From new moon to full, the moon moves with the dark edge foremost; and from full moon to new, it moves with the illuminated edge foremost. During the former interval, stars disappear at the dark edge, and reappear at the bright edge; while during the latter period they disappear at the bright edge, and reappear at the dark edge. The occultation of a star at the dark limb is extremely striking, inasmuch as the star seems to be instantly extinguished at a point of the sky where there is apparently nothing to interfere with it.

CHAPTER X.

METHODS OF FINDING THE LONGITUDE OF A PLACE.

236. *Difference of Time under different Meridians.*—Mean noon at any place occurs when the mean sun (Art. 117) is on the meridian of that place. Now the sun, in his apparent diurnal motion from east to west, passes successively over the meridians of different places, and noon occurs later and later as we travel westward from any given meridian. The sun will cross the meridian of a place 15° west of Greenwich one hour later than it crosses the Greenwich meridian—that is, at one o'clock of Greenwich time. A difference of longitude of 15° corresponds to a difference of one hour in local times; and the difference of longitude of two places is the difference of their local times. In order, then, to determine the longitude of any place from Greenwich, we must accurately determine the local time, and compare this with the corresponding Greenwich time.

237. *Longitude by Artificial Signals.*—The difference of the local times of two places may be determined by means of any signal which can be seen at both places at the same instant. When the places are not very distant from each other, the flash of gunpowder, or the explosion of a rocket, may serve this purpose. By employing a sufficient number of intermediate stations, the difference of longitude of distant places may be determined in this manner.

238. *Longitude by Chronometers.*—Let a chronometer which keeps accurate time be carefully adjusted to the time of some place whose longitude is known—for example, Greenwich Observatory. Then let the chronometer be carried to a place whose longitude is required, and compared with the correct local time of that place. The difference between this time and that shown by the chronometer will be the difference of longitude between the given place and Greenwich.

It is not necessary that the chronometer should be regulated so as neither to gain nor lose time. This would be difficult, if not impracticable. It is necessary, however, that its error and rate should be well determined, and an allowance can then be made for its gain or loss during the time of its transportation from one place to the other.

The manufacture of chronometers has attained to such a degree of perfection that this method of determining difference of longitude, especially of stations not very remote from each other, is one of the best methods known. When great accuracy is required, it is customary to employ a large number of chronometers as checks upon each other; and the chronometers are transported back and forth a considerable number of times.

This is the method by which the mariner commonly determines his position at sea. Every day, when practicable, he measures the sun's altitude at noon, and hence determines his latitude, Art. 112. About three hours before or after noon he also measures the sun's altitude, and from this he computes his local time by Art. 123. The chronometer which he carries with him shows him the true time at Greenwich, and the difference between the two times is his longitude from Greenwich.

239. *Longitude by Lunar Eclipses.*—An eclipse of the moon is seen at the same instant of absolute time in all parts of the earth where the eclipse is visible. Therefore, if at two distant places the times of the beginning of the eclipse are carefully observed, the difference of these times will be the difference of longitude between the places of observation; but, on account of the gradually increasing darkness of the penumbra, it is impossible to assign the precise instant when the eclipse begins, and therefore this method is of no value except under circumstances which preclude the use of better methods.

The eclipses of Jupiter's satellites afford a similar method of determining difference of longitude, but it is attended with the same inconvenience as that of lunar eclipses.

240. *Longitude by Solar Eclipses.*—The absolute times of the beginning and end of an eclipse of the sun are not the same for all places upon the earth's surface. We can not, therefore, use a solar eclipse as an instantaneous signal for comparing directly the local times at the two stations, but from the observed beginning and end of an eclipse we may by computation deduce the time of conjunction as it would appear if it could be seen from the centre of the earth; and this is a phenomenon which happens at the same absolute instant for every observer on the earth's surface. If the eclipse has been observed under two different meridians, we may determine the instant of true conjunction from the observations at each station; and since the absolute instant is the same for both places, the difference of the results thus obtained is the difference of longitude of the two stations. This is one of the most accurate methods known to astronomers for determining the difference of longitude of two stations remote from each other.

An occultation of a star by the moon affords a similar method of determining difference of longitude, and these occultations are of far more frequent occurrence than solar eclipses.

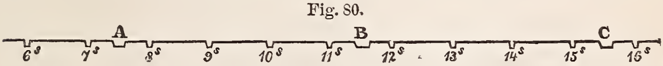
241. *Longitude by the Electric Telegraph.*—The electric telegraph affords the most accurate method of determining difference of longitude. By this means we are able to transmit signals to a distance of a thousand miles or more with almost no appreciable loss of time. Suppose there are two observatories at a great distance from each other, and that each is provided with a good clock, and with a transit instrument for determining its error; then, if they are connected by a telegraph wire, they have the means of transmitting signals at pleasure to and fro for the purpose of comparing their local times. For convenience, we will call the most eastern station E, and the western W.

A plan of operations having been previously agreed upon, the astronomer at E strikes the key of his register, and makes a record of the time according to his observatory clock. Simultaneously with this signal at E, the armature of the magnet at W is moved, producing a click like the ticking of a watch. The astronomer at W hears the sound, and notes the instant by his clock. The difference between the time recorded at E and that at W is the difference between the two clocks. A single good comparison in this way will furnish the difference of longitude to the nearest second; but to obtain the greatest precision, the signals are repeated many times at intervals of ten seconds.

The astronomer at W then transmits a series of signals to E in the same manner, and the times are recorded at both stations. By this double set of signals we obtain an extremely accurate comparison of the two clocks.

242. *How a Clock may break the Electric Circuit.*—The most accurate method of determining difference of longitude consists in employing one of the clocks to break the electric circuit each second. This may be accomplished in the following manner: Near the lower extremity of the pendulum place a small metallic cup containing a globule of mercury, so that once in every vibration the pointer at the end of the pendulum may pass through the mercury. A wire from one pole of the battery is connected with the supports of the pendulum, while another wire from the other pole of the battery connects with the cup of mercury. When the pointer is in the mercury, the electric circuit will be complete through the pendulum; but as soon as it passes out of the mercury, the circuit will be broken. When the connections are properly made, there will be heard a click of the magnet at each station simultaneously with the beats of the electric clock. If each station be furnished with a proper registering apparatus, there will be traced upon a sheet of paper a series of lines of equal length, separated by breaks, as shown in Fig. 80. The mode of using the register for mark-

Fig. 80.



ing the date of any event is to strike the key of the register at the required instant, when a break will be made in one of the lines of the graduated scale, as shown at A, B, and C, and the position of this break will indicate not only the second, but the fraction of a second at which the signal was made.

243. *Transits of Stars Telegraphed.*—We now employ the electric circuit for telegraphing the passages of a star across the wires of a transit instrument. A list of stars having been selected beforehand, and furnished to each observer, the astronomer at E points his transit telescope upon one of the stars as it is passing his meridian, and strikes the key of his register at the instant the star passes successively each wire of his transit, and the instants are recorded not only upon his own register, but also upon that at W. When the same star reaches the meridian of W, the observer there repeats the same operations, and his observations are printed upon both registers.

These observations furnish the difference of longitude of the two stations, independently of any error in the tabular place of the star employed, and also independently of the absolute error of the clock.

The transits of a considerable number of stars are observed in the same manner, and the observations may be varied by introducing into the circuit the clocks at the two stations alternately. By this method have been determined the longitudes of the principal stations along the entire Atlantic coast of the United States.

CHAPTER XI.

THE TIDES.

244. *Definitions.*—The alternate rise and fall of the surface of the ocean twice in the course of a lunar day, or about 25 hours, is the phenomenon known by the name of the *tides.* When the water is rising it is said to be *flood* tide, and when it reaches the highest point it is called *high* water. When the water is falling it is called *ebb* tide, and when it reaches the lowest point it is called *low* water.

245. *Time of High Water.*—The interval between one high water and the next is, at a mean, 12h. 25m. The time of high water is mainly dependent upon the position of the moon, and, for any given place, always occurs about the same length of time after the moon's passage over the meridian. This interval is very different at different places, being at some places two or three hours, while at others it is six, nine, or twelve hours.

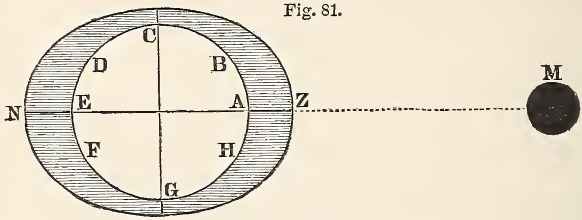
246. *Height of the Tide.*—The height of high water is not always the same at the same place, but varies from day to day, and these variations depend upon the phases of the moon. Near the time of new and full moon the tides are the highest, and these are called the *spring tides.* Near the quadratures, or when the moon is 90° distant from the sun, the tides are the least, and these are called the *neap tides.* At New York the average height of the spring tides is 5.4 feet, and of the neap tides 3.4 feet, which numbers are nearly in the ratio of 3 to 2.

247. *Tides affected by Moon's Distance, etc.*—The height of the tide is affected by the distance of the moon from the earth, being highest near the time when the moon is in perigee, and lowest near the time when she is in apogee. Unusually high tides will therefore occur when the time of new or full moon coincides with the time of perigee.

The tides are also sensibly affected by the declinations of the sun and moon.

248. *Cause of the Tides.*—The facts just stated indicate that the moon has some agency in producing the tides. It is not, however, the whole attractive force of the moon which is effective in raising a tide, but the *difference* of its attraction upon the different particles of the earth's mass. Let ACEG represent the earth, and let us suppose its entire sur-

Fig. 81.



face to be covered with water; also let M be the place of the moon. The different parts of the earth's surface are at unequal distances from the moon. Hence the attraction which the moon exerts upon a particle at A is greater than that which it exerts at B and H, and still greater than that which it exerts at C and G, while the attraction which it exerts at E is least of all. The attraction which the moon exerts upon the mass of water immediately under it, near the point Z, is greater than that which it exerts upon the solid mass of the earth. The water will therefore be heaped up over A, forming a convex protuberance; that is, high water will take place immediately under the moon. The water which thus collects at A will flow from the regions C and G, where the quantity of water must therefore be diminished; that is, there will be low water at C and G.

The water at N is *less* attracted than the solid mass of the earth. The solid mass of the earth will therefore be drawn away from the waters at N; that is, it will leave the water behind, which will thus be heaped up at N, forming a convex protuberance, or high water similar to that at Z. The water of the ocean is therefore drawn out into an ellipsoidal form, having its major axis directed toward the moon.

249. *Effect of the Sun's Attraction.*—The attraction of the sun raises a tide wave similar to the lunar tide wave, but of less height, because, on account of its greater distance, the *inequality* of the sun's attraction on different parts of the earth is very small. It has been computed that the tidal wave due to the action of the moon is about double that which is due to the sun.

There is therefore a solar as well as a lunar tide wave, the latter being greater than the former, and each following the luminary from which it takes its name. When the sun and moon are both on the same side of the earth, or on opposite sides—that is, when it is either new or full moon—both bodies tend to produce high water at the same place, and the result is an unusually high tide, called *spring tide.*

When the moon is in quadrature, the action of the sun tends to produce low water where that of the moon produces high water, and the result is an unusually small tide, called *neap tide.*

250. *Effect of the Moon's Declination on the Tides.*—The height of the tide at a given place is influenced by the distance of the moon from the equator. When the moon is upon the equator, the highest tides should occur along the equator, and the heights should diminish from thence both toward the north and the south; but the two daily tides at any place should have the same height. When the moon has north declination, the highest tides on the side of the earth next the moon will be at places having a corresponding north latitude; and of the two daily tides at any place, that which occurs when the moon is nearest the zenith should be the greatest. This phenomenon is called the *diurnal inequality*, and in some places constitutes the most remarkable peculiarity of the tides.

251. *Nature of the Tide Wave.*—The great wave which constitutes the tide is to be regarded as an undulation of the waters of the ocean, in which (except where it passes over shallows or approaches the shore) there is but little *progressive* motion of the water. This wave, if left undisturbed, would travel with a velocity depending upon the depth of water. In water whose depth is 25 feet, the velocity of the wave should be 19 miles per hour, while in water whose depth is 50,000 feet, or nearly ten miles, its velocity should be 865 miles per hour.

252. *Why the Phenomena of the Tides are so complicated.*—The actual phenomena of the tides are far more complicated than they would be if the earth were entirely covered with an ocean of great depth. Two vast continents extend from near the north pole to a great distance south of the equator, thus interrupting the regular progress of the tidal wave across the globe. In the northern hemisphere the waters of the Atlantic communicate with those of the Pacific only by a narrow channel too small to allow the transmission of any considerable wave, while in the southern hemisphere the only communication is between Cape Horn and the Antarctic Continent. Through this opening the motion of the tidal wave is eastward, and not westward; from which we see that the tides of the Atlantic are not propagated into the Pacific.

253. *Cotidal Lines.*—The phenomena of the tides being thus exceedingly complicated must be learned chiefly from observations; and in order to present the results of observations most conveniently upon a map, we draw a line connecting all those places which have high water at the same instant of absolute time. Such lines are called *cotidal lines.* Charts have been constructed showing the cotidal lines of nearly every ocean at intervals of 1h., 2h., 3h., etc., after the meridian transit of the moon at Greenwich.

254. *Origin and Progress of the Tidal Wave.*—By inspecting a chart of cotidal lines, we perceive that the great tidal wave originates in the Pacific Ocean, not far from the western coast of South America, in which region high water occurs about two hours after the moon has passed the meridian. This wave travels toward the northwest, through the deep water of the Pacific, at the rate of 850 miles per hour. The same wave travels westward and southwestward at the rate of about 400 miles per hour, reaching New Zealand in about

12 hours. Passing south of Australia, it travels westward and northward into the Indian Ocean, and is 29 hours old when it reaches the Cape of Good Hope. Hence it is propagated through the Atlantic Ocean, traveling northward at the rate of about 700 miles per hour, and in 40 hours from its first formation it reaches the shallow waters of the coast of the United States, whence it is propagated into all the bays and inlets of the coast.

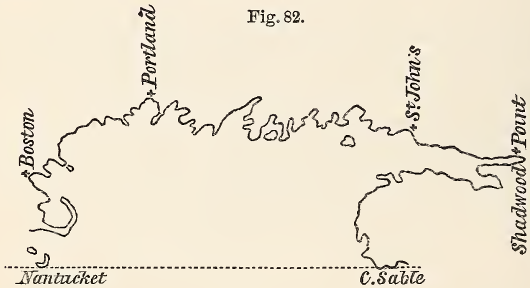
A portion of the great Atlantic wave advances up Baffin's Bay, but the principal part of it turns eastward, and in 44 hours brings high water to the western coast of Ireland. After passing Scotland, a portion of this wave turns southward with diminished velocity into the North Sea, and thence follows up the Thames, bringing high water to London at the end of 66 hours from the first formation of this wave in the Pacific Ocean.

255. *Velocity of the Tidal Wave in Shallow Water.*—As the tidal wave approaches the shallow water of the coast, its velocity is speedily reduced from 500 or perhaps 900 miles per hour, to 100 miles, and soon to 30 miles per hour; and in ascending bays and rivers its velocity becomes still less. From the entrance of Chesapeake Bay to Baltimore the tide travels at the average rate of 16 miles per hour, and it advances up Delaware Bay with about the same velocity. From Sandy Hook to New York city the tide advances at the rate of 20 miles per hour, and it travels from New York to Albany at the average rate of nearly 16 miles per hour.

256. *Height of the Tides.*—At small islands in mid-ocean the tides never rise to a great height—sometimes even less than one foot; and the average height of the tides for the islands of the Atlantic and Pacific Oceans is only 3½ feet. Upon approaching an extensive coast, where the water is shallow, the velocity of the tidal wave is diminished, the cotidal lines are crowded more closely together, and the height of the tide is thereby increased; so that while in mid-ocean the average height of the tides does not exceed 3½ feet, the average in the neighborhood of continents is not less than 4 or 5 feet.

257. *Tides modified by the conformation of the Coast.*—Along the coast of an extensive continent the height of the tides is greatly modified by the form of the shore line. When the coast is indented by broad bays which are open in the direction of the tidal wave, this wave, being contracted in breadth, increases in height, so that at the head of a bay the height of the tide may be twice as great as at the entrance. Such a bay lies between Cape Florida and Cape Hatteras; another lies between Cape Hatteras and Nantucket; and another between Nantucket and Cape Sable. In the bay first mentioned, the range of the tides increases from two feet at the Capes to seven feet at Savannah. In the second bay, the range increases from two feet to nearly five feet at Sandy Hook; and in the third bay, the tide increases from two feet at Nantucket to ten feet at Boston, and 18 feet at the entrance to the Bay of Fundy; while at the head of the bay it sometimes rises to the height of 70 feet. This increase of height results from the contraction in the width of the channel into which the advancing wave is forced.

Fig. 82.



258. *Tides of Rivers.*—The tides of rivers exhibit the operation of similar principles. The velocity varies with the depth of water; and the height of the tide increases where the river contracts, and decreases where the channel expands. Hence, in ascending a long river, it may happen that the height of the tides may alternately increase and decrease. Thus, at New York, the mean height of the tide is 4.3 feet; at West Point, 55 miles up the Hudson River, the tide rises only 2.7 feet; at Tivoli, 98 miles from New

York, the tide rises 4 feet; while at Albany it rises only 2.3 feet.

259. *Tidal Currents.*—The currents produced by the tides in the shallow waters of bays and rivers must not be confounded with the movement of the tidal wave. Their velocity is much less than that of the tidal wave, and the change of the current does not generally correspond in time to the change of the tide. The maximum current in Long Island Sound is about two miles per hour, and in New York Bay three miles per hour. In New York Bay the ebb stream begins at one sixth of the ebb tide, while at Montauk Point the ebb stream does not begin until half ebb tide.

Tidal currents owe their origin partly to differences of level, and partly to the resistance opposed to the tidal wave by contracted channels and shallow water. Their velocity is greatest in narrow channels like Hell Gate and the Race off Fisher's Sound.

260. *Diurnal Inequality in the Height of the Tides.*—On the Pacific coast of the United States, when the moon is far from the equator, there is one large and one small tide during each day. At San Francisco the difference between high and low water in the forenoon is sometimes only *two inches*, while in the afternoon of the same day the difference is $5\frac{1}{2}$ feet. When the moon is on the equator, the two daily tides are nearly equal.

At other places on the Pacific coast this inequality in the two daily tides is more remarkable. Near Vancouver's Island, in lat. 48°, when the moon has its greatest declination, there is *no* descent corresponding to morning low water, but merely a temporary check in the rise of the tide. Thus one of the two daily tides becomes obliterated—that is, we find but one tide in 24 hours. Similar phenomena occur at places farther north along the Pacific coast.

Along the Atlantic coast of the United States, when the moon has its greatest declination, the difference between high water in the forenoon and afternoon averages about 18 inches. On the coast of Europe the diurnal inequality is still smaller, and at many places it can with difficulty be detected.

261. *Cause of these Variations in the Diurnal Inequality.*—The tide actually observed at any port is the effect, not simply of the *immediate* action of the sun and moon upon the waters of the ocean, but is rather the resultant of their continued action upon the waters of the different seas through which the wave has advanced from its first origin in the Pacific until it reaches the given port, embracing an interval sometimes of one or two days, and even longer. During this period the moon's action sometimes tends to produce a large tide and sometimes a small one; and in a tide whose age is more than 12 hours, these different effects may be combined so as nearly to obliterate the diurnal inequality. This is probably the reason why the diurnal inequality is less noticeable in the North Atlantic than in the North Pacific.

262. *Tides of the Gulf of Mexico.*—The Gulf of Mexico is a shallow sea, about 800 miles in diameter, almost entirely surrounded by land, and communicating with the Atlantic by two channels each about 100 miles in breadth. Since the width of the Gulf is so much greater than that of the channels through which the tidal wave enters, the height of the tide is very small. At Mobile and Pensacola the average height is only one foot. The diurnal inequality is also quite large, so that at most places (except when the moon is near the equator) one of the daily tides is well-nigh inappreciable, and the tide is said to ebb and flow but once in 24 hours.

263. *Tides of Inland Seas.*—In small lakes and seas which do not communicate with the ocean there is a daily tide, but so small that it requires the most accurate observations to detect it. There is a perceptible tide in Lake Michigan, the average height at Chicago being $1\frac{3}{4}$ inches. The ratio of this height to that of the tide in mid-ocean is about equal to the ratio of the length of the lake to the diameter of the earth.

264. *Tides of the Coast of Europe.*—Along the coast of Europe the highest tides prevail in the Bristol Channel and on the northwest coast of France. In the Bristol Channel the tides sometimes rise to the height of 70 feet, and at St. Malo to the height of 40 feet. The mean range of the spring tides at Liverpool is 26 feet, at London Docks about 20 feet, and at Portsmouth nearly 13 feet. These tides are not due to any peculiarity in the moon's immediate action at these localities, but are simply the mechanical effect of the tidal wave being forced up a narrow channel.

The lowest tides occur on the eastern coast of Ireland, north of the entrance to St. George's Channel, where the range of the tides is only two feet. The tide is diverted from the coast of Ireland by a projecting promontory, and is driven upon the coast of Wales, where it rises to the height of 36 feet.

265. *The Establishment of a Port.*—The interval between the time of the moon's crossing the meridian and the time of high water at any port is nearly constant. The mean interval on the days of new and full moon is called the *establishment* of the port. The mean interval at New York is 8h. 13m.; and the difference between the greatest and the least interval occurring in different parts of the month is 43 minutes.

The mean establishment of Boston is 11h. 27m.; of Philadelphia, 13h. 44m.; and of San Francisco, 12h. 6m.

CHAPTER XII.

THE PLANETS—THEIR APPARENT MOTIONS.—ELEMENTS OF THEIR ORBITS.

266. *Number, etc., of the Planets.*—The planets are bodies of a globular form, which revolve around the sun as a common centre, in orbits which do not differ much from circles. The name planet is derived from a Greek word signifying a wanderer, and was applied by the ancients to these bodies because their apparent movements were complicated and irregular. Five of the planets—Mercury, Venus, Mars, Jupiter, and Saturn—are very conspicuous, and have been known from time immemorial. Uranus was discovered in 1781, and Neptune in 1846, making eight planets, including the earth. Besides these there is a large group of small planets, called asteroids, situated between the orbits of Mars and Jupiter. The first of these was discovered in 1801, and the number known at the end of 1868 was 107.

The orbits of Mercury and Venus are included within the orbit of the earth, and they are hence called *inferior* planets, while the others are called *superior* planets. The terms inferior and superior, as here used, do not refer to the magnitude of the planets, but simply to their position with respect to the earth and sun.

267. *The Orbits of the Planets.*—The orbit of each of the planets is an ellipse, of which the sun occupies one of the foci. That point of the orbit of a planet which is nearest the sun is called the *perihelion*, and that point which is most remote from the sun is called the *aphelion.*

The *eccentricity* of an elliptic orbit is the ratio which the distance from the centre of the ellipse to either focus bears to the semi-major axis. The eccentricities of most of the planetary orbits are so minute, that if the form of the orbit were exactly delineated on paper, it could not be distinguished from a circle except by careful measurement.

268. *Geocentric and Heliocentric Places, etc.*—The *geocentric* place of a body is its place as seen from the centre of the earth, and the *heliocentric* place is its place as it would be seen from the centre of the sun.

A planet is said to be in *conjunction* with the sun when it has the same longitude, being then in nearly the same part of the heavens with the sun. It is said to be in *opposition* with the sun when its longitude differs by 180° from that of the sun, being then in the quarter of the heavens opposite to the sun. A planet is said to be in *quadrature* when its longitude differs by 90° from that of the sun.

An inferior planet is in conjunction with the sun when it is between the sun and the earth, as well as when it is on the opposite side of the sun. The former is called the *inferior* conjunction, the latter the *superior* conjunction.

A planet, when in conjunction with the sun, passes the meridian about noon, and is therefore above the horizon only during the day. A planet, when in opposition with the sun, passes the meridian about midnight, and is therefore above the horizon during the night. A planet, when in quadrature, passes the meridian about six o'clock either morning or evening. The angle formed by lines drawn from the earth to the sun and a planet is called the *elongation* of the planet from the sun, and it is east or west, according as the planet is on the east or west side of the sun.

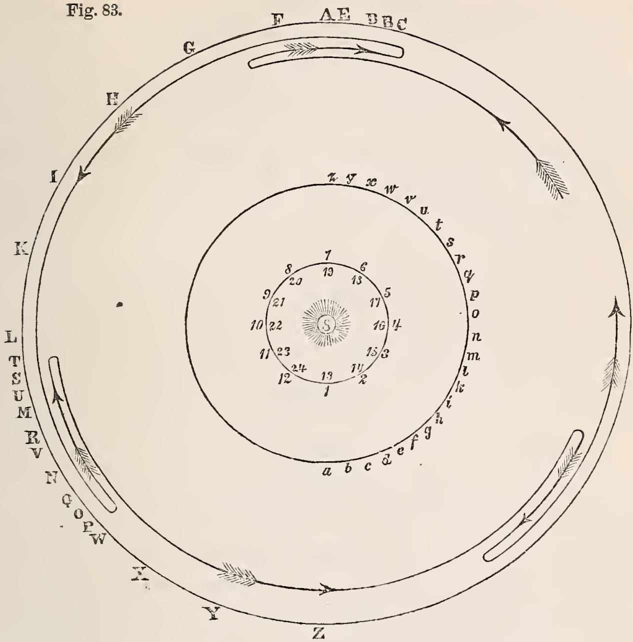
269. *The Satellites.*—Some of the planets are centres of secondary systems, consisting of smaller globes revolving around them in the same manner as they revolve around the sun. These secondary globes are called *satellites* or *moons.* The primary planets which are thus attended by satellites carry the satellites with them in their orbits around the sun. Of the satellites known at the present time, four revolve around Jupiter, eight around Saturn, four around Uranus, and one around Neptune. The Moon is also a satellite to the earth.

270. *Why the apparent Motions of the Planets differ from the real Motions.*—If the planets could be viewed from the sun as a centre, they would all be seen to advance invariably in the same direction, viz., from west to east, in planes only slightly inclined to each other, but with very unequal velocities. Mercury would advance eastward with a velocity about one third as great as our moon; Venus would advance in the same direction with a velocity less than half that of Mercury; the more distant planets would advance still more slowly; while the motions of Uranus and Neptune would be scarcely appreciable except by comparing observations made at long intervals of time. None of the planets would ever appear to move from east to west.

The motions of the planets as they actually appear to us are very unlike those just described: first, because we view them from a point remote from the centre of their orbits, so that their distances from the earth are subject to great variations; and, second, because the earth itself is in motion, and hence the planets have an apparent motion resulting from the real motion of the earth.

271. *The apparent Motion of an Inferior Planet.*—In order to deduce the apparent motion of an inferior planet from its real motion, let CKZ represent a portion of the heavens lying in the plane of the ecliptic; let *a*, *b*, *c*, *d*, etc., be the orbit of the earth; and 1, 2, 3, 4, etc., be the orbit of Mercury. Let the orbit of Mercury be divided into 12 equal parts, each of which is described in $7\frac{1}{3}$ days; and let *ab*, *bc*, *cd*, etc., be the spaces described by the earth in the same time. Suppose that when the earth is at the point *a*, Mercury is at the point 1; Mercury will then appear in the heavens at A, in the direction of the line *a* 1. In $7\frac{1}{3}$ days Mercury will have arrived at 2, while the earth has arrived at *b*, and therefore Mercury will appear at B. When the earth is at *c*, Mercury will appear at C, and so on. By laying the edge of a ruler on the points *c* and 3, *d* and 4, *e* and 5, and so on, the successive apparent places of Mercury in the heavens may be determined. We thus find that from A to C his apparent motion is from east to west; from C to P his apparent motion is from west to east; from P to T it is from east to west; and from T to Z the apparent motion is from west to east.

Fig. 83.



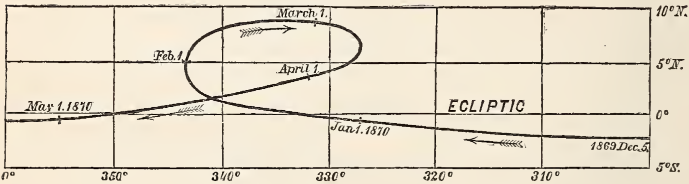
272. *Direct and Retrograde Motion.*—When a planet appears to move among the stars in the direction in which the sun appears to move along the ecliptic, its apparent motion is said to be *direct;* and when it appears to move in the contrary direction, its motion is said to be *retrograde.* The apparent motion of the inferior planets is always direct, except near the inferior conjunction, when the motion is retrograde.

If we follow the movements of Mercury during several successive revolutions, we shall find its apparent motion to be such as is indicated by the arrows in Fig. 83. Near inferior conjunction its motion is retrograde from A to C. As it approaches C, its apparent motion westward becomes gradually slower until it stops altogether at C, and becomes stationary. It then moves eastward until it arrives at P, where it again becomes stationary, after which it again moves westward through the arc PT, when it again becomes stationary, and so on. The middle point of the arc of progression, CP, is that at which the planet is in superior conjunction; and the middle point of the arc of retrogression, PT, is that at which the planet is in inferior conjunction.

These apparently irregular movements suggested to the ancients the name of *planet*, or wanderer.

Fig. 84 shows the apparent motion of Venus for a period of five months.

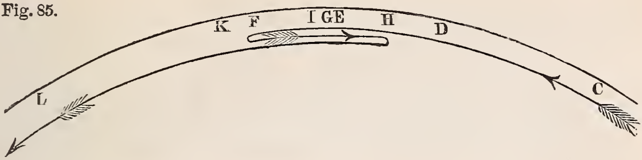
Fig. 84.

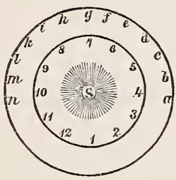


273. *Apparent Motion of a Superior Planet.*—In order to deduce the apparent motion of a superior planet from the real motions of the earth and planet, let S be the place of the sun; 1, 2, 3, etc., be the orbit of the earth; *a*, *b*, *c*, etc., the orbit of Mars; and CGL a part of the starry firmament. Let the orbit of the earth be divided into 12 equal parts, each of which is described in one month; and let *ab*, *bc*, *cd*, etc., be the spaces described by Mars in the same time. Suppose the earth to be at the point 1 when Mars is at the point *a*, Mars will then appear in the heavens in the direction of the line 1*a*. When the earth is at 3 and Mars at *c*, he will appear in the heavens at C. While the earth moves from 4 to 5, and from 5 to 6, Mars will appear to have advanced among the stars from D to E, and from E to F, in the direction from east to west. During the motion of the earth from 6 to 7, and from 7 to 8, Mars will appear to go backward from F to G, and from G to H, in the direction from east to west. During the motion of the earth from 8 to 9, and from 9 to 10, Mars will appear to advance from H to I, and from I to K, in the direction from west to east, and the motion will continue in the same direction until near the succeeding opposition.

The apparent motion of a superior planet projected on

Fig. 85.

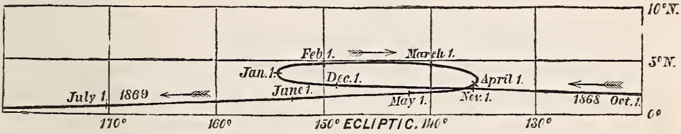




the heavens is thus seen to be similar to that of an inferior planet, except that the retrogression of the inferior planets takes place near inferior conjunction, and that of the superior planets takes place near opposition.

Fig. 86 shows the apparent motion of Mars during a period of nine months.

Fig. 86.



274. *Conditions under which a Planet is Visible.*—One or two of the planets are sometimes seen when the sun is above the horizon; but generally, in order to be visible without a telescope, a planet must have an elongation from the sun of at least 30°, so as to be above the horizon after the close of the evening twilight, or before the commencement of the morning twilight.

The greatest elongation of the inferior planets never exceeds 47°. If they are east of the sun, they pass the meridian in the afternoon, and being visible above the horizon after sunset, are called *evening stars.* If they are west of the sun, they pass the meridian in the forenoon, and being visible above the eastern horizon before sunrise, are called *morning stars.*

A superior planet, having any degree of elongation from 0° to 180°, may pass the meridian at any hour of the day or night. At opposition, the planet passes the meridian at midnight, and is therefore visible from sunset to sunrise.

275. *Phases of the Planets.*—The inferior planets exhibit the same variety of phases as the moon. At the inferior conjunction the dark side of the planet is turned directly toward the earth. Soon afterward the planet appears a thin crescent, which increases in breadth until at the greatest elongation it becomes a half moon. After this the planet becomes gibbous, and at superior conjunction it appears a full circle. These phases are easily accounted for by supposing the planet to be an opaque spherical body, which shines by reflecting the sun's light.

The distances of the superior planets from the sun are (with the exception of Mars) so much greater than that of the earth, that the hemisphere which is turned toward the earth is sensibly the same as that turned toward the sun, and these planets always appear full.

276. *Distinctive Peculiarities of Different Planets.*—The planets can generally be distinguished from each other either by a difference of aspect or by a difference of their apparent motions. The two most brilliant planets are Venus and Jupiter. They are similar in appearance, but their apparent motions among the stars are very different. Thus Venus never recedes beyond 47° from the sun, while Jupiter may have any elongation up to 180°. Mars may be distinguished by his red or fiery color, while Saturn shines with a faint reddish light.

277. *Elements of the Orbit of a Planet.*—In order to be able to compute the place of a planet for any assumed time, it is necessary to know for each planet the position and dimensions of its orbit, its mean motion, and its place at a specified epoch. The quantities necessary to be known for this computation are called the *elements of the orbit*, and are seven in number, viz.:

1. The periodic time.
2. The mean distance from the sun, or the semi-major axis of the orbit.
3. The longitude of the ascending node.
4. The inclination of the plane of the orbit to the plane of the ecliptic.
5. The eccentricity of the orbit.
6. The heliocentric longitude of the perihelion.
7. The place of the planet in its orbit at some specified epoch.

The third and fourth elements define the *position of the plane* of the planet's orbit; the second and fifth define the *form and dimensions* of the orbit; and the sixth defines the *position of the orbit in its plane.*

If the mass of a planet is known, or is so small that it may be neglected, the mean distance can be computed from the periodic time by means of Kepler's third law, in which case the number of elements will be reduced to six.

The orbits of the planets can not be determined in the same manner as that of the moon, Art. 185, because the centre of the earth may be regarded as a fixed point relative to the moon's orbit, but it is *not* fixed relative to the planetary orbits. The methods therefore employed for determining the orbits of the planets are in many respects quite different from those which are applicable to determining the orbit of the moon, and also that of the earth.

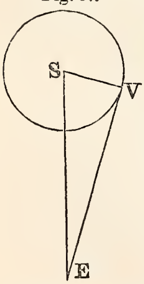
278. *To find the Periodic Time.*—Each of the planets, during about half its revolution around the sun, is found to be on one side of the ecliptic, and during the other half on the opposite side. The interval which elapses from the time when a planet is at one of its nodes till its return to the same node (allowance being made for the motion of the nodes), is the sidereal period of the planet. When a planet is at either of its nodes it is in the plane of the ecliptic, and its latitude is then zero. Let the right ascension and declination of a planet be observed from day to day near the period when it is passing a node, and let these places be converted into longitudes and latitudes. From these we may, by a proportion, obtain the time when the planet's latitude was zero. If similar observations are made when the planet passes the same node again, we shall have the time of a revolution.

When the orbit of a planet is but slightly inclined to the ecliptic, a small error in the observations has a great influence on the computed time of crossing the ecliptic. A more accurate result will be obtained by employing observations separated by a long interval, and dividing this interval by the number of revolutions of the planet.

279. *Sidereal Period deduced from the Synodic.*—The synodical period of a planet is the interval between two consecutive oppositions, or two conjunctions of the same kind. If we compare the instant of an opposition which has been observed in modern times with that of an opposition observed by the earlier astronomers, and divide the interval between them by the number of synodic revolutions contained in it, we may obtain the mean synodical period very accurately. From the synodical period, the sidereal period may be deduced by computation.

280. *To find the Distance of a Planet from the Sun.*—The distance of an inferior planet from the sun may be determined by observing the angle of greatest elongation.

Fig. 87.



In the triangle SEV, let S be the place of the sun, E the earth, and V an inferior planet at the time of its greatest elongation. Then, since the angle SVE is a right angle, we have

$$SV : SE :: \sin. SEV : \text{radius};$$

or $$SV = SE \sin. SEV.$$

If the orbits of the planets were exact circles, this method would give the mean distance of the planet from the sun; but since the orbits are elliptical, we must observe the greatest elongation in different parts of the orbit, and thus obtain its average value, whence its mean distance can be computed.

The distance of a superior planet whose periodic time is known may be found by measuring the retrograde motion of the planet in one day at the time of opposition.

281. *Diameters of the Planets.* — Having determined the distances of the planets, it is only necessary to measure their apparent diameters, and we can easily compute their absolute diameters in miles. The apparent diameters of the planets are variable, since they depend upon the distances, which are continually varying. In computing the absolute diameter of a planet we must therefore combine the apparent diameter with the distance of the planet at the time of observation.

282. *The mean distances of the planets from the sun*, expressed in miles, are in round numbers as follows: Mercury, 35 millions; Venus, 66 millions; the Earth, 92 millions; Mars, 140 millions; Asteroids, 245 millions; Jupiter, 478 millions; Saturn, 876 millions; Uranus, 1762 millions; and Neptune, 2758 millions. The distance of Neptune is 77 times that of Mercury, and 30 times that of the earth.

Fig. 88.

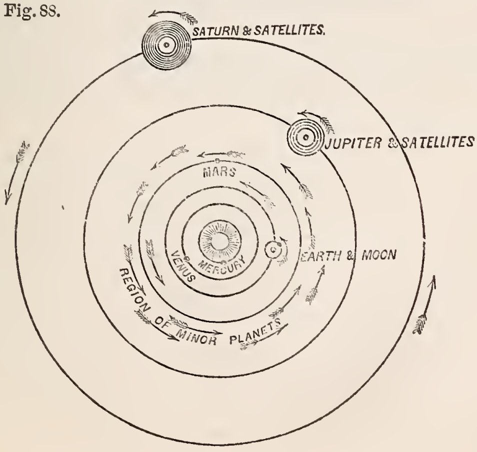


Fig. 88 shows the relative distances of the planets from the sun, with the exception of the two most distant ones, which are shown on Fig. 101, page 187.

The approximate periods of revolution of the planets are: of Mercury, 3 months; Venus, 7½ months; the Earth, 1 year; Mars, 2 years; Asteroids, 4½ years; Jupiter, 12 years; Saturn, 29 years; Uranus, 84 years; and Neptune, 164 years. The periods and mean distances are more exactly given in Tables I. and II., pages 247 and 248.

283. *How to determine the Mass and Density of a Planet.*—The quantity of matter in those planets which have satellites may be determined by comparing the attraction of the planet for one of its satellites with the attraction of the sun for the planet. These forces are to each other directly as the masses of the planet and the sun, and inversely as the squares of the distances of the satellite from the planet, and of the planet from the sun.

The quantity of matter in those planets which have *no* satellites may be determined from the perturbations which they produce in the motions of other planets, or one of the periodic comets.

Having determined the quantity of matter in the sun and planets, and knowing also their volumes, Art. 281, we can compute their densities, for the densities of bodies are proportional to their quantities of matter divided by their volume. Knowing also the specific gravity of the earth, Art. 45, we can compute the specific gravity of each member of the solar system.

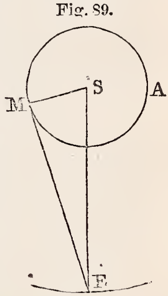
CHAPTER XIII.

THE INFERIOR PLANETS, MERCURY AND VENUS.—TRANSITS.

284. *Greatest Elongations of Mercury and Venus.*—Since the orbits of Mercury and Venus are included within that of the Earth, their elongation or angular distance from the sun is never great. They appear to accompany the sun, being seen alternately on the east and west side of it.

Let S be the place of the sun, E that of the earth, MA the orbit of Mercury, and M the place of the planet when at its greatest elongation, at which time the angle EMS is a right angle. Since the distances of the sun from the earth and planet are variable, the greatest elongation of the planet is variable. The elongation will be the greatest possible when SE is least and SM is greatest; that is, when the earth is in perihelion and Mercury in aphelion, at which time the greatest elongation of Mercury is 28° 20′; but when the earth is in aphelion and Mercury in perihelion, the greatest elongation is only 17° 36′.

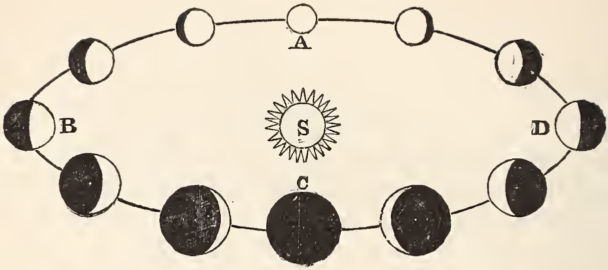
Fig. 89.



In a similar manner we find the greatest elongation of Venus to vary from 45° to 47° 12′.

285. *Phases of Mercury and Venus.*—To the naked eye the discs of all the planets appear circular, but when observed with a telescope the planets Mercury and Venus exhibit the same variety of phases as the moon. Near superior conjunction at A, the planet is lost for a little time in the sun's rays; when first seen after sunset its disc is nearly circular, but it soon becomes *gibbous*, and at the greatest elongation at B we see only half the disc illuminated. As the planet advances toward inferior conjunction, the form becomes that of a crescent, with the horns turned from the sun, until it is again lost in the sun's rays at C. In passing

Fig. 90.



from inferior to superior conjunction, the same variety of phases is exhibited, but in the inverse order.

These phases are accounted for by supposing the planet to be an opaque spherical body which shines by reflecting the sun's light.

MERCURY.

286. *Period, Distance from the Sun, etc.*—Mercury performs its revolution around the sun in a little less than three months, but its synodic period, or the time from one inferior conjunction to another, is 116 days, or nearly four months.

Its mean distance from the sun is 35 millions of miles. The eccentricity of its orbit is *one fifth*, so that its distance from the sun, when at aphelion, is 42 millions of miles, but at perihelion it is only 28 millions.

When between the earth and the sun, the disc of Mercury subtends an angle of about 12 seconds, but near the superior conjunction it subtends an angle of only 5 seconds. Its real diameter is about 3000 miles.

287. *Visibility of Mercury.*—Since the elongation of Mercury from the sun never exceeds 28°, this planet is seldom seen except in strong twilight either morning or evening, but it often appears as conspicuous as a star of the first magnitude would be in the same part of the heavens. The circumstances favorable to its visibility are, first, a clear atmosphere; second, a short twilight; third, the planet should be near aphelion; and, fourth, the planet should be on the north side of the ecliptic.

288. *Time of greatest Brightness.*—Mercury does not appear most brilliant when its disc is circular like a full moon, because its distance from us is then too great; neither when it is nearest to us, because then almost the entire illumined part is turned away from the earth. The greatest brightness must then occur at some intermediate point. This point is near the greatest elongation. When Mercury is an evening star, the greatest brightness occurs a few days *before* the greatest elongation; when it is a morning star, the greatest brightness occurs a few days *after* the greatest elongation.

289. *Rotation on its Axis.*—By observing Mercury with powerful telescopes, some astronomers have supposed that they discovered distinct spots upon it, and by observing these from day to day, it has been concluded that the planet performs a rotation on its axis in 24h. $5\frac{1}{2}$m. Other astronomers, with equally good means of observation, have never remarked upon the planet's surface any spots by which they could approximate to the time of rotation.

There is but little difference between the polar and equatorial diameters of the planet, and the compression does not probably exceed $\frac{1}{150}$.

VENUS.

290. *Period, Distance, and Diameter.*—Venus is the most brilliant of all the planets, and is generally called the *evening* or the *morning* star. It revolves round the sun in about $7\frac{1}{2}$ months, but its synodic period, or the time from one inferior conjunction to the next, is about 19 months. Its mean distance from the sun is 66 millions of miles; and, since the eccentricity of its orbit is very small, this distance is subject to but slight variation.

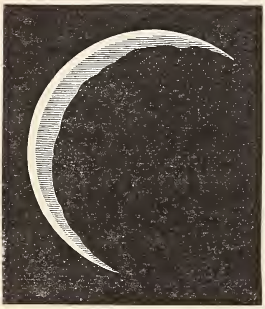
The apparent diameter of Venus varies more sensibly than that of Mercury, owing to the greater variation of its distance from the earth. At inferior conjunction it subtends an angle of 64 seconds, while at superior conjunction its diameter is less than 10 seconds. Its real diameter is 7800 miles, or nearly the same as that of the earth.

291. *Venus visible in the daytime.*—The greatest elongation of Venus from the sun amounts to 47°, and, on account of its proximity to the earth, it is one of the most beautiful objects in the firmament. When it rises before the sun it is called the *morning* star; when it sets after the sun, it is called the *evening* star. When most brilliant, it can be distinctly seen at midday by the naked eye, especially if it is also near its greatest north latitude. Its brightness is greatest about 36 days before and after inferior conjunction, when its elongation is about 40°, and the enlightened part of the disc not more than one quarter of a circle. At these periods the light is so great that it casts a sensible shadow at night.

292. *Rotation on an Axis. Twilight.*—Astronomers have frequently seen upon Venus irregularities, or dusky spots, and have found that these appearances recurred at equal intervals of about 23½ hours; whence it is inferred that this is the time of one rotation of the planet.

The edge of the enlightened part of the planet—that is, the boundary of the illuminated and dark hemispheres—is shaded, or the light *gradually* fades away into the darkness. This phenomenon is analogous to twilight upon the earth, and indicates the existence of a dense atmosphere. Moreover, when the disc is seen as a narrow crescent, a faint light stretches from the horns of the crescent beyond a semicircle; and when very near conjunction, an *entire ring* of light has sometimes been seen surrounding the planet. This appearance is due to the refraction of the sun's rays by the atmosphere of the planet, and it has been computed that the atmosphere of Venus is one fourth denser than that of the earth.

Fig. 91.

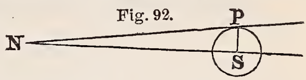


TRANSITS OF MERCURY AND VENUS.

293. Mercury and Venus sometimes pass between the sun and earth, and are seen as black spots crossing the sun's disc. This phenomenon is called a *transit* of the planet. It takes place whenever, at the time of inferior conjunction, the planet is so near its node that its distance from the eclip-tic is less than the apparent semi-diameter of the sun.

294. *When Transits are possible.*—Transits can only take place when the planet is within a small distance of its node. Let N represent the node of the planet's orbit; S the centre of the sun's disc on the ecliptic, and at such a distance from the node that the edge of the disc just touches the orbit NP of the planet. A transit is possible only when the distance of the sun's centre from the node is less than NS.

Fig. 92.

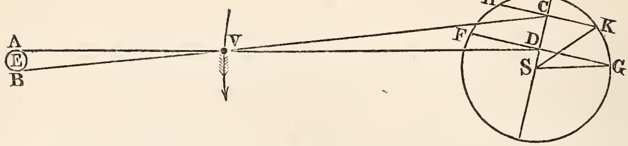


Transits can therefore only happen when the earth is near one of the nodes of the planet's orbit. Those of Mercury must occur either in May or November, while those of Venus occur either in June or December. The last transit of Mercury occurred November 4, 1868, and the next will occur May 6, 1878. The last transit of Venus occurred June 3, 1769, and the next will occur December 8, 1874.

295. *Sun's Parallax and Distance.*—The transits of Venus are important, since they furnish a method by which the sun's distance from the earth can be determined with greater precision than by any other known method. The transits of Mercury afford a similar method, but less reliable, on account of the greater distance of that planet from the earth.

At the time of a transit, observers at different stations upon the earth refer the planet to different points upon the sun's disc, so that the transit takes place along different chords, and is accomplished in unequal periods of time. Let the circle FHKG represent the sun's disc; let E represent the earth, and A and B the places of two observers, supposed to be situated at the opposite extremities of that diameter of the earth which is perpendicular to the ecliptic;

Fig. 93.



also let V be Venus moving in the direction represented by the arrow. To the observer at A the planet will appear to describe the chord FG, and to the observer at B the parallel chord HK. Also, when to the observer at A the centre of the planet appears to be at D, to the observer at B it will appear to be at C.

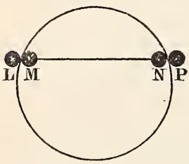
Now, by similar triangles, we have

AV : DV :: AB : CD.

The *relative* distances of the planets from the sun can be computed by Kepler's third law when we know their periods of revolution. Hence we can compute the value of CD expressed in *miles.*

The value of CD expressed in *seconds* may be derived from the observed times of beginning and ending of the transit at A and B. Each observer notes the time when the disc of the planet appears to touch the sun's disc on the

Fig. 94.



outside at L, and also on the inside at M, and again when the planet is leaving the sun's disc. Then, since the planet's rate of motion is already known, the number of seconds in the chord described by the planet can be computed. Knowing the length of DG, which is the half of FG, and knowing also SG, the apparent radius of the sun, we can compute SD. In the same manner, from the length of the chord HK, we can compute SC. The difference between these lines is the value of CD, supposed to be expressed in *seconds.* But we have already ascertained the value of CD in *miles;* hence we can determine the linear value of one second at the sun as seen from the earth, which is found to be 462 miles; and hence the angle which the earth's radius subtends at the sun will be $\frac{3963}{462}$, or 8″.58. This angle is called the *sun's horizontal parallax;* and from it, when we know the radius of the earth, we can compute the distance of the earth from the sun.

296. *Observations of Transit of* 1769.—Expeditions were fitted out by several of the governments of Europe, and sent to remote parts of the earth, to observe the transit of Venus in 1769. The value of the sun's parallax deduced by Professor Encke from these observations is 8″.58, but recent computers have deduced from the same observations the value 8″.91.

As there is some uncertainty respecting the exact value of the sun's parallax, and consequently an uncertainty respecting the distance of the earth from the sun, astronomers are accustomed to call the mean distance of the earth from the sun *unity*, and estimate all distances in our planetary system by reference to this unit.

CHAPTER XIV.

THE SUPERIOR PLANETS—THEIR SATELLITES.

297. *How the Superior Planets are distinguished from the Inferior.*—Since the superior planets revolve in orbits exterior to that of the earth, they never come between us and the sun—that is, they have no inferior conjunction; but they are seen in superior conjunction and in opposition; nor do they exhibit to us phases like those of Mercury and Venus. The disc of Mars sometimes appears gibbous; but the other superior planets are so distant that their enlightened surface is always turned nearly toward the earth, and the gibbous form is not perceptible.

MARS.

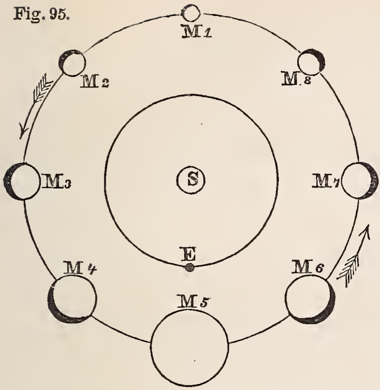
298. *Period, Distance, etc.*—Mars makes one revolution about the sun in 23 months; but its synodic period, or the interval from opposition to opposition, is 26 months.

Its mean distance from the sun is 140 millions of miles; but, on account of the eccentricity of its orbit, this distance is subject to a variation of nearly one tenth its entire amount. Its greatest distance from the sun is 152 millions of miles, and its least distance 127 millions.

The distance of Mars from the earth at opposition is sometimes only 34 millions of miles, while at conjunction it is sometimes as great as 245 millions. Its apparent diameter varies in the same ratio, or from 3″ to 24″. Its real diameter is 4000 miles.

299. *Phases, Rotation, etc.*—At conjunction and opposition, since the same hemisphere is turned toward the earth and sun, the planet appears circular, as shown at M_1 and M_5. In all other positions it appears slightly gibbous; but the deficient portion never exceeds about one ninth of a hemisphere.

Fig. 95.



When examined with a good telescope, the surface of Mars is seen to be diversified with large spots of different shades, which, with occasional variations, retain always the same size and form. These are supposed to be continents and seas; and by observing these spots, the planet has been found to make one rotation upon its axis in $24\frac{1}{2}$ hours, and its axis is inclined to the plane of its orbit about 60°.

Hence we see that on Mars the days and nights are nearly of the same length as on the earth; and the year is diversified by a change of seasons, not very different from what prevails on our own globe.

300. *Spheroidal Form.*—The polar diameter of Mars is sensibly less than the equatorial, the difference according to some measurements amounting to one fiftieth, and according to others to one thirty-ninth of the equatorial diameter.

301. *Telescopic Appearance.*—Many of the spots on this planet retain the same forms, with the same varieties of light and shade, even at the most distant intervals of time. But about the polar regions are sometimes seen white spots, with a well-defined outline, which are conjectured to be *snow*, since they are reduced in size and sometimes disappear during their protracted summer, and are greatest when first emerging from the long night of their polar winter.

Fig. 96.

Mars usually shines with a red or fiery light; but this redness is more noticeable to the naked eye than when viewed with a telescope. This color is probably the result of the tinge of the general soil of the planet.

302. *Sun's Parallax.* — When Mars is in opposition, it sometimes approaches almost as near to the earth as Venus does at inferior conjunction. Its horizontal parallax then amounts to 22″. From the parallax of Mars the parallax of the sun is easily computed, since the relative distances of the Earth and Mars from the sun may be determined from the times of revolution. The horizontal parallax of the sun which has been deduced from these observations is 8″.95. The mean of the best results which have been obtained for the sun's parallax is 8″.9, which is probably correct to within a small fraction of a second.

THE MINOR PLANETS, OR ASTEROIDS.

303. *A deficient Planet between Mars and Jupiter.*—It was long ago discovered that there was something like a regular progression in the distances of the planets from the sun, and it was perceived that these distances conformed to a tolerably simple law, if we supplied an intermediate term between Mars and Jupiter. It was hence suspected that in this part of the solar system there existed a planet hitherto undiscovered; and in 1800 there was formed an association of observers for the purpose of searching for the supposed planet.

In 1801, Piazzi, an Italian astronomer, discovered the planet Ceres, and its distance corresponded very nearly with that required by the law just referred to.

In 1802, Dr. Olbers, while searching for Ceres, discovered another planet whose orbit had nearly the same dimensions as that of Ceres. This planet was called Pallas.

304. *Hypothesis of Olbers.*—The minuteness of these two bodies, and their near approach to each other, led Olbers to suppose that they were the fragments of a much larger planet once revolving between Mars and Jupiter, and which had been broken into pieces by volcanic action or by some internal force. He concluded that other fragments probably existed, and immediately commenced a search for them.

In 1804, Harding discovered a third planet, whose mean distance from the sun was nearly the same as that of Ceres and Pallas. This planet was named Juno.

In 1807, Olbers discovered a fourth planet, whose orbit had nearly the same dimensions as those of the preceding. This planet was named Vesta.

305. *Number of the Asteroids.* — Olbers continued his search for planets till 1816 without farther success. In 1845, Hencke, a Prussian observer, after many years' search, discovered another small planet, which has been named Astræa. Since that time the progress of discovery has been astonishingly rapid, the total number of asteroids known in 1868 amounting to 107.

On account of the close resemblance in appearance between these small planets and the fixed stars, Herschel proposed to call them *Asteroids.* Some astronomers employ the term *Planetoid;* but the term *minor planet* is more descriptive, and is now in common use among astronomers.

306. *Brightness of the Asteroids.*—The asteroids are all extremely minute, the largest of them being estimated at 228 miles in diameter. Vesta is the only one among them which is ever visible to the naked eye, and this only under the most favorable circumstances. They all closely resemble small stars, and are only to be distinguished from fixed stars by their motion. Many of them are so small that they can be seen only near the opposition, even by the largest telescopes.

It is probable that there is a multitude of asteroids yet remaining to be discovered.

307. *Distance of the Asteroids.*—The average distance from the sun of the asteroids hitherto discovered is 2.67, or 245 millions of miles; but their distances differ widely from each other. The asteroid nearest to the sun is Flora, with a mean distance of 200 millions of miles; the asteroid most remote from the sun is Sylvia, with a mean distance of 320 millions of miles. The orbit of Flora is therefore nearer to that of Mars than to that of Sylvia.

308. *Is Olbers's hypothesis admissible?*—The hypothesis of Olbers has lost most of its plausibility since the discovery of so many asteroids. If these bodies had once composed a single planet which burst into fragments, then, since the fragments all started from a common point, each must return to the same point in every revolution; that is, all the orbits should have a common point of intersection. Such, however, is far from being the case. The orbits are spread over a large extent, and the smallest of the orbits is every where distant from the largest by at least 50 millions of miles.

JUPITER.

309. *Period, Distance, etc.*—Jupiter makes one revolution about the sun in 12 years, but the interval between two successive oppositions is 399 days.

Its mean distance from the sun is 478 millions of miles; and, since the eccentricity of its orbit is about $\frac{1}{20}$th, this distance is augmented in aphelion and diminished in perihelion by 24 millions of miles. On account of its great distance from the sun, Jupiter exhibits no sensible phases.

Jupiter is the largest of the planets, its volume exceeding the sum of all the others. Its equatorial diameter is 88,000 miles, or 11 times that of the Earth, and its volume is 1300 times that of the Earth. When near opposition, Jupiter is more conspicuous than any other planet except Venus, and is easily seen in the presence of a strong twilight.

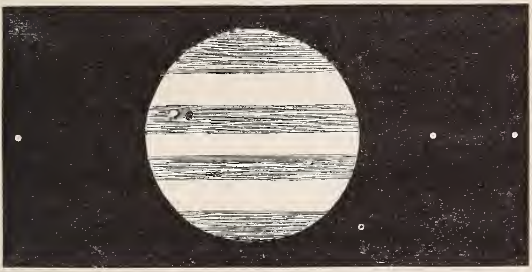
310. *Rotation on an Axis, etc.*—Permanent marks have been occasionally seen on Jupiter's disc, by means of which its rotation has been distinctly proved. The time of one rotation is 9h. 56m. A particle at the equator of Jupiter must therefore move with a velocity of more than 450 miles per minute, or 27 times as fast as a place on the terrestrial equator.

Jupiter's equator is but slightly inclined to the plane of its orbit, and hence the change of temperature with the seasons is very small.

The disc of Jupiter is not circular, the polar diameter being to the equatorial as 16 to 17. This oblateness is found by computation to be the same as would be produced upon a liquid globe making one rotation in about ten hours.

311. *Belts of Jupiter.*—When examined with a good telescope, Jupiter's disc exhibits a light yellowish color, and has several brownish-gray streaks, called *belts*, which are

Fig. 97.



nearly parallel to the equator of the planet. Two belts are generally most conspicuous, one north and the other south of the equator, separated by a light zone. Near the poles the streaks are more faint and less regular. These belts, although tolerably permanent, are subject to slow variations, such that, after the lapse of some months, the appearance of the disc is totally changed. Occasionally spots are seen upon the belts so well defined as to afford the means of determining the time of the planet's rotation.

312. *Cause of the Belts.*—It is inferred that Jupiter is surrounded by an atmosphere, in which float dense masses of clouds, which conceal a considerable portion of the surface of the planet. The brightest portion of the disc probably consists of dense clouds which reflect the light of the sun, while the dusky bands are portions of the atmosphere nearly free from clouds, and showing the surface of the planet with more or less distinctness.

The arrangement of the clouds in lines parallel to the equator is probably due to atmospheric currents analogous to our trade winds, but more steady and decided, on account of the more rapid rotation and greater diameter of Jupiter.

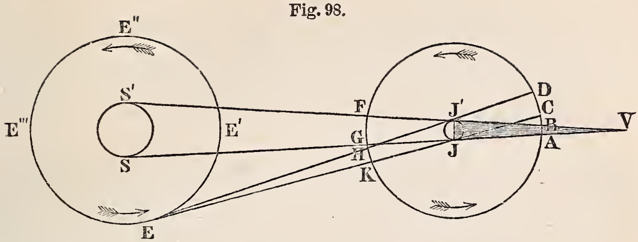
313. *Jupiter's Satellites.*—Jupiter is attended by four moons, or satellites, revolving round the primary, as our moon revolves around the Earth, but with a much more rapid motion. They are numbered *first, second*, etc., in the order of their distances from the primary. They were discovered by Galileo in 1610, soon after the invention of the telescope.

The nearest moon completes a revolution in 42 hours, in an orbit whose radius is 270,000 miles. The second satellite completes a revolution in 85 hours, at a distance of 420,000 miles. The third satellite completes a revolution in 172 hours, at a distance of 675,000 miles. The fourth satellite completes a revolution in 400 hours, at a distance of 1,200,000 miles.

The diameter of the smallest satellite is 2200 miles, being the same as the diameter of our moon, and the diameter of the largest satellite is 3500 miles. The satellites shine with the brilliancy of stars of between the sixth and seventh magnitude; but, on account of their proximity to the planet, which overpowers their light, they are generally invisible without the aid of a telescope. They move alternately from one side of the planet to the other nearly in a straight line. Sometimes all are on the right of the planet, and sometimes all are on the left of it, but generally we find one or two on each side.

314. *Eclipses of the Satellites, etc.*—Jupiter's satellites frequently pass into the shadow of the primary and become invisible. The length of Jupiter's shadow is more than 50 millions of miles; and, since the distance of the most remote satellite is but little over one million miles, if the orbits of the satellites lay in the plane of Jupiter's orbit, an eclipse of each satellite would occur at every revolution. In fact, the orbits of the satellites are inclined about three degrees to the plane of Jupiter's orbit, so that the fourth satellite sometimes passes through opposition without entering the shadow.

Fig. 98.



Let JJ′ represent the planet Jupiter; JVJ′, its conical shadow; SS′, the sun; E and E″, the positions of the Earth when the planet is in quadrature; and let ADFK represent the orbit of one of the satellites whose plane we will suppose to coincide with the ecliptic. From E draw the lines EJ, EJ′, meeting the path of the satellite at H and K, as also at C and D. Let A and B be the points where the path of the satellite crosses the limits of the shadow.

In the revolution of the satellites about the planet, four different classes of phenomena are observed:

1st. When a satellite passes into the shadow of the planet, it is said to be *eclipsed.* The satellite disappears at A and reappears at B.

2d. When a satellite, passing behind the planet, is between the lines EJC and EJ′D, it is concealed from our view by the interposition of the body of the planet. This phenomenon is called an *occultation* of the satellite by the planet. The satellite disappears at C and reappears at D.

3d. When a satellite passes between the sun and Jupiter, its shadow is projected on the surface of the planet in the same manner as the shadow of the moon is projected on the Earth in a solar eclipse. This is called a *transit of the shadow*, and the shadow may be seen to move across the disc of the planet as a small round black spot. The entrance of the shadow upon the disc is called the *ingress*, and its departure is called its *egress.*

4th. When a satellite passes between the Earth and planet, its disc is projected on that of the planet; and it may sometimes be seen with a good telescope when it is projected on a portion of the disc either darker or brighter than itself. This is called a *transit of the satellite.*

From the preceding phenomena, it results that frequently not more than two or three of the satellites are visible; sometimes only one satellite is visible; and in a few instances all four have been invisible for a short time. Such a case occurred August 21, 1867.

315. *Longitude determined by observations of the Eclipses.*—The time of occurrence of the eclipses of Jupiter's satellites is computed several years beforehand and published in the Nautical Almanac, and is expressed in Greenwich mean time. If, then, the time at which one of them occurs at any other station be observed, the difference between the local time and that given in the Almanac will be the longitude of the place from the meridian of Greenwich.

Since the light of a satellite decreases gradually while entering the shadow, and increases gradually on leaving it, the *observed* time of disappearance or reappearance of a satellite must depend on the power of the telescope employed, and hence this method of determining longitude is not very accurate.

316. *Velocity of Light.*—Soon after the invention of the telescope, Roemer, a Danish astronomer, computed a table showing the time of occurrence of each eclipse of Jupiter's satellites for a period of twelve months. He then observed the moments of their occurrence, and compared his observed times with the times which he had computed. At the commencement of his observations the Earth was at E′, where it is nearest to Jupiter (Fig. 98). As the Earth moved toward E″, the eclipses occurred a *little later* than the time computed. As the Earth moved toward E‴, the eclipses were more and more retarded, until at E‴ they occurred more than 16 minutes later than the computed time. While the Earth moved from E‴ to E′ the retardation became less and less, until, on arriving at E′, the observed time agreed exactly with the computed time.

Now, since the eclipse must commence as soon as the satellite enters Jupiter's shadow, the delay in the observed time must be due to the time required for the light, which left the satellite just before its immersion in the shadow, to reach the eye. This retardation amounted to a little over 16 minutes for a distance equal to the diameter of the Earth's orbit, which makes the velocity of light 184,000 miles per second.

SATURN.

317. *Period, Distance, etc.*—Saturn makes one revolution about the sun in 29½ years, but the interval between two successive oppositions is 378 days.

Its mean distance from the sun is 876 millions of miles; and, since the eccentricity of its orbit is about $\frac{1}{20}$th, this distance is augmented at aphelion and diminished at perihelion by 44 millions of miles.

Saturn is the largest of all the planets except Jupiter. Its equatorial diameter is 74,000 miles, being more than nine times that of the Earth, and its volume is nearly 800 times that of the Earth. It appears as a star of the first magnitude, with a faint reddish light.

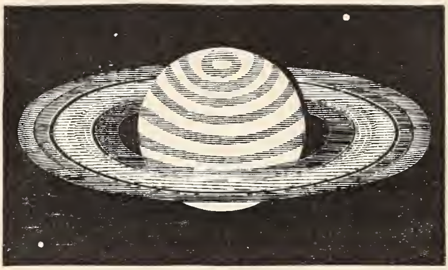
318. *Rotation on an Axis, etc.*—Saturn makes one rotation upon its axis in 10½ hours, and the inclination of the planet's equator to the plane of the ecliptic is 28°. Thus the year of Saturn is diversified by the same succession of seasons as prevail on our globe.

The disc of Saturn is not circular, the equatorial diameter being $\frac{1}{10}$th greater than the polar. The disc is frequently crossed with dark bands or belts parallel to its equator, but these belts are much more faint than those of Jupiter. These belts indicate the existence of an atmosphere surrounding the planet, and attended with the same system of currents which prevail on Jupiter.

319. *Saturn's Ring.*—Saturn is surrounded by a broad but thin ring, situated in the plane of its equator, and entirely detached from the body of the planet. This ring sometimes throws its shadow on the body of the planet, on the side nearest the sun, and on the other side is partially hidden by the shadow of the planet, showing that the ring is opaque, and receives its light from the sun.

The ring is inclined to the plane of the ecliptic at an angle

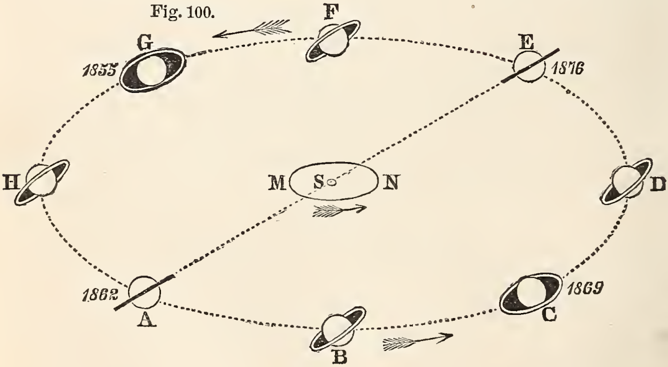
Fig. 99.



of 28°, and while the planet moves in its orbit round the sun, the plane of the ring is carried parallel to itself. The true form of the ring is very nearly circular; but since we never view it perpendicularly, its apparent form is that of an ellipse more or less eccentric. Twice in every revolution—that is, at intervals of 15 years, the plane of the ring must pass through the sun; and the ring, if seen at all, must appear as a straight line. As the planet advances in its orbit, the ring appears as a very eccentric ellipse. This eccentricity diminishes until Saturn has advanced 90° in its orbit, when the minor axis of the ellipse becomes equal to about half the major axis, from which time the minor axis decreases, until, at the end of half a revolution, the ring again appears as a straight line.

These different positions of the ring are represented in Fig. 100, where S represents the sun, MN the orbit of the

Fig. 100.



earth, and A, B, C, D, etc., different positions of Saturn. When Saturn is at A, the plane of the ring passes through the sun, and only the edge of the ring can be seen, as represented in the figure; when Saturn arrives at B, the ring appears as an ellipse; and when it arrives at C, the minor axis of the ellipse is equal to about half the major axis. After this the minor axis decreases, and when the planet reaches E the ring again appears as a straight line.

320. *Disappearance of the Ring.*—The ring of Saturn may become invisible from the Earth either because the part turned toward the Earth is not illumined by the sun, or because the illumined portion subtends no sensible angle.

1st. When the plane of the ring passes through the sun, only the edge of the ring is illumined, and this is too thin to be seen by any but the most powerful telescopes.

2d. When the plane of the ring passes through the Earth, the ring, for the same reason, disappears to ordinary telescopes.

3d. When the Earth and the sun are on opposite sides of the plane of the ring—that is, when the plane of the ring, if produced, passes between the Earth and the sun, the dark face of the ring is turned toward the Earth, and the ring entirely disappears.

The last disappearance of Saturn's ring took place in 1862; and it will attain its greatest opening in 1870.

321. *Divisions of the Ring.*—What we have called Saturn's ring consists of several concentric rings, entirely detached from each other. It is uncertain what is the number of the rings, but in ordinary telescopes a narrow black line can be seen dividing the ring into two concentric rings of unequal breadth. Similar fainter lines have been occasionally remarked on both rings, inducing the suspicion that they may be composed of several narrow ones.

Between the interior bright ring and the planet there has been lately detected another *dark* ring, only discernible in powerful instruments; and it is translucent to such a degree that the body of the planet can be seen through it.

322. *Dimensions of the Rings.*—The inner dark ring approaches within about 8000 miles of the body of the planet. The distance from the surface of the planet to the inside of the nearest bright ring is 18,000 miles; the breadth of this ring is 16,000 miles; the interval between the two bright rings is 1800 miles; and the breadth of the exterior ring is 10,000 miles. The greatest diameter of the outer ring is 165,000 miles. The thickness of the rings is extremely small, and is estimated not to exceed 50 or 100 miles.

323. *What sustains Saturn's Rings?*—Saturn's rings are sustained in the same manner as our moon is sustained in its revolution about the Earth. We may conceive two moons to revolve about the Earth in the same orbit as the present one, and both would be sustained by the same law of attraction. In like manner, three, four, or a hundred moons might be sustained. Indeed, we may suppose a series of moons arranged around the earth in contact with each other, and forming a complete ring; they would all be sustained in the same manner as our present moon is sustained. If we conceive these moons to be cemented together by cohesion, we shall have a continuous solid ring; and the ring must rotate about its axis in the same time as a moon, situated near the middle of its breadth, would revolve about the primary. From observations made upon bright spots seen on the ring of Saturn, Herschel discovered that it rotated about an axis passing nearly through the centre of the planet in a period of 10h. 32m., and this is the period in which a satellite whose distance was equal to the mean distance of the particles of the ring would revolve around the primary.

324. *Constitution of the Rings.*—The discovery of a new ring, together with the apparently variable number of the divisions of the brighter rings, has suggested the idea that the rings consist of matter in the *liquid* condition. It is believed, however, that all the appearances may be explained by supposing that the rings consist of solid matter, but divided into myriads of little bodies which have no cohesion, each revolving independently in its orbit as a satellite to the primary, giving rise to the appearance of a bright ring when they are closely crowded together, and a very dim one when they are most scattered. This supposition will explain the phenomena observed about the time of disappearance of the rings, when the rings frequently present the appearance of a *broken line* of light projecting from each side of the planet's disc.

The *faint* appearance of the newly-discovered ring, and its partial *transparency*, may be explained by supposing that the solid portions of which it is composed are separated by considerable intervals, these portions being too small to be seen individually. The fact that this inner ring was not seen by Sir W. Herschel may be explained by supposing that the orbits of some of those portions which once belonged to the brighter rings have recently been materially changed, and that they now approach much nearer to the body of the planet.

325. *Appearance of the Rings from the Planet Saturn.*—The rings of Saturn must present a magnificent spectacle in the firmament of that planet, appearing as vast arches spanning the sky from the eastern to the western horizon. Their appearance varies with the position of an observer upon the planet. To an observer stationed at Saturn's equator, the ring will pass through the zenith at right angles to the meridian, descending to the horizon at the east and west points. If we suppose the observer to travel from the equator toward the pole, the ring will present the appearance of an arch in the heavens, bearing some resemblance in form to a rainbow. The elevation of the bow will diminish as the observer recedes from the equator, and near lat. 63° it will descend entirely below the horizon.

326. *Satellites of Saturn.*—Saturn is attended by eight satellites, all of which, except the most distant one, move in orbits whose planes coincide very nearly with the plane of the rings. The satellites are numbered 1, 2, 3, etc., in the order of their distance from the primary.

The sixth satellite is the largest, and was discovered in 1655. Its distance from the centre of the planet is 770,000 miles, and the time of one revolution is about 16 days. Its diameter is about 3000 miles, and it can be seen with a small telescope.

The eighth satellite was discovered in 1671. Its distance from the centre of the planet is 2,177,000 miles, which is nearly twice that of the farthest satellite of Jupiter, and the time of one revolution is 79 days. Its diameter is about 1800 miles. It is subject to periodical variations of brightness, which indicate that it rotates on its axis in the time of one revolution round the primary. This is the only satellite which takes a longer time to revolve round its primary than our moon.

The fifth satellite was discovered in 1672. Its period of revolution is $4\frac{1}{2}$ days, and its diameter 1200 miles.

The fourth satellite was discovered in 1684. Its period of revolution is $2\frac{3}{4}$ days, and its diameter about 500 miles.

The third satellite was discovered in 1684. Its period is less than two days, and its diameter about 500 miles.

The second satellite was discovered in 1787, and its period is $1\frac{1}{3}$ day.

The first satellite was discovered in 1789, and its period is 22 hours. The first and second satellites are so small and so near the ring that they can only be seen by the largest telescopes under the most favorable circumstances.

The seventh satellite was discovered in 1848. Its period of revolution is 22 days, and it is the faintest of all the satellites.

URANUS.

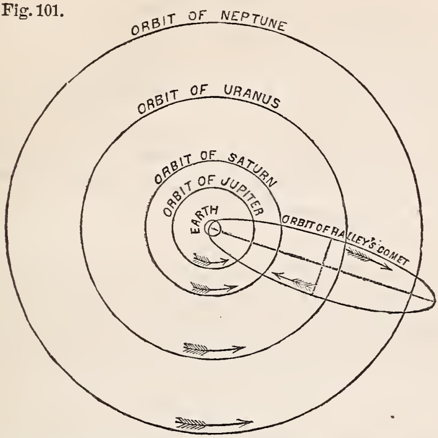
327. *Discovery, Period, etc.*—Uranus was discovered to be a planet by Sir W. Herschel in 1781. It had been previously observed by several astronomers, and its place recorded as a fixed star, but Herschel was the first person who determined it to be a planet.

Its period of revolution is 84 years, but the interval between two successive oppositions is only 370 days.

Its mean distance from the sun is 1762 millions of miles.

328. *Diameter, etc.*—The diameter of Uranus is 33,000 miles, being about half that of Saturn, and more than four times that of the Earth. Its apparent diameter is about 4″. It is not visible without a telescope except near opposition, when, under favorable circumstances, it is barely discernible to the naked eye.

Fig. 101.



The disc of Uranus appears uniformly bright, without any appearance of spots or belts.

329. *Satellites.*—Uranus is attended by four satellites, whose periods range from 2½ days to 13 days. The two outer satellites have been repeatedly observed and are comparatively bright; the two others are very faint objects, and can only be seen in the very best telescopes. The orbits of these satellites are inclined 79° to the plane of the ecliptic, and their motions in these orbits are *retrograde*—that is, contrary to that of the Earth in her orbit.

Sir W. Herschel supposed he had seen six satellites to Uranus, but the existence of more than four has not been established.

NEPTUNE.

330. *History of its Discovery.*—The existence of this planet was detected from the disturbance which it produced in the motion of Uranus. It was ascertained that there were irregularities in the motion of Uranus which could not be referred to the action of the known planets, and in 1845 the astronomers Le Verrier and Adams attempted to determine the place and magnitude of a planet which would account for these irregularities. They demonstrated that these irregularities were such as would be caused by an undiscovered planet revolving about the sun at a distance nearly double that of Uranus, and they pointed out the place in the heavens which the planet ought at present to occupy.

On the 23d of September, 1846, Dr. Galle, of Berlin, discovered the new planet within one degree of the place assigned by Le Verrier. This planet has been called Neptune.

331. *Period, Distance, etc.*—It has been found that Neptune had been repeatedly observed as a fixed star before it was recognized as a planet at Berlin. With the aid of these observations, its orbit has been very accurately determined.

Its period of revolution is 164 years, and its mean distance from the sun is 2758 millions of miles. Its apparent diameter is about $2\frac{1}{2}$ seconds, and its real diameter is 36,000 miles, which is about the same as that of Uranus.

332. *Satellite of Neptune.*—Neptune has one satellite, which makes a revolution around the primary in six days, at a distance about the same as the distance of our moon from the earth. The orbit of this satellite is inclined 29° to the plane of the ecliptic, and its motion in this plane is *retrograde.* This fact is remarkable, since the only other instance of retrograde motion among the planets or their satellites is in the case of the satellites of Uranus.

333. *Solar System as observed from Neptune.*—The apparent diameter of the sun, as seen from Neptune, is about the same as the greatest apparent diameter of Venus seen from the earth; and the illuminating effect of the sun at that distance is about midway between our sunlight and our moonlight.

As seen from Neptune, the other planets would never appear to recede many degrees from the sun. The greatest elongation of Uranus would be 40°, of Saturn 18°, and of the other planets still less. The nearer planets might perhaps be seen by the inhabitants of Neptune as faint stars, and the planets would occasionally appear to travel across the sun's disc, but these phenomena would be of rare occurrence.

CHAPTER XV.

COMETS.—COMETARY ORBITS.—SHOOTING STARS.

334. *What is a Comet?*—A comet is a nebulous body revolving around the sun in an orbit of considerable eccentricity. The orbits of all known comets are more eccentric than any of the planetary orbits. The most eccentric planetary orbit is an ellipse, of which the distance between the foci is about *one third* of the major axis. The least eccentric cometary orbit is an ellipse, of which the distance between the foci is more than *half* the major axis. In consequence of this eccentricity, and of the faintness of their illumination, all comets, during a part of every revolution, disappear from the effect of distance—that is, they can not be observed during their entire revolution about the sun.

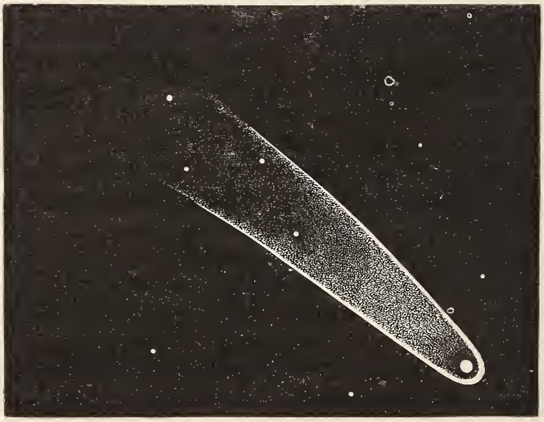
335. *Number of Comets.*—The number of comets which have been recorded since the birth of Christ is over 600, but the number belonging to the solar system must be far greater than this. Before the invention of the telescope, only those comets were recorded which were conspicuous to the naked eye, but within the past fifty years 80 comets have been recorded. Their periods are generally of vast length, so that probably not more than half the whole number have returned twice to their perihelia within the last two thousand years. Hence we may conclude that if the heavens had been closely watched with a telescope two thousand years, at least 2500 different comets would have been seen, so that the total number of cometary bodies must amount to many thousands.

336. *Position of Cometary Orbits.*—Comets are confined to no particular region of the heavens, but traverse every part indifferently, and may be seen near the poles of the heavens as well as near the ecliptic. Their orbits exhibit every possible variety of position. They have every inclination to the ecliptic from zero to 90 degrees, and their motion is as frequently retrograde as direct.

337. *Period of Visibility.*—The period of visibility of a comet depends on its intrinsic brightness, as well as upon its position with reference to the earth and sun. This period varies from a few days to more than a year, but usually it does not exceed two or three months. Only seven comets have been observed so long as eight months.

338. *The Coma, Nucleus, Tail, etc.*—The general appearance of a brilliant comet is that of a mass of nebulous matter termed the *head*, condensed toward the centre so as sometimes to exhibit a tolerably bright point, which is called the *nucleus* of the comet; while from the head there proceeds, in a direction opposite to the sun, a stream of less

Fig. 102.



luminous matter, called the *tail* or train of the comet. Frequently the centre of the head exhibits nothing more than a higher degree of condensation of the nebulous matter, which is not very distinctly defined. The nebulosity which surrounds a highly condensed nucleus is called the *coma*, or the *nebulous envelope.*

The tail gradually increases in width and diminishes in brightness from the head to its extremity, where it is lost in the general light of the sky.

339. *The Nebulous Envelope.*—The central nucleus is enveloped on the side toward the sun by a nebulous mass of great extent. It does not entirely surround the nucleus except in the case of comets which have no tails, but forms a sort of hemispherical cap to the nucleus on the side toward the sun. The tail begins where the nebulous envelope terminates, being merely the continuation of the envelope in a direction opposite to the sun. Between the nucleus and the nebulous envelope there is ordinarily a space less luminous than the envelope. The tail has the form of a hollow truncated cone, with its smaller base united to the nebulous envelope, the sides of the tail being, however, sensibly curved, and the convexity being turned toward the region to which the comet is moving. That the tail is hollow is inferred from the fact that it always appears less bright along the middle than near the borders.

340. *The Nucleus.*—The nucleus of a comet does not generally exceed a few hundred miles in diameter. The great comet of 1811 had a nucleus 428 miles in diameter, and some have been found less than a hundred miles in diameter. The majority of comets have no bright nucleus at all.

In a few instances the diameter of the nucleus has been estimated at 5000 miles; but it is probable that in these cases the object measured was not a solid body, but simply nebulous matter in a high degree of condensation. The dense nebulosity about the nucleus sometimes exceeds 5000 miles in diameter, but it is probable that the true nucleus never exceeds 500 miles in diameter.

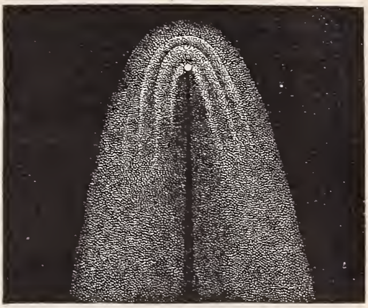
It is probable that the nucleus of the brightest comets is a solid of permanent dimensions, with a thick stratum of condensed vapor resting upon its surface.

341. *Dimensions of the Nebulous Envelope.*—The head of a comet is sometimes more than 100,000 miles in diameter, and that of the comet of 1811 exceeded a million of miles in diameter. The head of the great comet of 1843 was about 30,000 miles in diameter.

The dimensions of the nebulous envelope are subject to continual variations. In several instances the envelope has *diminished* in size during the approach to the sun, and *dilated* on receding from the sun. Such an effect might result from the change of temperature to which the comet is exposed. As the comet approaches the sun, the vapor which composes the nebulous envelope may be converted by intense heat into a transparent and invisible elastic fluid. As it recedes from the sun and the temperature declines, this vapor may be gradually condensed and assume the form of a visible cloud, in which case the *visible* volume of the comet may be increased, although its *real* volume is diminished.

342. *Changes in the Nebulous Envelope.*—When a comet has a bright nucleus and a splendid train, the nebulous envelope undergoes remarkable changes as it approaches the sun. The nucleus becomes much brighter, and throws out a jet or stream of luminous matter toward the sun. Sometimes two, three, or more jets are thrown out at the same time in diverging directions. This ejection of nebulous matter sometimes continues, with occasional interruptions, for several weeks. The form and direction of these luminous streams undergo frequent changes, so that no two successive nights present the same appearance. These jets, though very bright at their point of emanation from the nucleus, become diffuse as they expand, and at the same time curve backward from the sun, as if encountering a resistance from the sun. These streams combined form the outline of a bright parabolic envelope surrounding the nucleus, and the envelope steadily recedes from the nucleus. After a few days a second luminous envelope is sometimes formed within the first, the two being separated by a band comparatively dark, and the second envelope increases in its dimensions from day to day. A few days later a third envelope is sometimes formed, and so on; while each envelope, as it expands, declines in brightness, and finally disappears. Donati's comet in 1858 showed seven such envelopes, each separated from its neighbor by a band comparatively dark, and each steadily receding from the nucleus. See the representation, Fig. 103.

Fig. 103.



These envelopes seem to be formed of matter driven off from the nucleus by a repulsive force on the side next the sun, as light particles are thrown off from an excited conductor by electric repulsion; and the dark bands separating the successive envelopes probably result from a temporary cessation or diminished activity of this repulsive force.

343. *The Tail.*—The tail of a comet is but the prolongation of the nebulous envelope surrounding the nucleus. Each particle of matter, as it recedes from the nucleus on the side next to the sun, gradually changes its direction by a curved path, until its motion is almost exactly away from the sun. The brightness and extent of the train increase with the brightness and magnitude of the envelopes, and the tail appears to consist exclusively of the matter of the envelopes driven off by a powerful repulsive force emanating from the sun. On the side of the nucleus opposite to the sun there is no appearance of luminous streams, and hence results a dark stripe in the middle of the tail, dividing it longitudinally into two distinct parts. This stripe was formerly supposed to be the shadow of the head of the comet; but the dark stripe remains even when the tail is turned obliquely to the sun. It is inferred that the tail is a hollow envelope; and when we look at the edges, the visual ray traverses a greater quantity of nebulous particles than when we look at the central line, whence the central line appears less bright than the sides.

344. *Rapid Formation of the Tail.*—When a comet first appears its light is generally faint, and no tail is perceived. As it approaches the sun it becomes brighter, the tail shoots out from the nebulous envelope, and increases from day to day in extent and brightness. It attains its greatest length and splendor soon after perihelion passage, after which it fades gradually away.

When near perihelion, the tail sometimes increases with immense rapidity. The tail of Donati's comet in 1858 increased in length at the rate of two millions of miles per day; that of the great comet of 1811, nine millions of miles per day; while that of the great comet of 1843, soon after passing perihelion, increased 35 millions of miles per day.

345. *Dimensions of the Tail.*—The tails of comets often extend many millions of miles. That of 1843 attained a length of 120 millions of miles; that of 1811 had a length of over 100 millions of miles, and a breadth of about 15 millions; and there have been four other comets whose tails attained a length of 50 millions of miles.

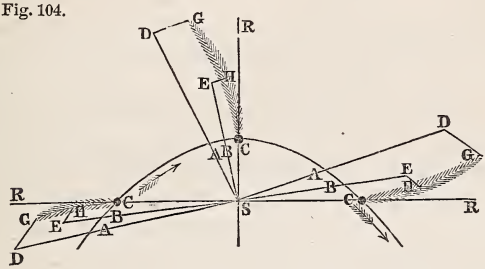
The *apparent* length of the tail depends not merely upon its absolute length, but upon the direction of its axis and its distance from the earth. There are on record six comets whose tails subtended an angle of at least 90°—that is, whose tails would reach from the horizon to the zenith; and there are about a dozen more whose tails subtended an angle of at least 45°.

346. *Position of the Axis of the Tail.*—The axis of a comet's tail is not a straight line, and, except near the nucleus, is not turned exactly *from* the sun, but always makes an angle with a line joining the sun and comet. This angle generally amounts to 10° or 20°, and sometimes even more, the tail always inclining *from* the region toward which the comet proceeds. If the tail were formed by a repulsive force emanating from the sun, which carried particles *instantly* from the comet's head to the extremity of the tail, then the axis of the tail would be turned exactly *from* the sun; but, in fact, the nebulous matter requires several days to travel from the comet's head to the extremity of the tail, and the head meanwhile is moving forward in its orbit, whence result both the curvature and backward inclination of the tail.

We shall assume the existence of a repulsive force by which certain particles of a comet are driven off from the nucleus, and that these particles are then acted upon by a more powerful repulsive force emanating from the sun.

Let S represent the position of the sun, and ABC a por-

Fig. 104.



tion of the comet's orbit, the comet moving in the direction of the arrows. Suppose, when the nucleus is at A, a particle of matter is expelled from the head of the comet in the direction SAD. This particle, in consequence of its inertia, will retain the motion in the direction of the orbit which the nucleus had at the time of parting from it; and this motion will carry the particle over the line DG, while the head is moving from A to C. When the nucleus reaches B, another particle is driven off in the direction SBE. This particle will also retain the motion which it had in common with the nucleus, and which will carry it over EH, while the head is moving from B to C. Thus, when the nucleus has reached the point C, the particles which were expelled from the head during the period of its motion from A to C will all be situated upon the line CHG. This line will be a curve line, tangent at C to the radius vector SC produced, and always concave toward the region from which the comet proceeds.

347. *Form of a Section of the Tail.*—A transverse section of the tail of a comet is not generally a circle, but a complex curve somewhat resembling an ellipse. In the case of Donati's comet, the longest diameter of this curve was four times the least, and in the comet of 1744 the ratio was probably still greater. The longest diameter of the transverse section coincides nearly with the plane of the orbit; in other words, the tail of a comet spreads out like a fan, so that its breadth, measured in the direction of the plane of the orbit, is much greater than its breadth measured in a transverse direction.

These facts seem to indicate that all the particles which form the tail of a comet are not repelled by the sun with the same force. Those particles upon which the repulsive force of the sun is greatest, form a tail which is turned almost exactly *from* the sun; but those particles upon which the repulsive force of the sun is small, form a tail which falls very much behind the direction of a radius vector. If, then, the head of the comet consists of particles which are *unequally* acted upon by the sun, the nebulous matter will be more widely dispersed in the plane of the comet's orbit than in a direction perpendicular to that plane.

348. *Multiple Tails.*—When a comet has more than one nebulous envelope, Art. 342, each of them may be prolonged into a train, Art. 343; and each of these tails, being hollow, may be so faint near the middle as to have the appearance of two distinct tails. A comet with three separate envelopes might thus appear to have six tails, like the comet of 1744 (see Fig. 105). If the different envelopes were not distinctly separated from each oth-

Fig. 105.

er, then all the trains would appear to proceed from the same nebulous mass, but the whole would present a striped appearance, like Donati's comet in 1858. See Fig. 112.

349. *Telescopic Comets.*—Comets which are visible only in telescopes generally have no distinct nucleus, and are often entirely destitute of a tail. They have the appearance of round masses of nebulous matter, somewhat more dense toward the centre. As they approach the sun they generally become somewhat elongated, and the point of greatest brightness does not occupy the centre of the nebulosity.

In some cases the absence of a tail may result from the smallness of the comet and the faintness of its light, so that, although a tail is really formed, it entirely escapes observation. It is, however, remarkable, that those comets whose time of revolution is shortest have no tails, but only exhibit a slight elongation as they approach the sun, which has been supposed to indicate that, by frequent returns to the sun, they have lost nearly all that class of particles which are repelled by the sun, and which contribute to form the tail.

350. *Small Mass and Density.*—The quantity of matter in comets is exceedingly small. This is proved by the fact that comets have been known to pass near to some of the planets and their satellites, and to have had their own motions much disturbed by the attraction of these bodies, but without producing any visible disturbance in the motion of the planets or their satellites. Such was the case with the comet of 1770. (See Art. 366.) Since the quantity of matter in comets is inappreciable in comparison with the satellites, while their volumes are enormously large, the density of this nebulous matter must be incalculably small.

The *transparency* of the nebulosities of comets is still more remarkable. Faint telescopic stars have been repeatedly seen through a nebulosity of 50,000 or 100,000 miles in diameter, and generally no perceptible diminution of the star's brightness can be detected.

351. *Do Comets exhibit Phases?*—Comets exhibit *no* phases like those presented by the moon, and which might be expected from a solid nucleus shining by reflected light. Some have therefore concluded that comets are self-luminous; but observations with the polariscope have proved that comets shine in a great degree by reflected light. The same is also proved by the fact that comets gradually become dim as they recede from the sun, and they vanish simply from loss of light, while they still subtend a sensible angle, whereas a self-luminous surface appears equally bright at all distances as long as it has a sensible magnitude.

The nucleus of a comet is too small to exhibit a distinct phase, and the nebulosity which surrounds it is so rare as to be penetrated throughout by the sun's rays.

352. *Orbits of Comets.*—It was first demonstrated by Newton that a body projected into space, and acted upon by a central force like gravitation, whose intensity decreases as the square of the distance increases, must move in one of the conic sections—that is, either a parabola, an ellipse, or an hyperbola. Several comets are known to move in ellipses of considerable eccentricity; the paths of most comets can not be distinguished from parabolic arcs; while a few have been thought to move in hyperbolas. Since the parabola and hyperbola consist of two diverging branches of infinite length, a body moving in either of these curves could not complete a revolution about the sun. It would enter the solar system from an indefinite distance, and, after passing perihelion, would move off in a different direction never to return. Hence bodies moving in parabolas and hyperbolas are not periodic; but comets moving in elliptic orbits must make successive revolutions like the planets.

It is probable that the orbits which are not distinguishable from parabolas are, in fact, ellipses of great eccentricity, which differ but little from parabolas in that portion described by the comet while it is visible to us.

353. *Distance of Comets from the Sun.*—Some comets, when at perihelion, come into close proximity to the sun. The comet of 1843 approached within 70,000 miles from the sun's surface, and the comet of 1680 came almost equally near. On the other hand, the comet of 1729, when at its perihelion, was distant from the sun 380 millions of miles. The perihelia of more than two thirds of the computed orbits fall within the orbit of the earth.

When at aphelion, Encke's comet is distant from the sun only 388 millions of miles, and it completes its entire revolution in $3\frac{1}{3}$ years. There are also 24 comets whose orbits are wholly included within the orbit of Neptune; but most comets recede from the sun far beyond the orbit of Neptune, to such a distance that it requires many centuries to complete a revolution.

354. *How the Period of a Comet is determined.*—Since comets are only seen in that part of their orbit which is nearest to the sun, and since, in the neighborhood of perihelion, an ellipse, a parabola, and an hyperbola depart but slightly from each other, it is difficult to determine in which of these curves a comet actually moves; but if the orbit be an ellipse, the comet will return to perihelion after completing its revolution. If, then, we find that two comets, visible in different years, moved in the same path—that is, have the same elements—we presume that they were the same body reappearing after having completed a circuit in an elliptic orbit; and if the comet has been observed at several returns, this evidence may amount to absolute demonstration.

There are 250 different comets whose orbits have been determined, and of these 47 have been computed to move in elliptic orbits. There are seven comets which have been observed at successive returns to the sun, and whose periods are therefore well established, viz., Halley's, Encke's, Biela's, Faye's, Brorsen's, D'Arrest's, and Winnecke's. See Fig. 106.

There are also two or three other comets which are presumed to have been observed at two different returns to the sun, but the predictions of their return to perihelion are not yet verified, so that their periods are not fully established.

Halley's Comet.

355. About the year 1705, Halley, an eminent English astronomer, found that a comet which had been observed in 1682 pursued an orbit which coincided very nearly with those of comets which had been observed in 1607 and 1531.

Fig. 106.

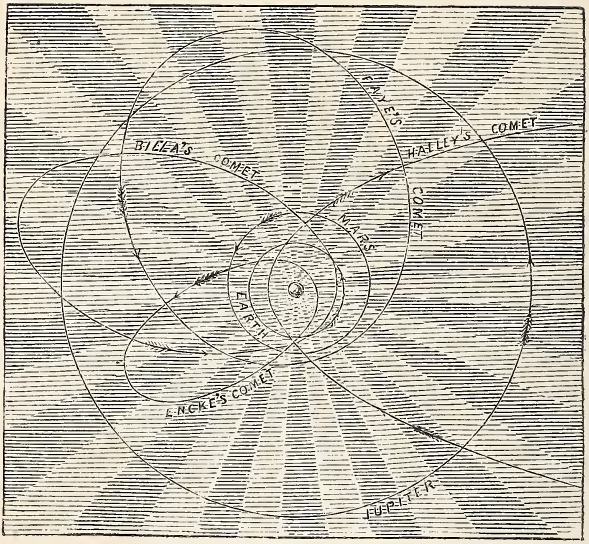


Fig. 107.

He hence concluded that the same comet had made its appearance in these several years, and he predicted that it would again return to its perihelion toward the end of 1758 or the beginning of 1759.

Previous to its appearance, Clairaut, a distinguished French astronomer, undertook to compute the disturbing effect of the planets upon the comet, and predicted that it would reach its perihelion within a month of the middle of April, 1759. It actually passed its perihelion on the 12th of March, 1759.

The last perihelion passage took place on the 16th of November, 1835, within a few days of the predicted time.

The period of this comet is about 76 years, but is liable to a variation of a year or more, from the effect of the attractions of the planets. It approaches the sun to within about one half the distance of the Earth, and recedes from him to a distance considerably greater than that of Neptune. The inclination of its orbit to the plane of the ecliptic is 18°, and its motion is retrograde. See Fig. 101.

Encke's Comet.

356. This comet is remarkable for its short period of revolution, which is only $3\frac{1}{3}$ years. At perihelion it passes within the orbit of Mercury, while at aphelion its distance from the sun is $\frac{4}{5}$ths that of Jupiter. The inclination of its orbit to the ecliptic is 13°, and its motion is direct. Its period was determined by Professor Encke, of Berlin, in 1819, on the occasion of its fourth recorded appearance. Since then it has made 15 returns to perihelion, and has been observed at each return. Its last return took place in September, 1868.

Fig. 108.

357. *Indications of a Resisting Medium.*—By comparing observations made at the successive returns of this comet, it is found that, after allowance has been made for the disturbing action of the planets, the periodic time is continually diminishing and the orbit is slowly contracting. The diminution amounts to about three hours in each revolution. Professor Encke attributed this effect to the action of an extremely rare medium, which causes no sensible obstruction to the motions of dense bodies like the planets, but which sensibly resists the motion of so light a body as a comet. The effect of such a medium must be to diminish the velocity in the orbit, and consequently the comet is drawn nearer to the sun, and moves in an orbit lying within that which would otherwise be described; its mean distance from the sun is therefore diminished, and it performs its revolution in less time. If this diminution of the orbit should continue indefinitely, the comet must ultimately be precipitated upon the sun.

Encke's comet is the only body at present known which requires us to admit the existence of a resisting medium, and, according to Professor Encke, this resistance is not appreciable beyond the orbit of Venus. This resistance may arise from collision with innumerable small bodies similar to those which the Earth daily encounters, and which produce the phenomena of shooting stars.

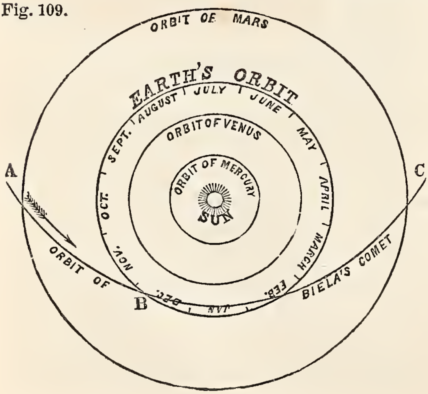
Biela's Comet.

358. In 1826, M. Biela discovered a comet, and found that its orbit was similar to those of the comets of 1772 and 1805, and he concluded that it revolved in an elliptic orbit with a period of about $6\frac{2}{3}$ years. At perihelion the distance of this comet from the sun is a little less than that of the earth, while at aphelion its distance somewhat exceeds that of Jupiter.

The orbit of this comet very nearly intersects the orbit of the Earth, and in 1805 the comet passed within six million miles of the earth.

359. *The appearance of a Comet depends upon the position of the Earth.*—Comets are intrinsically the most luminous soon after passing perihelion, but their apparent size and brightness depend greatly upon the position of the Earth in its orbit. This will appear from Fig. 109, which represents the orbit of the Earth, and also a portion of the orbit

Fig. 109.



of Biela's comet. If, when the comet is at B, the Earth should be near the same point, the comet would be the most conspicuous possible. This case happens when Biela's comet passes its perihelion in January. But if, when the comet is at B, the Earth should be in the opposite part of its orbit, the comet would be in the most unfavorable position to be observed, because its distance would be great, and the comet would be lost in the sun's rays. This case happens when the comet passes its perihelion in July.

Since, at the successive returns of the same comet to perihelion, the Earth may have every variety of position in its orbit, the apparent size and brilliancy of a comet may be very different at its different returns to the sun.

360. *Division of Biela's Comet.*—In 1846, this comet presented the singular phenomenon of a double comet, or two distinct comets moving side by side. See Fig. 110. The orbits of these two bodies were found to be ellipses entirely independent of each other, and during their entire visibility in 1846, their distance apart was about 200,000 miles.

Fig. 110.

This comet reappeared in August, 1852, as a double comet, the distance of the two bodies from each other being about 1,500,000 miles.

This comet was not seen in 1866, although its perihelion passage should have occurred in January, when its position is the most favorable for observation.

It has been found by computation that near the close of December, 1845, Biela's comet passed extremely near and probably *through* the stream of November meteors. (Art. 374.) It has been conjectured that this collision may have produced the separation of this comet into two parts; and that, by subsequent encounters in 1859 and 1866, it may have been farther subdivided and dissipated, so as to be permanently lost to our view.

Faye's Comet.

361. In 1843, M. Faye, of the Paris Observatory, discovered a comet, and determined its orbit to be an ellipse with a period of only 7½ years. Its succeeding return to perihelion was predicted for April 3, 1851, and it arrived within about a day of the time predicted. The comet made its third appearance in September, 1858, and its fourth appearance in 1865, and its observed positions agreed almost exactly with those which had been predicted, showing that this body does not encounter any appreciable resistance.

The distance of Faye's comet from the sun at perihelion is 154 millions of miles, and at aphelion 542 millions. This comet is remarkable as having an orbit approaching nearer in form to the orbits of the planets than any other cometary orbit known, its eccentricity being only $\frac{55}{100}$.

Brorsen's Comet.

362. In February, 1846, Mr. Brorsen, of Denmark, discovered a telescopic comet, which has been found to revolve around the sun in about 5½ years. In March, 1857, it was again observed on its return to perihelion; and its third return to perihelion was observed in April, 1868, at which time the comet was found within one degree of the place previously computed.

The distance of this comet from the sun at perihelion is 60 millions of miles, being less than the distance of Venus; and at aphelion 516 millions, which is somewhat greater than the distance of Jupiter. The orbit of this comet, when projected on the ecliptic, is included wholly within that of Biela.

D'Arrest's Comet.

363. In 1851, Dr. D'Arrest, of Leipsic, discovered a faint telescopic comet whose orbit was computed to be an ellipse, having a period of 6.4 years. The comet was observed again on its return to perihelion in November, 1857, according to prediction. Owing to its unfavorable position, the comet was not seen in 1864, but it is predicted that it will return again to perihelion September 22, 1870, under circumstances extremely favorable for observation.

The distance of this comet from the sun at perihelion is 107 millions of miles, and at aphelion 524 millions.

Winnecke's Comet.

364. In 1819, M. Pons, at Marseilles, discovered a comet whose orbit was computed to be an ellipse, with a period of 5.6 years. This comet was rediscovered in 1858 by Dr. Winnecke, at Bonn, having made seven revolutions since its apparition in 1819, showing the time of one revolution to be 5.54 years. Owing to its unfavorable position, this comet was not seen in 1863, but it is expected to be seen again in 1869.

The distance of this comet from the sun at perihelion is 70 millions of miles, and at aphelion 505 millions.

The orbits of the six periodical comets last mentioned show a striking resemblance to each other. The direction of their motion about the sun is the same as that of the planets, and they move in planes not more inclined to the ecliptic than the orbits of the asteroids. In the dimensions and positions of their orbits, in the degree of their eccentricity as well as in the direction of their motions, they show a family resemblance nearly as decided as that between the different individuals of the group of asteroids.

The Comet of 1744.

365. The comet of 1744 was remarkable for the brilliancy of its head and for the complexity of its train. When near perihelion the head was seen with a telescope at midday, and it was seen with the naked eye some time after sunrise. The tail also exhibited remarkable curvature, and spread out like a fan divided into several branches, presenting the appearance of six tails, which extended from 30° to 44° from the head of the comet. See Fig. 105.

The distance of this comet from the sun at perihelion was but little more than one half the mean distance of Mercury, and the form of the orbit is sensibly parabolic.

The Comet of 1770.

366. The comet of 1770 is remarkable for its near approach to the Earth and Jupiter, and the consequent changes in the form of its orbit. From the observations made in 1770, its orbit was computed to be an ellipse, with a period of $5\frac{1}{2}$ years; still, though a very bright comet, it had not been seen before 1770, and has not been seen since.

By tracing back the comet's path, it was found that in 1767 it passed near Jupiter, and the attraction of that planet had changed its orbit from a very large to a very small ellipse. Previous to 1767 its perihelion distance was about 300 millions of miles, at which distance it could never be seen from the earth.

Moreover, this comet has not been seen since 1770. On its return to perihelion in 1776, the comet was at a great distance from the earth, and continually hid by the sun's rays; and before its next return it again passed so near to Jupiter that its orbit was greatly enlarged, and its perihelion distance again became about 300 millions of miles, so as to be invisible from the earth.

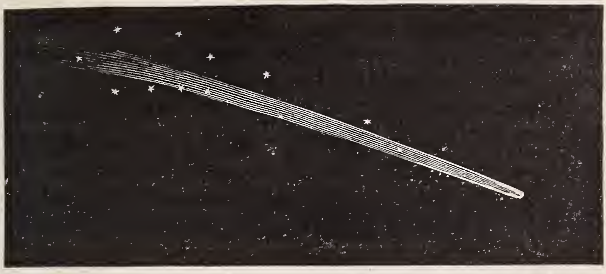
367. *Mass of this Comet.*—In July, 1770, this comet made a nearer approach to the earth than any other comet on record, its distance being only 1,400,000 miles. It has been computed that if the mass of this comet had been equal to that of the Earth, it would have changed the Earth's orbit to such an extent as to have increased the length of the year by 168 minutes. But astronomical observations show that the length of the year has not been increased so much as *two seconds;* from which it follows that the mass of this comet can not have been so great as $\frac{1}{5000}$th of the mass of the Earth.

The mass of the comet must have been smaller than this estimate; for, although the comet approached Jupiter within a distance less than that of his fourth satellite, the motions of the satellites were not sensibly disturbed.

The Great Comet of 1843.

368. This comet was remarkable for its brilliancy, and for its near approach to the sun. On the 28th of February it was seen at midday close to the sun, and soon after this it became a very conspicuous object in the evening twilight. Its tail attained a length of 120 millions of miles, and subtended an angle of from 50 to 70 degrees.

Fig. 111.



At perihelion this comet came within 70,000 miles of the sun's surface, and the heat to which it was subjected explains the enormous length of its tail, and the rapidity with which it was formed.

The best computations indicate that this comet moves in an elliptic orbit, with a period of about 170 years.

Donati's Comet of 1858.

369. This was the most brilliant comet which has appeared since 1843, and was remarkable for the changes in its nebulous envelopes. (Art. 342.) The tail attained a length of 50 millions of miles, and subtended an angle of 60°. The nucleus was uncommonly large and was intensely brilliant. Its perihelion distance was 50 millions of miles; its orbit is elliptical, and its period about two thousand years.

Fig. 112.

370. *Is it possible for a Comet to strike the Earth?*—Since comets move through the planetary spaces in all directions, it is possible that the Earth may some time come in collision with one of them. The comet of 1770 passed within 1,400,000 miles of the earth. The first comet of 1864 passed within 600,000 miles of the Earth's orbit; and Biela's comet passes so near, that a portion of the Earth's orbit must at times be included within the nebulosity of the comet.

The consequences which would result from a collision between the Earth and a comet would depend upon the mass of the comet. If the comet had no solid nucleus, it is probable that it would be entirely arrested by the earth's atmosphere, and no portion of it might reach the earth's surface. Shooting stars and aerolites are probably comets, or portions of comets so small as to be invisible before penetrating the earth's atmosphere.

Shooting Stars.

371. Sometimes, upon a clear evening, we observe a bright object, in appearance resembling a planet or a fixed star, shoot rapidly across the sky and suddenly vanish. This phenomenon is known by the name of shooting star or falling star. They may be seen on every clear night, and at times follow each other so rapidly that it is quite impossible to count them. They generally increase in frequency from the evening twilight throughout the night until the morning twilight, and when the light of day does not interfere, they are most numerous about 6 A.M.

372. *Height, Velocity, etc.*—By means of simultaneous observations made at two or more stations at suitable distances from each other, we may determine their height above the earth's surface, the length of their paths, and the velocity of their motion. It is found that they begin to be visible at an average elevation of 74 miles, and they disappear at an average elevation of 52 miles. The average length of their visible paths is 28 miles. The average velocity relative to the earth's surface, for the brighter class of shooting stars, amounts to about 30 miles per second; and they come in the greatest numbers from that quarter of the heavens toward which the earth is moving in its annual course around the sun.

373. *Meteoric Orbits, etc.*—Having determined the velocity and direction of a meteor's path with reference to the earth, we can compute the direction and velocity of the motion with reference to the sun. In this manner it has been shown that these bodies, before they approached the earth, were revolving about the sun in ellipses of considerable eccentricity. In some instances the velocity has been so great as to indicate that the path differed little from a parabola.

It is thus demonstrated that ordinary shooting stars are small bodies moving through space in paths similar to the comets; and it is probable that they do not differ materially from the comets except in their dimensions, and perhaps, also, in their density.

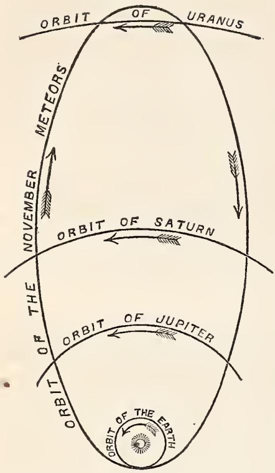
Their light is probably due to the high temperature resulting from the resistance of the air to the rapid motion of the meteor. It is true that, at the ordinary elevation of shooting stars, the air is exceedingly rare; but the resistance of this air suffices entirely to destroy the motion of a body moving about 30 miles per second, and the heat thus developed must be sufficient to melt or disintegrate the meteor.

374. *Periodic Meteors of November.*—In the year 1833, shooting stars appeared in extraordinary numbers on the morning of November 13th. It was estimated that they fell at the rate of 575 per minute. Most of these meteors moved in paths which, if traced backward, would meet in a point situated near Gamma, in the constellation Leo. A similar exhibition took place on the 12th of November, 1799, and there are recorded ten other similar appearances at about the same season of the year.

There was a repetition of this remarkable display of meteors on the morning of November 14th, 1866, when the number amounted to 120 per minute; also November 14th, 1867, when the number of meteors for a short time amounted to 220 per minute; and November 14, 1868, the display of meteors was about equally remarkable.

375. *Period of the November Meteors.*—The great displays of November meteors recur at intervals of about one third of a century, but a considerable display may occur on

Fig. 113.



three consecutive years. It is concluded that these meteors belong to a system of small bodies describing an elliptic orbit about the sun, and extending in the form of a stream along a considerable arc of that orbit, and making a revolution about the sun in 33 years.

376. *The Periodical Meteors of August.*—Meteors appear in unusual numbers about the 10th of August, when the number is five times as great as the average for the entire year. They seem chiefly to emanate from a fixed point in the constellation Perseus.

The August meteors are believed to describe a very large elliptic orbit about the sun, extending considerably beyond the orbit of Neptune; and the meteors are spread over the entire circumference of this orbit, but not in equal numbers.

Detonating Meteors.

377. Ordinary shooting stars are not accompanied by any audible sound, although they are sometimes seen to break into pieces. Occasionally meteors of extraordinary brilliancy are succeeded by a loud explosion, followed by a noise like that of musketry or the discharge of cannon. These have been called detonating meteors.

On the morning of November 15th, 1859, a meteor passed over the southern part of New Jersey, and was so brilliant that the flash attracted general attention in the presence of an unclouded sun. Soon after the flash there was heard a series of terrific explosions, which were compared to the discharge of a thousand cannon. From a comparison of numerous observations, it was computed that the height of this meteor when first seen was over 60 miles; and when it exploded its height was 20 miles. The length of its visible path was more than 40 miles. Its velocity relative to the earth was at least 20 miles per second, but its velocity relative to the sun was about 28 miles per second, indicating that it was moving about the sun in a very eccentric ellipse, or perhaps a parabola.

378. *Number, Velocity, etc.* — The number of detonating meteors recorded in scientific journals is over 800. Their average height at the instant of apparition is 92 miles, and at the instant of vanishing is 32 miles. Their average velocity relative to the earth is 19 miles per second.

An unusual number of detonating meteors has been seen about November 13th and August 10th. This coincidence, taken in connection with the results obtained respecting their paths and velocities, leads us to conclude that both belong to the same class of bodies, and that they probably do not differ much from each other except in size and perhaps in density. The noise which succeeds their appearance is probably, in great part, due to the collapse of the air rushing into the vacuum which is left behind the advancing meteor. No audible sound proceeds from ordinary shooting stars, because they are bodies of small size or of feeble density, and are generally consumed while yet at an elevation of 50 miles above the earth's surface.

Aerolites.

379. Ordinary shooting stars are consumed or dissipated before reaching the denser part of the earth's atmosphere, but occasionally one is large enough and dense enough to penetrate entirely through our atmosphere and reach the surface of the earth. These bodies are called *aerolites.* When they present mainly a stony appearance, they are called *meteoric stones;* when they are chiefly metallic, they are called *meteoric iron.* Numerous examples of aerolites have been recorded.

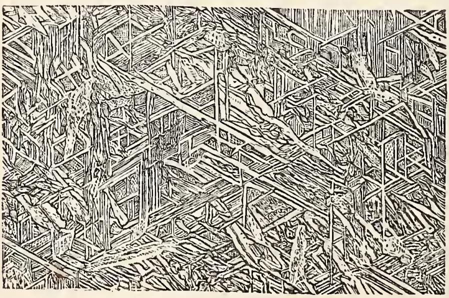
380. *The Weston Aerolite.*—In December, 1807, a meteor of great brilliancy passed over the southern part of Connecticut, and soon after its disappearance there were heard three loud explosions like those of a cannon, and there descended numerous meteoric stones. The entire weight of all the fragments discovered was at least 300 pounds. Their specific gravity was 3.6; their composition was one half silex, one third oxide of iron, and the remainder chiefly magnesia. The length of the visible path of this meteor exceeded 100 miles, and its velocity relative to the earth was about 15 miles per second.

381. *Number and Composition of Aerolites.*—There are 19 well-authenticated cases in which aerolites have fallen in the United States, and their aggregate weight is 1250 pounds. The entire number of known aerolites, the date of whose fall is well determined, is 262, and there are many more the date of whose fall is uncertain. Besides these there have been found 86 masses, which, from their peculiar composition, are believed to be aerolites, although the date of their fall is unknown. The weight of these masses varies from a few pounds to several tons.

Aerolites are composed of the same elementary substances as occur in terrestrial minerals, not a single new element having been found in their analysis; yet they differ greatly in the proportions of these ingredients. Some contain 96 per cent. of iron, while others contain less than one per cent. The appearance of aerolites is quite peculiar, and the grouping of the elements—that is, the compound formed by them, is so peculiar as to enable us, by chemical analysis, to distinguish an aerolite from any terrestrial substance.

382. *Widmannstäten Figures.*—Meteoric iron possesses a

Fig. 114.



highly crystalline structure. If the surface be carefully polished, and the mass be heated to a straw yellow, after cooling, the surface will be covered with lines and streaks having considerable regularity in their position. Often we find a system of lines nearly parallel with each other, intersected by others at angles of sixty degrees, forming triangles nearly equilateral. The same figures can also be developed by the use of acids.

Ordinary iron will not exhibit these figures, but iron melted directly out of some volcanic rocks does exhibit them.

383. *Origin of Aerolites.*—It has been conjectured that aerolites are masses ejected from *terrestrial volcanoes.* This supposition is inadmissible, because the greatest velocity with which stones have ever been ejected from volcanoes is less than two miles per second, and the direction of this motion must be nearly vertical, while aerolites frequently move in a direction nearly horizontal, and with a velocity of several miles per second.

It has been conjectured that aerolites have been ejected from *volcanoes in the moon* with a velocity sufficient to carry them out of the sphere of the moon's attraction into that of the earth's attraction. It has been estimated that if an indefinite number of bodies were projected from the moon in all directions and with different velocities, not one in a million would have precisely that direction and that rate of motion which would be requisite to allow it to reach the earth. We can not, then, admit that lunar volcanoes have ejected rocks in such quantities as to account for the known aerolites, especially as the lunar volcanoes are to all appearance nearly, if not entirely extinct.

384. *Conclusions.*—A comparison of all the facts which are known respecting shooting stars, detonating meteors, and aerolites, leads to the conclusion that they are all minute bodies revolving like the comets in orbits about the sun, and are encountered by the Earth in its annual motion. The visible path of aerolites is somewhat nearer to the earth's surface than that of ordinary shooting stars, a result which may be ascribed to their greater size or greater density. It is probable also that the velocity with which they describe their visible path is somewhat less than that of ordinary shooting stars, a result which may be due to their descending into an atmosphere of greater density, which causes, therefore, greater resistance to their motion.

CHAPTER XVI.

THE FIXED STARS—THEIR DISTANCE AND THEIR MOTIONS.

385. *What is a Fixed Star?*—The fixed stars are so called because from century to century they preserve almost exactly the same positions with respect to each other. Many of the stars form groups which are so peculiar that they are easily identified, and the relative positions of these stars are nearly the same now as they were two thousand years ago. Accurate observations, however, have shown that great numbers of them have a slow progressive motion along the sphere of the heavens. This change of place is quite small, there being only about 30 stars whose motion is as great as one second in a year, and generally the motion is only a few seconds in a century.

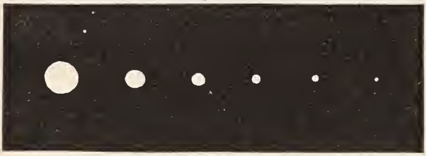
386. *How the Fixed Stars are classified.*—The stars are divided into classes, according to their different degrees of apparent brightness. The brightest are termed stars of the *first magnitude;* those which are next in order of brightness are called stars of the *second magnitude*, and so on to stars of the *sixth magnitude*, which includes all that can be distinctly located by the naked eye. Stars smaller than the sixth magnitude are called *telescopic* stars, being invisible without the assistance of the telescope. Telescopic stars are classified in a similar manner down to the twelfth, and even smaller magnitudes.

According to the best authority, the number of stars of the first magnitude is 20; of the second magnitude, 34; of the third, 141; fourth, 327; fifth, 959; and sixth, 4424; making 5905 stars visible to the naked eye. Of these, only about one half can be above the horizon at one time, and it is only on the most favorable nights that stars of the sixth magnitude can be clearly distinguished by the naked eye.

The number of stars of the seventh magnitude is estimated at 13,000; of the eighth magnitude, 40,000; and ninth magnitude, 142,000; making about 200,000 stars from the first to the ninth magnitude. It is estimated that the number of stars visible in Herschel's reflecting telescope of 18 inches' aperture was more than 20 millions, and the number visible in larger telescopes is still greater.

387. *Comparative Brightness of the Stars.*—Sir W. Herschel estimated that the average brightness of stars from the first to the sixth magnitude might be represented approximately by the numbers 100, 25, 12, 6, 2, 1. Fig. 115 is designed to give an idea of the relative brightness of stars of the first six magnitudes.

Fig. 115.



It is probable that these varieties of brightness are chiefly caused by difference of distance rather than by difference of intrinsic splendor. Those stars which are nearest to our solar system appear bright in consequence of their proximity, and are called stars of the first magnitude; those which are farther off are more numerous and appear less bright; and thus, as the distance of the stars increases, their apparent brightness diminishes, until at a certain distance they become invisible to the naked eye.

388. *Have the Fixed Stars a sensible Disc?*—When Jupiter or Saturn is viewed with a telescope, the planet appears with a considerable disc, like that which the moon presents to the naked eye, but it is different even with the brightest of the fixed stars. A bright star, viewed by the naked eye, generally appears to subtend an appreciable angle, but the telescope exhibits it as a lucid point of very small diameter, even when the highest magnifying powers are employed. With a power of 6000, the apparent diameter of the star seems *less* than with lower powers.

The term *magnitude*, applied to the fixed stars, designates simply their relative *brightness.* None of the stars have any measurable magnitude at all. The quantity of light which they emit leads us to infer, however, that their absolute diameters are very great, and hence we conclude that their distance is so enormous that their apparent diameter, seen from the earth, is 6000 times less than the smallest angle which the naked eye is capable of appreciating.

389. *Division into Constellations.*—In order to distinguish the fixed stars from each other, they have been divided into groups called *constellations.* These constellations are imagined to form the outlines of figures of men, of animals, or of other objects. In a few instances the arrangement of the stars may be conceived to bear some resemblance to the object from which the constellation is named, as, for example, the Swan and the Scorpion, while in most instances no such resemblance can be traced. This mode of grouping the stars is of great antiquity, and the names given by the ancients to individual constellations are still retained.

390. *Names of the Constellations.*—The constellations are divided into three classes—*northern* constellations, *southern* constellations, and constellations of the *zodiac.*

There are twelve constellations lying upon the zodiac, and hence called the *zodiacal constellations*, viz., Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, and Pisces. These are also the names of the *signs* of the zodiac, or portions of 30° each into which the ecliptic has been divided; but the effect of precession, which throws back the place of the equinox 50″ a year, has caused a displacement of the signs of the zodiac with respect to the constellations bearing the same names. The vernal equinox, or first point of the sign Aries, is near the beginning of the constellation Pisces, the sign Taurus is in the constellation Aries, and so on, the signs having retreated among the stars 30° since the present division of the zodiac was adopted.

The principal constellations north of the zodiacal constellations are:

Andromeda.	Cassiopeia.	Draco.	Perseus.
Aquila.	Cepheus.	Hercules.	Serpentarius.
Auriga.	Corona Borealis.	Lyra.	Ursa Major.
Boötes.	Cygnus.	Pegasus.	Ursa Minor.

The principal constellations south of the zodiacal constellations are:

Argo Navis.	Cetus.	Ophiuchus.
Canis Major.	Crux.	Orion.
Canis Minor.	Eridanus.	Phœnix.
Centaurus.	Hydra.	Piscis Australis.

Others will be found upon celestial globes and charts, raising the total number of constellations generally recognized by astronomers to eighty-six.

391. *How individual Stars are designated.*—Many of the brighter stars had proper names assigned them at a very early date, as Sirius, Arcturus, Regulus, Rigel, etc., and by these names they are still commonly distinguished.

In 1604, Bayer, a German astronomer, published maps of the heavens, in which the stars of each constellation were distinguished by the letters of the Greek and Roman alphabets, the brightest being denoted by α, the next β, and so on. Thus Alpha (α) Lyræ denotes the brightest star in the constellation Lyra, Beta (β) Lyræ the second star, and so on.

Flamsteed, the first astronomer royal at Greenwich, distinguished the stars of each constellation by the numerals 1, 2, 3, etc., in the order of their right ascensions.

392. *Remarkable Constellations enumerated.*—One of the most conspicuous constellations in the northern firmament is Ursa Major, or the Great Bear, in which we find seven bright stars, which may easily be conceived to form the outline of a *dipper* with a curved handle, four of the stars forming the bowl and three the handle. The two stars on the side of the bowl opposite to the handle are called the *pointers*, because a straight line drawn through them passes nearly through the pole star. The dipper is within the circle of perpetual apparition at New York, and hence is visible at all seasons of the year, although in different positions as it revolves around the pole.

The constellation Ursa Minor contains seven small stars, which may also be conceived to form the outline of a *small dipper*, which occupies a reversed position from that of the Great Dipper, the pole star forming the extremity of the handle.

The constellation Cassiopeia presents five stars of the third magnitude, which, with one or two smaller ones, may be conceived to form the outline of a *chair*. It is situated on the opposite side of the pole from the Great Dipper. The principal stars of these three constellations are represented in Fig. 2, page 15.

The *square* of Pegasus is formed by four bright stars situated at the angles of a large square about 15° upon each side. The equinoctial colure passes very nearly through the two most easterly stars of this square.

In the constellation Cygnus are five stars so arranged as to form a large and regular *cross*, the one at the northern extremity being a star of the first magnitude.

In the constellation Leo are six bright stars, presenting the form of a *sickle;* Regulus, a star of the first magnitude, being at the extremity of the handle.

Fig. 116.

In the head of Taurus are several stars called the *Hyades*, presenting the outline of the letter V; Aldebaran, a ruddy star of the first magnitude, being situated at the most eastern extremity of the letter. About 12° to the northwest is a group of stars called the *Pleiades*. The naked eye discovers six or seven stars, but in the telescope upward of 200 are visible.

The constellation Orion presents four bright stars in the form of a long quadrangle, near the middle of which are three bright stars arranged at equal distances in a straight line, pointing on the east side to Sirius, the most splendid star in the heavens, and on the west side to the Hyades and the Pleiades. These three stars are called the *belt* of Orion, and sometimes the *Ell and yard*. See Fig. 116.

393. *Catalogues of Stars.*—Various catalogues of stars have been formed, in which are indicated their right ascensions and declinations, and sometimes their longitudes and latitudes. Hipparchus, 128 years before the Christian era, constructed the first catalogue of stars of which we have any knowledge. His catalogue included 1022 stars. Modern catalogues contain over 200,000 stars.

394. *Periodic Stars.*—Some stars exhibit periodical changes of brightness, and are therefore called *periodic* stars. One of the most remarkable of this class is the star Omicron Ceti, commonly called *Mira*, or the wonderful star. This star retains its greatest brightness for about two weeks, being then usually a star of the second magnitude. It then gradually decreases, and in about two months ceases to be visible to the naked eye, and in about three months more becomes reduced to the ninth or tenth magnitude. After remaining invisible to the naked eye for six or seven months, it reappears, and increases gradually for two months, when it recovers its maximum splendor. It generally goes through all its changes in 332 days, but this period has fluctuated from 317 to 350 days.

Another remarkable periodic star is Algol, in the constellation Perseus. For a period of about 61 hours it appears as a star of the second magnitude, after which it begins to diminish in brightness, and in less than four hours is reduced to a star of the fourth magnitude, and thus remains about twenty minutes. It then begins to increase, and in about four hours more it recovers its original splendor, going through all its changes in 2d. 20h. 49m.

There are more than 100 stars known to be variable to a greater or less extent. The periods of these changes vary from a few days to many years.

395. *Temporary Stars.*—Several instances are recorded of stars appearing suddenly in the heavens where none had before been observed, and afterward fading gradually away without changing their positions among the other stars. Such a star appeared in 1572 in the constellation Cassiopeia. When brightest it surpassed Jupiter, and was distinctly visible at midday. In sixteen months it entirely disappeared, and has not been seen since.

A similar example was recorded by Hipparchus 125 B.C.; another in 389 A.D., in the constellation Aquila; others occurred in the years 949, 1264, 1604, 1670, and 1848.

In the year 1866, a star in Corona Borealis, which some years ago was of the ninth magnitude, suddenly flashed up and shone as a star of the second magnitude. In a week it changed to the fourth magnitude, and in a month afterward it returned to the ninth magnitude.

It is possible that the temporary stars do not differ from the periodic stars except in the length of their periods.

396. *Explanation of Periodic Stars.*—The phenomena of periodic stars have been explained, 1st, by supposing that they have the form of thin flat discs, and, by rotation upon an axis, present to us their edge and their flat side alternately, thereby producing corresponding changes of brightness. This hypothesis will not explain the sudden changes in the brightness of Algol, nor the inequality in the periods of Mira.

2d. It has been supposed that a dark opaque body may revolve about the variable star so as at times to intercept a portion of its light. This hypothesis will explain the general phenomena of Algol, but it will not explain the long-continued obscuration of Mira.

3d. It has been supposed that a nebulous body of great extent may revolve around the variable star so as at times to intercept a portion of its light. This hypothesis may be made to accommodate itself so as to explain the phenomena of most of the periodic stars.

4th. The variable star may not be uniformly luminous upon every part of its surface, but, by rotation upon an axis, may occasionally present to the earth a disc partially covered with dark spots, and shining therefore with a dimmer light. This hypothesis will not explain the sudden changes in the brightness of Algol, nor will it explain the fluctuations in the period of Mira, or in the maxima and minima of its brightness, unless we admit that the dark spots upon its surface are variable, like the dark spots upon our sun.

If we suppose that spots are periodically developed upon the surface of the variable star similar to those which are observed upon our sun, but of vastly greater extent, the phenomena of most of the variable stars may be explained.

397. *Distance of the Fixed Stars.*—The following consideration proves that the distance of the fixed stars from the earth must be immense. The Earth, in its annual course around the sun, revolves in an orbit whose diameter is 183 millions of miles. The station from which we observe the stars on the 1st of January is distant 183 millions of miles from the station from which we view them on the 1st of July; yet, from these two remote points, the stars are seen in the same relative positions and of the same brightness, proving that the diameter of the Earth's orbit must be a mere point compared with the distance of the nearest stars.

398. *Annual Parallax.*—The greatest angle which the radius of the Earth's orbit subtends at a fixed star is called its annual parallax. If the annual parallax of a star were known, we could compute its distance from the earth, for we should know the angles and one side of a right-angled triangle, from which the other sides could be computed. If a fixed star had any appreciable parallax, it could be detected by a comparison of the places of the star as observed at opposite seasons of the year. Such observations have been made upon an immense number of stars, but, until recently, none of them have shown any measurable parallax. These observations are made with such accuracy that if the parallax amounted to so much as one second, it could not have escaped detection. Hence we conclude that the annual parallax of every fixed star which has been carefully observed is *less than one second.*

399. *Parallax of Alpha Centauri.*—Observations made upon the star Alpha Centauri, one of the brightest stars of the southern hemisphere, indicate an annual parallax of $\frac{92}{100}$ths of a second. Having determined the parallax, we compute the distance of the star by the proportion

sin. $0''.92 : 1 :: 92$ millions of miles : the distance of the star, which is found to be *twenty millions of millions* of miles. This distance is so immense that a ray of light, which would make the circuit of our globe in *one eighth of a second*, requires more than three years to travel from this star to the earth. We do not see the star as it actually is, but as it was more than three years ago. Hence, if this star were obliterated from the heavens, we should continue to see it for more than three years after its destruction; yet Alpha Centauri is probably our nearest neighbor among the fixed stars.

400. *How differences of Parallax may be detected.*—This method consists in finding the *difference* between the parallaxes of a given star and some other star of much smaller magnitude, which is therefore supposed to be at a much greater distance. This difference is found by measuring with a micrometer the annual changes in the distance of the two stars, and in the position of the line which joins them. The difference of the parallaxes will differ from the absolute parallax of the nearest star by only a small part of its whole amount.

By this indirect method a much smaller angle of parallax can be detected than by the direct method employed in Art. 398, for the angular distance between two neighboring stars can be measured within a small fraction of a second; and, since both stars are seen in nearly the same direction, they will be equally affected by refraction, aberration, precession, and nutation. The relative situation of the two stars is therefore independent of most of the errors that are inevitably committed in determining the absolute places of the stars by means of their right ascensions and declinations.

401. *Parallax of* 61 *Cygni.*—By the method here indicated, the parallax of the star 61 Cygni was determined by the great astronomer Bessel. Observations of the same star, since made by several other astronomers, give nearly the same result. The mean of all the observations is $0''.45$, indicating a distance of 42 millions of miles, a space which light would require *seven years* to traverse.

402. *Parallax of other Stars.*—No other star has yet been found whose parallax exceeds about one quarter of a second. Sirius and Alpha Lyræ have apparently a parallax of about a quarter of a second, and observations have indicated about an equal parallax in four other small stars. All the other stars of our firmament are apparently at a greater distance from us; and if the distance of the nearest stars is so great, we must conclude that those faint stars, which are barely discernible in powerful telescopes, are much more distant. Hence we conclude that we do not see the stars as they now are, but as they were years ago—perhaps, in some instances, with the rays which proceeded from them several thousand years ago. The changes which we observe in the periodic and temporary stars do not indicate changes actually going on in the stars at the time of the observations, but rather those which took place years—perhaps centuries ago.

403. *Magnitude of the Fixed Stars.*—The fixed stars must be *self-luminous*, for no light reflected from our sun could render them visible at such enormous distances from us. Indeed, it is demonstrable that many of the fixed stars actually emit as much light as our sun. It is estimated that the light of our sun is 450,000 times greater than that of the full moon, and that the light of the full moon is 13,000 times greater than that of Sirius—that is, the light of the sun is about 6000 million times greater than that of Sirius. Since the quantity of light which the eye receives from a star varies inversely as the square of its distance, and since the distance of Sirius is 800,000 times that of the sun, it follows that, if Sirius were brought as near to us as the sun, its light would be 640,000 million times as great as it appears at present—that is, the light emitted by Sirius is a hundred times that emitted by our sun.

A similar comparison shows us that Alpha Lyræ emits more light than our sun, and probably the same is true of many other of the fixed stars. We may also infer that many of the stars are larger than our sun—that is, are more than a million of miles in diameter, otherwise the intensity of their illumination must be much greater than that of our sun. The fixed stars, therefore, are not mere brilliant points of light, but material bodies of vast size and intensely luminous—that is, they are *suns;* and our own sun appears so conspicuous in size and brilliancy only because it is comparatively near to us.

404. *Physical Constitution of the Stars.*—When the light of a fixed star is passed through a prism, it exhibits a spectrum bearing a general resemblance to that of our sun, but crossed by a system of dark lines, some of which are common to nearly all the stars, while others belong only to particular stars. The position of these lines is considered as proving that several elementary substances which are common upon the earth are also found in the atmospheres of the fixed stars. The substances most widely diffused among the stars are sodium, magnesium, iron, and hydrogen. These observations lead to the conclusion that the stars have a physical constitution analogous to that of our sun, and, like it, contain several elementary forms of matter which enter into the composition of the earth.

405. *Proper Motion of the Stars.*—After allowing for the effects of precession, aberration, and nutation upon the position of the stars, it is found that many of them have a progressive motion along the sphere of the heavens from year to year. This motion is called their *proper* motion. The velocity and direction of this motion continue from year to year the same for the same star, but are very different for different stars. One star of the seventh magnitude is traveling thus at the rate of seven seconds in a year. The star 61 Cygni, whose parallax has been determined (Art. 401), is moving at the rate of five seconds annually. The star Alpha Centauri has a proper motion of nearly four seconds annually, and most of the brighter stars of the firmament have a sensible proper motion. The result of this motion is a slow but constant change in the figures of the constellations. In the case of several stars this change in 2000 years has amounted to a quantity easily perceived by the naked eye. The proper motion of Arcturus in 2000 years has amounted to more than one degree; that of Sirius and Procyon to two thirds of a degree.

406. *Cause of this proper Motion.*—The proper motion of a star may be ascribed to two different causes. Either the star may have a *real* motion through space, such as it appears to us, or this apparent motion may be caused by a real motion through space of the sun, attended by the planets, this motion being in a direction opposite to the apparent motion of the star. On extending the inquiry to a great number of stars, we find that both causes must be in existence; that the solar system *is traveling through space*, and thus produces an apparent displacement of all the nearer stars, while some, and probably all the stars, have a real motion through space.

407. *Motion of the Solar System through Space.*—If we suppose the sun, attended by the planets, to be moving through space, we ought to be able to detect this motion by an apparent motion of the stars in a contrary direction, as when an observer moves through a forest of trees, his own motion imparts an apparent motion to the trees in a contrary direction. The stars which are nearest to us would be most affected by such a motion of the solar system, but they should all appear to recede from A, that point of the

Fig. 117.

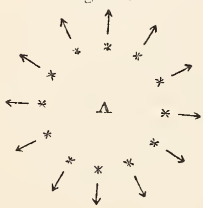
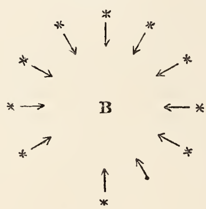


Fig. 118.



heavens *toward* which the sun is moving, while in the opposite quarter, B, the stars would become crowded more closely together.

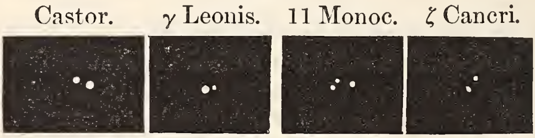
408. *Direction of the Sun's Motion.*—In 1783, Sir William Herschel announced that a part of the proper motion of the fixed stars could be explained by supposing that the sun has a motion toward a point in the constellation Hercules. More recent and extensive investigations have not only established the fact of the solar motion, but likewise indicated a direction very nearly the same as that assigned by Herschel, viz., toward the star ρ Herculis. Struve estimates that the motion of the sun in one year is about 150 millions of miles, which is about one fourth of the velocity of the Earth in its orbit, or five miles per second; but Airy makes the velocity of our solar system about twenty-seven miles per second.

409. *Motion of Revolution of the Stars.*—It is probable that the solar system does not advance from age to age in a straight line, but that it revolves about the centre of gravity of the group of stars of which it forms a member. This centre of gravity is probably situated in the principal plane of the Milky Way; and if the orbit of the sun is nearly circular, this centre must be about 90° distant from ρ Herculis, the point toward which the solar system is moving—that is, in the constellation Perseus. Maedler conjectured that the brightest star in the Pleiades was the central sun of our firmament, but without sufficient reason. The orbit of the solar system is probably so large that ages may elapse before it will be possible to detect any change in the direction of the sun's motion.

410. *Velocity of proper Motion of the Stars.*—For a star situated at right angles to the direction of the sun's motion, and placed at the mean distance of stars of the first magnitude, it is estimated that the angular displacement due to the sun's motion is one third of a second per year. Hence we conclude that when the proper motion of a star exceeds this amount, the excess must be due to a real motion of the star in space. In the case of the star 61 Cygni, nearly $5''$ of its annual proper motion must result from an actual motion in space, which motion has been computed to be at least 42 miles per second. In a similar manner we find that many other of the fixed stars have a motion in space more rapid than that of our sun.

411. *Double Stars.*—Many stars which, to the naked eye or with telescopes of small power, appear to be single, when examined with telescopes of greater power are found to consist of two stars in close proximity to each other. These are called *double stars.* Some of these are resolved into separate stars by a telescope of moderate power, as Castor, which consists of two stars of the third or fourth magnitude, at the distance of 5″ from each other. Many of them, however, can only be separated by the most powerful telescopes.

Fig. 119.



Some stars, which to ordinary telescopes appear only double, when seen through more powerful instruments are found to consist of three stars, forming a *triple* star; and there are also combinations of four, five, or more stars in close proximity, forming *quadruple*, *quintuple*, and *multiple* stars. Only four double stars were known until the time of Sir W. Herschel, who discovered upward of 500, and later observers have extended this number to 6000.

Double stars are divided into classes according to the distance between the two components, those in which the distance is least forming the first class.

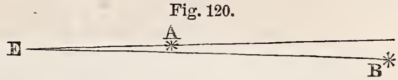
412. *Comparative Size.*—In some instances the two components of a double star are of equal brilliancy, but generally one star is brighter than the other. This inequality frequently amounts to three or four magnitudes, occasionally to seven or eight; and Sirius, the brightest star of the heavens, is attended by a minute companion-star estimated to be of the fourteenth magnitude.

413. *Color of the Stars.*—Many stars shine with a colored light. Thus the light of Sirius is white, that of Aldebaran is red, and that of Capella is yellow.

In numerous instances, the two components of a double star shine with different colors, and frequently these colors are complementary to each other—that is, if combined, they would form white light. Combinations of blue and yellow or green and yellow are not uncommon, while in fewer cases we find one star white and the other purple, or one white and the other red. In several instances each star has a rosy light.

414. *Stars optically Double.*—If two stars are nearly in the same line of vision, though one is vastly more distant from us than the other, they will form a star *optically* double, or one whose components appear in close proximity, simply in consequence of the direction from which they are viewed. Thus the two stars A and B, seen from the earth at E, will appear in close proximity, although they may be separated by an interval greater than the distance of the nearest from the earth. If the stars were scattered fortuitously over the firmament, the chances are against any two of them having a position so close to each other as 4″, yet many such cases of proximity are known to exist. It is probable, then, that in most cases the two components of a double star are at about the same distance from the sun.

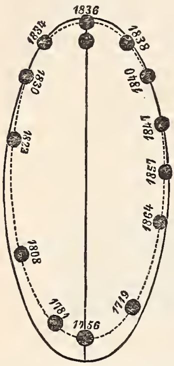
Fig. 120.



415. *Binary Stars.*—In the year 1780, Sir W. Herschel undertook an extensive series of observations of double stars, measuring the apparent distance of the components from each other, and also their relative position. By this means he hoped to be able to detect an annual variation, depending upon parallax as explained in Art. 400. He found, indeed, a change in the distance and relative position of the two components, but this change could not be ascribed to the Earth's motion about the sun. He ascertained that the change was produced by a motion of revolution of one star around the other, or of both around their common centre of gravity, and he announced that there are sidereal systems composed of two stars revolving about each other in regular orbits. These stars are termed *physically* double, or *binary stars*, to distinguish them from other double stars in which no such periodic change of position has been discovered.

416. *Periods and Orbits of Binary Stars.*—The orbits of several of the binary stars and the lengths of their periods have been satisfactorily determined. The orbits are ellipses of considerable eccentricity, and the periods vary from 36 years to many centuries. In Fig. 121 the dotted line represents the apparent orbit of one of the stars about the other, while the black line represents the form of the actual orbit as computed. The major axis of the ellipse is 7″, and the period of revolution is 145 years. The star Alpha Centauri consists of two components, one of the first, the other of the second magnitude, which revolve about each other in an ellipse whose major axis is about 30″, and period about 80 years.

Fig. 121.



417. *Number of the Binary Stars.*—There are 467 double stars, in which observations have indicated a change in their relative positions, and which are therefore shown to be binary stars. The shortest period yet found for any binary star is 36 years; there are only eight whose periods are less than a century; there are 142 whose periods are less than a thousand years; while the periods of 325 apparently exceed a thousand years. When the motion is so slow, observations must be extended over a long interval of time to determine satisfactorily the period of an entire revolution. It is probable that a large majority of the double stars will hereafter be proved to be physically connected.

418. *Actual Distance between the Components of a Binary Star.*—If we knew the distance of a binary star from the earth, we could compute the absolute dimensions of the orbit described. Now Alpha Centauri and 61 Cygni are both binary stars, and their distances are tolerably well determined. It has been computed that the diameter of the orbit described by the components of Alpha Centauri is about four fifths that described by Uranus; and that of 61 Cygni is considerably greater than the orbit of Neptune.

419. *Mass of a Binary Star computed.*—Since the relation between the dimensions of the orbit and the time of revolution determines the relative masses of the central bodies, we are able to compare the mass of a binary star with that of our sun when we know the periodic time of the star and the absolute radius of the orbit. We thus find that the mass of the double star Alpha Centauri is three fifths that of our sun; that of 61 Cygni is about two thirds of our sun; and that of the double star 70 Ophiuchi is three times that of our sun.

420. *The Fixed Stars are Suns.*—We thus see that the fixed stars possess the same property of attraction that belongs to the sun and planets. Some of them have a power of attraction nearly equal to that of our sun, and others have a greater power of attraction. Some of them emit more light than our sun. The fixed stars are therefore material bodies of vast size, and self-luminous, and are properly called *suns.* In the binary stars, then, we have examples, not of planets revolving round a sun, as in our solar system, but of one sun revolving around another sun; or, rather, of both around their common centre of gravity.

421. *Non-luminous Stars.*—There is no evidence that all the stars emit light of equal intensity, and the great inequality in the components of some of the binary stars favors the contrary supposition. Indeed, it has been surmised that some of the faint companions of double stars shine entirely by light reflected from the brighter star. This may perhaps be true of the companion of Sirius.

The proper motion of some of the stars exhibits inequalities which have not been satisfactorily explained; and it has been conjectured that around these stars there may revolve other bodies of a size sufficient to disturb their movements appreciably, but emitting a light so feeble that they can not be discerned with our telescopes. There is, then, some reason for supposing that there are stars which emit light of very feeble intensity, and perhaps others which are entirely non-luminous. Our sun is constantly emitting both heat and light, and, unless there is some provision which is unknown to us for renewing the supply, our sun must ultimately become a non-luminous body.

Fig. 122.

422. *Multiple Stars.*—Besides the binary stars, there are some triple stars which are proved to be physically connected. There are also quadruple stars in which all the components are believed to be physically connected, but the motion is so slow that it requires a longer period of observations to show the connection indisputably. There are also quintuple and sextuple stars which are presumed to be physically connected. Fig. 122 shows the multiple star ε Lyræ.

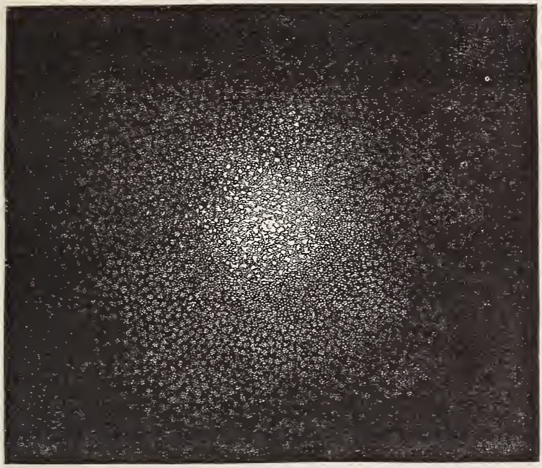
423. *Clusters of Stars.*—In many parts of the heavens we find stars crowded together into clusters, frequently in such numbers as to defy all attempts to count them. Some of these clusters are visible to the naked eye. In the cluster called the *Pleiades*, six stars are readily perceived by the naked eye, and we obtain glimpses of many more. With a telescope of moderate power 188 stars can be counted.

In the constellation Cancer is a luminous spot called *Præsepe*, or the Bee-hive, which a telescope of moderate power resolves entirely into stars. In the sword-handle of Perseus is another luminous spot thickly crowded with stars, which are separately visible with a common opera-glass.

One of the most magnificent clusters in the northern hemisphere occurs in the constellation Hercules. On clear nights it is visible to the naked eye as a hazy mass of light, which is readily resolved into stars with a telescope of moderate power. When examined with a powerful telescope, it presents the magnificent aspect of a countless host of stars crowded together into a perfect blaze of light.

The richest cluster in the entire heavens is seen in the constellation Centaurus, in the southern hemisphere. To the naked eye it appears like a nebulous or hazy star of the fourth magnitude, while a large telescope shows it to cover a space having two thirds of the apparent diameter of the moon, and to be composed of innumerable stars apparently almost in contact with each other.

Fig. 123.



We can not doubt that most of the stars in this cluster are near enough to each other to feel each other's attraction. They must therefore be in motion, and we must regard this cluster as a magnificent *astral system*, consisting of a countless number of suns, each revolving in an orbit about the common centre of gravity.

424. *Nebulæ.*—With the aid of the telescope we discern, scattered here and there over the firmament, dim patches of light, presenting a hazy or cloud-like appearance. These objects are called *nebulæ.* With one or two exceptions, these objects can not be seen without a telescope, and many of them are beyond the reach of any but the most powerful instruments.

The number of nebulæ and clusters of stars hitherto discovered is somewhat over 5000. They are very unequally distributed over the heavens, being most numerous in the constellations Leo, Virgo, and Ursa Major, while in some other constellations very few are found.

425. *Diversity of Form and Appearance.*—When viewed with telescopes of moderate power, most of the nebulæ appear round or oval, brighter toward their centres than at their borders. When examined with more powerful instruments, some of them are found to consist of a multitude of minute stars distinctly separate, without any remaining trace of nebulosity. About one twelfth of the whole number have thus been entirely resolved into *clusters of stars.* Many others present a mottled, glittering aspect, abounding with stars, but mingled with a nebulosity which has not hitherto been resolved into stars. Others present no appearance of stars, and retain the same cloud-like aspect under the highest power of the telescope.

426. *Classification of Nebulæ.*—The nebulæ are sometimes classified according to their forms as seen through the best telescopes. The following are the principal classes:

1. Spherical or Spheroidal Nebulæ.
2. Annular or Perforated Nebulæ.
3. Spiral Nebulæ.
4. Planetary Nebulæ.
5. Stellar Nebulæ.
6. Irregular Nebulæ.
7. Double and Multiple Nebulæ.

427. *Spherical or Spheroidal Nebulæ.*—Nebulæ of a spherical form are very common. Many of them have a spheroidal form; others are very much elongated; and some are so elongated as to be reduced almost to a straight line. They are generally most condensed toward the centre, and gradually fade away toward the margin.

Fig. 124.

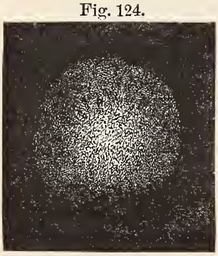
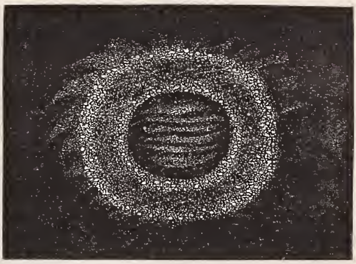


Fig. 125.

Fig. 126.

428. *Annular or Perforated Nebulæ.*—There are only four examples of annular nebulæ. Of these the most remarkable is that in Lyra, represented in Fig. 127. In Lord Rosse's telescope are seen fringes extending from each side of the ring, and also stripes crossing the central part.

Fig. 127.



429. *Spiral Nebulæ.*—Some of the nebulæ exhibit spiral convolutions proceeding from a common nucleus or from two nuclei. The most remarkable example of this form is situated near the extremity of the tail of the Great Bear.

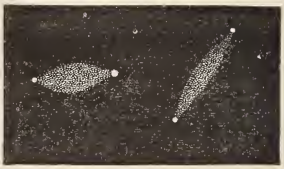
Fig. 128.

About forty spiral nebulæ have been discovered, and there are others which exhibit some trace of this form.

430. *Planetary Nebulæ.*—Planetary nebulæ have a round disc like a planet, exhibiting throughout a nearly uniform brightness, or only slightly mottled, and often very sharply defined at the margin. About twenty planetary nebulæ have been observed. They can not be globular clusters of stars, otherwise they would appear brighter in the middle than at the borders. It has been conjectured that they are assemblages of stars in the form of hollow spherical shells, or of flat circular discs, whose planes are nearly at right angles to our line of vision.

Fig. 129.

Fig. 130.



431. *Stellar Nebulæ.*—Stellar nebulæ are those in which one or more stars appear connected with a nebulosity. Sometimes we find a circular nebula with a star occupying the centre; sometimes we find an elliptic nebula with a star at each focus; sometimes we find a very elongated nebula with a star at each extremity of the major axis.

432. *Irregular Nebulæ.*—Most of the nebulæ have no simple geometrical form, and many of them exhibit remarkable irregularities, indicating an exceedingly complex structure. Of these, one of the most celebrated is the great nebula of Orion. It consists of irregular nebulous patches, whose apparent magnitude is more than twice that of the moon's disc. The brightest portion of the nebula resembles the head of a fish. It has been conjectured that this nebula has changed its form within two hundred years.

Other celebrated nebulæ which must be referred to this class are the great nebula in Andromeda (Fig. 131), the

Fig. 131.

Crab Nebula, the Dumb-bell Nebula (Fig. 132), etc., which

Fig. 132.

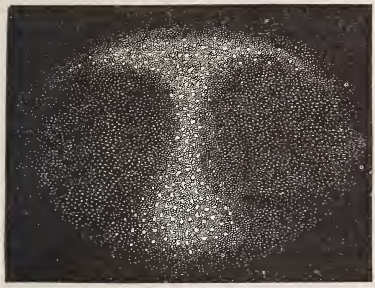
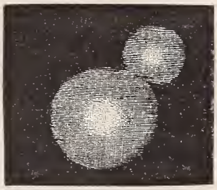


Fig. 133.



have been carefully delineated by Lord Rosse and other observers.

433. *Double and Multiple Nebulæ.*—Some nebulæ exhibit two centres of condensation. Sometimes the two portions are quite separate from each other, and sometimes they appear to penetrate each other. Sometimes we find three, four, or more centres of condensation. It seems probable that the component parts of most of these nebulæ are physically connected. More than 50 double nebulæ have been observed whose components are not more than five minutes apart. See Fig. 133.

434. *Magnitude of the Nebulæ.*—If we knew the distance of a nebula from the earth, we could deduce its absolute dimensions from its apparent diameter. We do not know the distance of any of the nebulæ, but it is probable that their distance is as great as that of the faint stars into which some of them are partially resolved by the best telescopes.

One of the planetary nebulæ has an apparent diameter of about 3′, the nebula of Orion has a diameter of 40′, and that in Andromeda 90′. Even supposing these bodies to be removed from us no farther than 61 Cygni, the absolute diameter of the planetary nebula would be 7 times that of the orbit of Neptune, the nebula of Orion would be more than 100 times, and that of Andromeda nearly 300 times the diameter of the orbit of Neptune. If, however, we suppose them to be situated at the same distance as the faint stars into which they have been partially resolved, their absolute diameters would be 500 times greater than the numbers here stated.

435. *Variations in the Brightness of Nebulæ.*—Some of the nebulæ are subject to variations of brightness. A nebula in Taurus, at the date of its discovery in 1852, was easily seen with a good telescope, whereas in 1862 it was invisible with instruments of far greater power. A small star close to this nebula has also experienced a similar diminution of brightness. Another nebula, situated near the Pleiades, could be seen with a three-inch telescope in 1859, whereas in 1862 it could only be seen with difficulty through the largest telescope. Five or six cases of this kind have been noticed. It is probable that these variations of brightness are due to the same causes as the changes of the variable stars.

436. *Variations in the Forms of Nebulæ.*—The forms of many of the nebulæ are so peculiar that it is difficult to regard them as having attained a condition of permanent equilibrium, and it has been supposed that we now see them in the state of transition toward stable forms. A comparison of the present appearance of many nebulæ with the representations of them furnished by former astronomers would lead to the conclusion that they had sensibly changed their form within 100 years, but this conclusion is rendered doubtful by the apparent imperfection of the earlier representations. It is probable that future astronomers will discover decided changes in many of the nebulæ.

437. *Are all Nebulæ resolvable into Stars?*—Clusters of stars exhibit every gradation of closeness, from the Pleiades down to those which resemble the diffuse light of a comet. Many clusters, in which with ordinary telescopes the component stars are undistinguishable, when seen through more powerful telescopes are resolved wholly into masses of stars, so that some have concluded that all nebulæ are but clusters of stars too remote for the individual stars to be separately seen. In other nebulæ, the most powerful telescopes resolve certain portions into masses of stars, while other portions still retain the nebulous appearance. This result may sometimes be ascribed to difference of distance, while in other cases certain portions of the nebulæ may consist of stars having actually a less magnitude, and crowded more closely together. Hitherto every increase of power of the telescope has augmented the number of nebulæ which are resolved into clusters; still it would be unsafe to infer that all nebulosity is but the glare of stars too remote to be separated by the utmost power of our instruments.

438. *Spectra of the Nebulæ.*—When the light of a fixed star is passed through a prism, its spectrum is generally continuous from the red end to the violet, and is crossed by a system of dark lines, some of which correspond to lines in the solar spectrum. Some of the nebulæ, as, for example, the great nebula in Andromeda, exhibit similar spectra. On the contrary, the spectra of some of the nebulæ are *not* continuous, but their light is wholly concentrated into three *bright lines*, separated by obscure intervals. The great nebula in Orion, the Dumb-bell nebula, and the annular nebula in Lyra, furnish spectra of this kind. Such a spectrum is emitted when matter in the gaseous state is rendered luminous by heat. The position of these bright lines indicates in these nebulæ the presence of hydrogen and nitrogen, and a third element not yet identified. Hence it is inferred that these nebulæ are not clusters of stars, but enormous masses of luminous gas.

The nebulæ may therefore be divided into two classes: 1. Those whose spectra resemble the spectra of the fixed stars, and which are therefore regarded simply as *clusters of stars*; and, 2. Those whose spectra resemble that of luminous gas. The latter are regarded, not as groups of stars, but *true nebulæ.* None of the nebulæ of this class have ever been resolved, although some exhibit a large number of minute stars, which, however, may be entirely distinct from the irresolvable matter of the nebula.

A few of the fixed stars also exhibit a spectrum with *bright lines*, which is considered to indicate that they are surrounded by an envelope of luminous gas.

439. *Belt of the Milky Way.*—The Galaxy, or Milky Way, is that whitish, luminous band of irregular form which, on a clear night, is seen stretching across the firmament from one side of the horizon to the other. The general course of the Milky Way is in a great circle, inclined about 63° to the celestial equator, and intersecting it near the constellations Orion and Ophiuchus. It varies in breadth at different points from 5° to 16°, having an average breadth of about 10°. To the naked eye it presents a succession of luminous patches, unequally condensed, intermingled with others of a fainter shade. From Cygnus to Scorpio it divides into two irregular streams, which in some places expand to a breadth of 22°.

When examined in a powerful telescope, the Milky Way is found to consist of myriads of stars, so small that no one of them singly produces a sensible impression on the unassisted eye. These stars are, however, very unequally distributed. In some regions several thousands are crowded together within the space of one square degree; in others, only a few glittering points are scattered upon the black ground of the heavens.

440. *Hypothesis of Sir William Herschel.*—Herschel attempted to explain the great accumulation of stars near the plane of the Milky Way by supposing that the stars of our firmament constitute a cluster with definite boundaries, the thickness of the cluster being small in comparison with its length and breadth, and the earth occupying a position somewhere about the middle of its thickness. If we suppose the stars to be scattered pretty uniformly through space, the number of the stars visible in the field of a telescope ought to be about the same in every direction, provided the stars extend in all directions to an equal distance. But if the stars about us form a cluster whose thickness is less than its length and breadth, then the number of stars visible in different directions will show both the exterior *form* of the cluster and the place occupied by the observer.

441. *Herschel's Hypothesis is untenable.*—This hypothesis assumes that the stars are distributed uniformly through space, and that Herschel's telescope penetrated to the outermost limits of our cluster. The first assumption is not true, for the stars are greatly condensed in the neighborhood of the plane of the Milky Way. The second assumption must also be abandoned, for every increase in the power of our telescopes discloses new stars which before have been invisible. We conclude, therefore, that the cluster of stars composing the Milky Way extends in all directions beyond the reach of the most powerful telescopes, and we have no knowledge of the exterior form of the cluster.

442. *Mädler's Hypothesis respecting the Milky Way.*—Mädler supposes that the stars of the Milky Way are grouped together in the form of an immense ring, or several concentric star rings of unequal thickness and various dimensions, but all situated nearly in the same plane. To an observer situated in the centre of such a system of rings, the inner ring would seem to cover the exterior ones; that is, the stars would seem to form but a single ring, and this ring would be a great circle of the sphere. The division of the Milky Way throughout a considerable portion of its extent into two separate branches indicates that in this part of the firmament the star rings do not cover each other, which Mädler explains by supposing that we are situated nearer to the southern than the northern side of the rings.

443. *Primitive Condition of the Solar System.*—We observe in our solar system several remarkable coincidences which we can not well suppose to be fortuitous, and which indicate a common origin of the system of planets circulating around the sun.

1. All the planets revolve about the sun in the same direction, viz., from west to east.

2. Their orbits all lie nearly in the same plane, viz., the plane of the sun's equator.

3. The sun rotates on an axis in the same direction as that in which the planets revolve around him.

4. The satellites (as far as known) revolve around their pri-

maries in the same direction in which the latter turn on their axes, and nearly in the plane of the equator of the primary.

5. The orbits of all the larger planets and their satellites have small eccentricity.

6. The planets, upon the whole, increase in density as they are found nearer the sun.

7. The orbits of the comets have usually great eccentricity, and have every variety of inclination to the ecliptic.

These coincidences are not a consequence of the law of universal gravitation, yet it is highly improbable that they were the result of chance. They seem rather to indicate the operation of some grand and comprehensive law. Can we discover any law from which these coincidences would necessarily result?

444. *Conclusions from Geological Phenomena.*—An examination of the condition and structure of the earth has led geologists to conclude that our entire globe was once liquid from heat, and that it has gradually cooled upon its surface, while a large portion of the interior still retains much of its primitive heat. The shape of the mountains in the moon seems to indicate that that body was formerly in a state of fusion. But if the earth and moon were ever subjected to such a heat, it is probable that the other bodies of the solar system were in a like condition, perhaps at a temperature sufficient to volatilize every solid and liquid body, constituting perhaps a single nebulous mass of very small density.

445. *The Nebular Hypothesis.* — Let us suppose, then, that the matter composing the entire solar system once existed in the condition of a single nebulous mass, extending beyond the orbit of the most remote planet. Suppose that this nebula has a slow rotation upon an axis, and that by radiation it gradually cools, thereby contracting in its dimensions. This contraction necessarily accelerates the velocity of rotation, and augments the centrifugal force, and ultimately the centrifugal force of the exterior portion of the nebula would become equal to the attraction of the central mass.

This exterior portion would thus become detached, and revolve independently of the interior mass as an immense nebulous zone or ring. As the central mass continued to cool and contract in its dimensions, other zones would in the same manner become detached, while the central mass continually decreases in size and increases in density.

The zones, thus successively detached, would generally break up into separate masses, revolving independently about the sun; and if their velocities were slightly unequal, the matter of each zone would ultimately collect in a single planetary but still gaseous mass, having a spheroidal form, and also a motion of rotation about an axis.

As each of these planetary masses became still farther cooled, it would pass through a succession of changes similar to those of the first solar nebula; rings of matter would be formed surrounding the planetary nucleus, and these rings, if they broke up into separate masses, would ultimately form satellites revolving about their primaries.

446. *Phenomena explained by this Hypothesis.*—The first six of the phenomena mentioned in Art. 443 are obvious consequences of this theory. The eccentricty of some of the planetary orbits and their inclination to the sun's equator may be explained by the accumulated effect of the disturbing action of the planets upon each other.

The planet Saturn presents the only instance in the solar system in which the detached nebulous zone condensed uniformly, and preserved its unbroken form. The group of small planets between Mars and Jupiter presents an instance in which a ring broke up into a great number of small fragments, which continued to revolve in independent orbits about the sun.

447. *Apparent Anomalies explained.*—The satellites of Uranus and Neptune form an exception to the general movement of the planets and their satellites from west to east, and this fact has been supposed to be inconsistent with the nebular hypothesis. There is, however, no such inconsistency. Planets formed in the manner here supposed would all have a movement of rotation, but they would not necessarily rotate in the same direction as the motion of revolution. The outer planets might rotate in the contrary direction, but in all cases the satellites must revolve in their orbits in the same direction as the rotation of the primary. If it shall be discovered that the planets Uranus and Neptune rotate upon their axes in a direction corresponding with the revolution of their satellites, these movements would be consistent with the nebular hypothesis.

The fact that cometary orbits exhibit every variety of inclination to the ecliptic has also been supposed to be inconsistent with the nebular hypothesis. The comets of short period move in orbits which differ but little from those of the minor planets, and we may suppose them to consist of small portions of nebulous matter which became detached in the breaking up of the planetary rings, and continued to revolve independently about the sun.

The comets which travel beyond the limits of the solar system probably consist of nebulous matter encountered by the solar system in its motion through space, and thus brought within the attractive influence of the sun. They are thus compelled to move in orbits around the sun, and these orbits may sometimes be so modified by the attraction of the planets that they may become permanent members of our solar system.

448. *How the Nebular Hypothesis may be tested.*—This hypothesis may be tested in the following manner. The time of revolution of each of the planets ought to be equal to the time of rotation of the solar mass at the period when its surface extended to the given planet. Let us, then, suppose the sun's mass to be expanded until its surface extends to the orbit of Mercury. If we compute the time of rotation of this expanded solar mass, we shall find it to be nearly four months, which corresponds with the time of revolution of Mercury. If we suppose the sun's mass to be farther expanded until its surface extends to each of the planets in succession, we shall find by computation that the time of rotation of the expanded solar mass is very nearly equal to the actual time of revolution of the corresponding planet.

So, also, if we suppose the earth to be expanded until its surface extends to the moon, we shall find by computation that its time of rotation corresponds nearly with the time of revolution of the moon. In like manner, if we suppose each of the primary planets to be expanded until its surface extends to each of its satellites in succession, we shall find that its computed time of rotation is very nearly equal to the actual time of revolution of the corresponding satellite.

The nebular hypothesis must therefore be regarded as possessing a high degree of probability, since it accounts for a large number of phenomena which hitherto had remained unexplained.

TABLE I.—ELEMENTS OF THE PRINCIPAL PLANETS.

Name.	Mean Distance from the Sun.		Eccentricity.
	Relative.	In Miles.	
Mercury	0.38710	35,552,000	0.20562
Venus	0.72333	66,431,000	.00683
Earth	1.00000	91,841,000	.01677
Mars	1.52369	139,937,000	.09326
Jupiter	5.20280	477,831,000	.04824
Saturn	9.53885	876,058,000	.05600
Uranus	19.18264	1,761,763,000	.04658
Neptune	30.03697	2,758,566,000	.00872

Name.	Sidereal Period in Years.	Synodical Period in Days.	Equatorial Diameter in Miles.	Mass.
Mercury	0.240	115.877	3,067	0.118
Venus	0.615	583.921	7,814	0.883
Earth	1.000		7,926	1.000
Mars	1.880	779.936	4,178	0.132
Jupiter	11.862	398.884	87,890	338.034
Saturn	29.458	378.092	74,327	101.064
Uranus	84.018	369.656	33,200	14.789
Neptune	164.622	367.489	36,100	24.648

No.	Planet's Name.	Date of Discovery.	Mean Distance.	Sidereal Period in Days.	Eccentricity.	Diameter in Miles.
1	Ceres	1801, Jan. 1	2.770	1684	0.080	227
2	Pallas	1802, March 28	2.770	1683	.240	172
3	Juno	1804, Sept. 1	2.667	1591	.258	112
4	Vesta	1807, March 29	2.361	1325	.090	228
5	Astræa	1845, Dec. 8	2.577	1511	.190	61
6	Hebe	1847, July 1	2.426	1380	.202	100
7	Iris	1847, Aug. 13	2.386	1346	.231	96
8	Flora	1847, Oct. 18	2.201	1193	.157	60
9	Metis	1848, April 25	2.386	1346	.123	76
10	Hygeia	1849, April 12	3.154	2046	.105	111
11	Parthenope	1850, May 11	2.453	1403	.099	62
12	Victoria	1850, Sept. 13	2.334	1303	.219	41
13	Egeria	1850, Nov. 2	2.576	1510	.087	73
14	Irene	1851, May 19	2.589	1522	.165	68
15	Eunomia	1851, July 29	2.643	1570	.187	92
16	Psyche	1852, March 17	2.921	1824	.136	93
17	Thetis	1852, April 17	2.473	1421	.127	52
18	Melpomene	1852, June 24	2.296	1270	.218	54
19	Fortuna	1852, Aug. 22	2.441	1393	.157	61
20	Massilia	1852, Sept. 19	2.409	1365	.144	68
21	Lutetia	1852, Nov. 15	2.435	1388	.162	40
22	Calliope	1852, Nov. 16	2.911	1814	.099	96
23	Thalia	1852, Dec. 15	2.631	1558	.232	42
24	Themis	1853, April 5	3.139	2031	.117	36
25	Phocæa	1853, April 7	2.401	1359	.255	31
26	Proserpine	1853, May 5	2.656	1581	.087	47
27	Euterpe	1853, Nov. 8	2.347	1313	.173	39
28	Bellona	1854, March 1	2.778	1692	.150	59
29	Amphitrite	1854, March 1	2.554	1491	.074	83
30	Urania	1854, July 22	2.367	1330	.127	51
31	Euphrosyne	1854, Sept. 1	3.151	2045	.221	50
32	Pomona	1854, Oct. 26	2.587	1520	.082	35
33	Polyhymnia	1854, Oct. 28	2.865	1771	.339	38
34	Circe	1855, April 6	2.687	1609	.107	29
35	Leucothea	1855, April 19	2.993	1891	.214	25
36	Atalanta	1855, Oct. 5	2.745	1661	.302	20
37	Fides	1855, Oct. 5	2.641	1568	.177	41
38	Leda	1856, Jan. 12	2.740	1657	.155	29
39	Lætitia	1856, Feb. 8	2.764	1680	.111	87
40	Harmonia	1856, March 31	2.267	1247	.046	61

No.	Planet's Name.	Date of Discovery.	Mean Distance.	Sidereal Period in Days.	Eccentricity.	Diameter in Miles.
41	Daphne	1856, May 22	2.758	1673	0.270	61
42	Isis	1856, May 23	2.440	1392	.226	39
43	Ariadne	1857, April 15	2.203	1194	.167	33
44	Nisa	1857, May 27	2.422	1377	.151	42
45	Eugenia	1857, June 27	2.721	1639	.082	44
46	Hestia	1857, Aug. 16	2.526	1466	.164	25
47	Aglaia	1857, Sept. 15	2.878	1784	.134	43
48	Doris	1857, Sept. 19	3.108	2001	.076	57
49	Pales	1857, Sept. 19	3.082	1978	.237	61
50	Virginia	1857, Oct. 4	2.652	1577	.284	25
51	Nemausa	1858, Jan. 22	2.366	1328	.068	38
52	Europa	1858, Feb. 6	3.107	2000	.101	72
53	Calypso	1858, April 4	2.621	1550	.203	29
54	Alexandra	1858, Sept. 10	2.709	1629	.199	40
55	Pandora	1858, Sept. 10	2.761	1676	.145	44
56	Melete	1857, Sept. 9	2.597	1528	.236	29
57	Mnemosyne	1859, Sept. 22	3.155	2048	.109	63
58	Concordia	1860, March 24	2.700	1620	.042	31
59	Elpis	1860, Sept. 12	2.713	1632	.117	36
60	Echo	1860, Sept. 15	2.393	1352	.185	17
61	Danaë	1860, Sept. 19	2.987	1885	.161	38
62	Erato	1860, Oct.	3.131	2023	.170	40
63	Ausonia	1861, Feb. 10	2.395	1354	.125	49
64	Angelina	1861, March 4	2.681	1603	.128	44
65	Cybele	1861, March 8	3.420	2311	.120	63
66	Maia	1861, April 9	2.651	1577	.158	18
67	Asia	1861, April 17	2.422	1376	.185	22
68	Leto	1861, April 29	2.781	1695	.188	60
69	Hesperia	1861, April 29	2.975	1873	.172	32
70	Panopæa	1861, May 5	2.613	1543	.184	36
71	Niobe	1861, May 29	2.754	1670	.174	46
72	Feronia	1861, Aug. 13	2.266	1245	.120	
73	Clytia	1862, April 7	2.665	1589	.044	
74	Galatea	1862, Aug. 29	2.780	1693	.237	
75	Eurydice	1862, Sept. 22	2.670	1594	.307	
76	Freia	1862, Oct. 21	3.388	2277	.188	
77	Frigga	1862, Nov. 12	2.674	1596	.136	
78	Diana	1863, March 15	2.623	1552	.206	
79	Eurynome	1863, Sept. 14	2.444	1395	.193	
80	Sappho	1864, May 2	2.296	1270	.200	

No.	Planet's Name.	Date of Discovery.	Mean Distance.	Sidereal Period in Days.	Eccentricity.	Diameter in Miles.
81	Terpsichore	1864, Sept. 30	2.854	1761	0.211	
82	Alcmene	1864, Nov. 27	2.760	1674	.226	
83	Beatrix	1865, April 26	2.431	1384	.086	
84	Clio	1865, Aug. 25	2.362	1325	.236	
85	Io	1865, Sept. 19	2.654	1579	.191	
86	Semele	1866, Jan. 4	3.112	2005	.210	
87	Sylvia	1866, May 16	3.494	2385	.082	
88	Thisbe	1866, June 15	2.769	1682	.165	
89	Julia	1866, Aug. 6	2.550	1486	.180	
90	Antiope	1866, Oct. 1	3.137	2029	.173	
91	Ægina	1866, Nov. 4	2.492	1437	.066	
92	Undina	1867, July 7	3.192	2083	.103	
93	Minerva	1867, Aug. 24	2.756	1671	.140	
94	Aurora	1867, Sept. 6	3.160	2052	.089	
95	Arethusa	1867, Nov. 23	3.069	1964	.146	
96	Ægle	1868, Feb. 17	3.054	1950	.140	
97	Clotho	1868, Feb. 17	2.669	1592	.257	
98	Ianthe	1868, April 18	2.685	1603	.189	
99	Atrophos	1868, May 28				
100	Hecate	1868, July 11	2.994	1892	.169	
101	Helena	1868, Aug. 15	2.573	1508	.139	
102	Miriam	1868, Aug. 22	2.662	1587	.254	
103		1868, Sept. 7	2.702	1622	.081	
104		1868, Sept. 13	3.180	2071	.197	
105		1868, Sept. 16	2.380	1341	.176	
106		1868, Oct. 10	3.201	2092	.195	
107	Camilla	1868, Nov. 17				

INDEX.

Page

Aberration, amount of 102
" illustrated 101
" of a star at the pole 102
Aerolites described 211
" orbits of 213
" origin of 213
Altitude and azimuth defined 13
" and azimuth instrument 51
" of a body determined 50
Altitudes measured by sextant 53
Annual parallax of stars 222
Annular mountains of moon 118
Apparent motion of inferior planet ... 156
" " of superior planet .. 158
Arc of meridian, how measured 28
Asteroid system, origin of 243
Asteroids, brightness of 175
" distance of 175
" number known 175
Astronomy defined 9
Atmosphere, illuminating effect of ... 61
Atmospheric refraction, law of 55

Biela's comet divided 203
" " history 202
Binary star, mass of 231
Binary stars defined 229
" " elements of 230
" " number of 230
Brorsen's comet 204

Calendar, Gregorian 79
" Julian 79
Cavendish's experiment 33
Celestial equator defined 12
" globe, problems on 86
" sphere defined 10
" " time of revolution ... 11
Centrifugal force, and force of gravity 27
" " and form of body .. 27
" " effects of 26
Change of seasons, cause of 66
" " made greater 68
Chronometers, longitude by 140
Clock, its error and rate 41
Clusters of stars 232
Color of the stars 228
Colures, equinoctial and solstitial 63
Coma, nucleus, etc., of comet 190
Cometary orbits, nature of 198
" " position of 189
Comet defined 189
" known to be periodic 199
" of 1744, history 205
" of 1770, history 205
" of 1770, mass of 206
" of 1843, history 206
" strike the earth 207

Page

Comet's tail, dimensions of 194
" " formation of 193
" " position of 194
" tails, theory of 195
Comets, number of 189
" period of visibility 190
" phases of 197
" quantity of matter 197
" telescopic 197
" variations of 192
" with several tails 196
Cone of earth's shadow 129
Conic sections, planets move in 126
Conjunction and opposition defined .. 107
" " " of a planet 155
Constellations enumerated 218
" names of 217
" origin of 217
Constitution of the sun 97
Corona in solar eclipses 136
Cotidal lines 148
Culminations of heavenly bodies 14
Curvilinear motion 121

D'Arrest's comet 204
Day, civil and astronomical 73
Declination defined 24
" how determined 50
Density of earth determined 32
" of a planet determined 164
Detonating meteors described 210
" " velocity 211
Differences of parallax detected 223
Dip of the horizon 53
Direction of sun's motion 226
Distance between two stars computed 230
" measured by sextant 53
" of a planet from sun 162
" of heavenly body computed. 82
" of the sun computed 89
Diurnal inequality in North Atlantic. 151
" " in Pacific 151
" " variations of 152
Diurnal motion, cause of 20
" " consequences of 13
" " described 9
" " never suspended 11
" " rate of 46
Diurnal paths of heavenly bodies 11
Donati's comet 207
Double stars classified 228
" " defined 227

Earth, circumference of 19
" dimensions of, important 15
" ellipticity of 31
" form and dimensions 30

	Page
Earth, proof that it is globular	16
Earth's annual motion, effects of	66
" atmosphere, effect of	132
" axis defined	21
" diameter, how determined	17
" motion in its orbit	71
" " velocity of	89
" orbit an ellipse	69
" " eccentricity of	69
" " form of	69
" penumbra defined	131
" rotation, direct proof of	35
" shadow, breadth of	130
" " form of	129
" " length of	130
' surface, irregularities of	19
Eclipse of sun, darkness of	136
Eclipses, cause of	129
" every month	129
" number in a year	136
" of Jupiter's satellites	178
" of sun and moon compared	136
" of sun, different kinds	135
" " duration of	135
Ecliptic, position of	103
Electric circuit broken by clock	143
Electro-chronograph	45
Encke's comet, history	201
" hypothesis considered	201
Enlargement of sun near horizon	58
Equation of time, value of	76
Equatorial telescope defined	10
Equinoxes and solstices	63
" precession of	103
Establishment of a port	153
Faculæ, cause of	92
Falling bodies, experiments	37
" " motion of	36
Faye's comet, history	204
Fixed star defined	215
Fixed stars are suns	231
" " classified	215
Force that retains the moon	124
Geocentric and heliocentric places	155
Geological phenomena	242
Globe, celestial, problems	86
" terrestrial, "	39, 82
Globes, artificial	37
Gravitation proportional to masses	125
Greatest heat after the solstice	70
Gregorian Calendar adopted	80
Halley's comet, history	199
" " return	201
Harvest moon explained	112
Herschel's hypothesis	240
Horizon, sensible and rational	12
Horizontal point determined	49
Hour circles defined	23
Inequality of solar days	74
Jupiter, belts of	177
" diameter	176
" distance and period	176
" rotation of	176
" spheroidal form	177
Jupiter's belts explained	177
" satellites, distances of	178
" satellites, eclipses of	178
Kepler's laws	121
" third law	128
Latitude and longitude defined	21
" " " of a star	65
" at sea determined	72
" of a place determined	71
" " " how known	23
Law of gravitation general	124
Le Verrier and Adams's researches	187
Librations of the moon	113
Light of sun and stars	224
" transmission of	180
Longitude by artificial signals	140
" " chronometers	140
" " eclipses of moon	141
" " electric telegraph	142
" " Jupiter's satellites	180
" " solar eclipse	142
Lunar eclipses, different kinds	131
" mountains, height of	115
" volcanoes extinct	120
Mädler's hypothesis	241
Mars, color of	173
" distance and period	172
" phases	172
" spheroidal form	173
" telescopic appearance	173
Measurements of meridian arcs	29
Mercury and Venus, elongations	165
" " " phases of	165
" " " transits of	169
" greatest brightness of	167
" period and distance	166
" rotation on axis	167
Mercury, visibility of	166
Meridian circle	50
Meridian mark	77
Meteoric orbits	208
Meteors of August and November	209
Milky way	240
Moon, causes no refraction	116
" circular craters	118
" diameter of	107
" distance of	107
" revolution of	108
" rotation and revolution of	112
" telescopic appearance	114
" visible in total eclipse	133
Moon's atmosphere	116
" disc, obscure part	111
" mountain forms	117
" orbit, eccentricity of	109
" form of	109
" phases	110
" rising, daily retardation	112
" rotation upon an axis	112
" shadow, breadth of	134
" " length of	133
" " velocity of	134
" transits, interval of	109
Motion, direct and retrograde	157
" of the solar system	226
" on a curve, law of	122
Multiple stars	232
Mural circle described	47
Nebula, dumb-bell	237

	Page
Nebula in Andromeda	236
" in Lyra	235
" spiral	235
Nebulæ, changes of	238
" classification of	234
" described	233
" planetary	235
" resolvable into stars	238
" spectra of	239
" spiral	235
" stellar	236
Nebular hypothesis, argument for	243
" " stated	242
Nebulosity of comets	191
Neptune discovered at Berlin	187
" distance and period	188
" satellite of	188
Nucleus of comet, dimensions of	191
Nutation, solar and lunar	105
Oblique sphere defined	25
Obliquity of ecliptic determined	68
Observations for moon's parallax	82
" made in meridian	41
Occultations of Jupiter's satellites	179
" of stars	139
Olbers's hypothesis inadmissible	176
" " stated	174
Orbit of a binary star	230
Parallax, diurnal, explained	80
" of Alpha Centauri	222
" of moon determined	81
" of 61 Cygni	223
" of various stars	224
Parallel sphere defined	25
Periodicity, cause of	221
Periodic time of a planet	161
Planet, deficient	174
" elements of orbit	160
" phases of	160
" when visible	159
Planets, apparent motion of	156
" attractive force of	124
" diameter of	163
" number of	154
" orbits of	154
" peculiarities of	160
Pole, altitude of	22
" of equator, motion of	103
" star, how found	15
" " varies	104
Precession of equinoxes, cause of	105
Projectiles, motion of	127
Proper motion of stars explained	227
Protuberances emanate from sun	137
" flame-like	137
" nature of	138
Reading microscope described	49
Refraction affected by temperature	57
" atmospheric	55
" determined by observation	56
Resisting medium	201
Reticle of telescope	44
Revolution of celestial sphere, time of	11
Revolutions, sidereal and synodic	108
Right ascension defined	23
" sphere defined	24
Satellites, number of	155
Saturn, diameter of	181
" distance and period of	181
" rotation of	181
Saturn's inner ring	183
" rings, appearance of	181
" " constitution of	184
" " dimensions of	183
" " disappearance of	183
" " how sustained	184
" " variations of	182
" satellites	185
Sextant described	52
Shooting stars described	208
" " height and velocity of	208
Sidereal and solar time compared	73
" day defined	11
" period, how determined	162
" time defined	72
Solar corona, cause of	138
" faculæ are elevations	92
" spots, black nucleus	90
" " changes of	91
" " depressions	95
" " described	90
" " latitude of	95
" " magnitude of	91
" " motion of	94
" " not planets	93
" " observations of	92
" " origin of	98
" " penumbra of	98
" " periodicity of	91
" system seen from Neptune	188
" time defined	72
Spirit-level described	43
Star Alpha Centauri	222
Stars, brightness of	216
" catalogues of	220
" constitution of	225
" distance of	222
" how designated	218
" how visible	216
" non-luminous	231
" optically double	229
" periodic	220
" proper motion of	225
" temporary	220
" which never set	15
Sun-dial described	78
Sun, diameter of	89
Sun's disc affected by refraction	58
" " bright part of	92
" envelope not solid	96
" equator, position of	95
" force of gravity	90
" motion in declination	62
" " in right ascension	62
" " rectilinear	226
" parallax and distance	169
" " determined	171
" " from Mars	174
" photosphere, nature of	97
" rotation, time of	94
Sunrise affected by refraction	58
Superior planets distinguished	172
Synodic period determined	108
Tail of comet	193
Tidal currents	151
Tidal wave in shallow water	149
" " near South America	148

	Page
Tidal wave, origin of	148
" " velocity of	148
Tides at perigee and apogee	145
" caused by the sun	147
" cause of	146
" defined	145
" depend on moon's declination	147
" diurnal inequality of	151
" height of	149
" how modified	150
" in Bay of Fundy	150
" of coast of Europe	152
" of Gulf of Mexico	152
" of inland seas	152
" of rivers	150
" of the Pacific Ocean	151
" on coast of Europe	152
" spring and neap	145
" why complicated	148
Time, apparent and mean	73
" by a single altitude	78
" determined	76
" under different meridians	140
Transit instrument adjusted	46
" " described	42
" " verified	47
Transits, mode of observing	44
" of Mercury, possible	169
" of stars telegraphed	144
" of Venus, observed	171
Tropics and polar circles	64
Twilight, cause of	59
" duration at equator	60
" " at poles	60
" " in middle latitudes	61
Uranus, diameter of	186
" distance and period of	186
" satellites of	187
Venus, morning star	168
" period and distance of	167
" rotation on axis of	168
" twilight of	168
" visible in daytime	168
Vernier described	48
Vertical circle defined	12
Volcanoes, lunar	118
" terrestrial	119
Water on the moon	117
Weight at pole and equator	27
" loss of, at equator	31
Winnecke's comet	205
Zenith and nadir defined	12
Zodiacal light	99
Zodiac, signs and constellations of	105
" " enumerated	64
Zones of the earth	65

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