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TEXT-BOOK

OF

POPULAR ASTRONOMY

FOR THE USE OF

COLLEGES, ACADEMIES, AND HIGH-SCHOOLS.

BY

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PECK'S ACADEMIC AND COLLEGIATE COURSE.

I.—MANUAL OF ALGEBRA.

II.—MANUAL OF GEOMETRY.

III.—TREATISE ON ANALYTICAL GEOMETRY.

IV.—DIFFERENTIAL AND INTEGRAL CALCULUS.

V.—POPULAR PHYSICS (FROM GANOT).

VI.—ELEMENTARY MECHANICS (WITHOUT THE CALCULUS).

VII.—ELEMENTS OF MECHANICS (WITH THE CALCULUS).

VIII.—POPULAR ASTRONOMY.

PREFACE.

THE following work has been prepared to meet the wants of the Author, but it is hoped that it will be of service not only to other teachers of Astronomy but also to the general scientific reader.

The book is intended to present, in a compact and popular form, all the facts and principles of the science that are needed in a general course of collegiate education. To this end, mathematical formulas and demonstrations have been avoided as far as possible, and when it has been deemed advisable to introduce them, they have been made inconspicuous by putting them in smaller type. If these subordinate paragraphs are omitted, it will be found that the remaining ones form a continuous treatise on Astronomy, which is as non-mathematical in its character as is consistent with a scientific treatment of the subject.

It will be found that the order of arrangement is somewhat different from that which is met with in most text-books. The stars have been treated of in a general way before any detailed consideration has been given to the solar system; the descriptions of instruments have been scattered through the book, no instrument being described until its use is indicated in the general development of the course; an effort has been made to distribute the definitions of terms so that they shall receive immediate illustration from the context; and, finally, the various subjects considered have been arranged in what seems to be a natural and consequently a logical order. It is believed that all the changes that have been made are of such a character as to secure the early and the continued attention of the student.

The author takes great pleasure in acknowledging his obligations to Prof. J. K. Rees, Director of the Columbia College Observatory, whose long experience as a teacher of Astronomy has enabled him to render much valuable assistance in the preparation of this work.

COLUMBIA COLLEGE,
September, 1883.

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ASTRONOMICAL SIGNS.

1°. Signs of the Zodiac.

♈	Aries.	♌	Leo.	♐	Saggitarius.
♉	Taurus.	♍	Virgo.	♑	Capricornus.
♊	Gemini.	♎	Libra.	♒	Aquarius.
♋	Cancer.	♏	Scorpio.	♓	Pisces.

2°. Signs of the Sun and Planets.

☉	The Sun.	⊕	The Earth.	♄	Saturn.
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♀	Venus.	♃	Jupiter.	♆	Neptune.

3°. Signs of Position.

☊	Ascending Node.	☌	Conjunction.	□	Quadrature.
☋	Descending Node.	☍	Opposition.		

THE GREEK ALPHABET.

α	Alpha.	η	Eta.	ν	Nu.	τ	Tau.
β	Beta.	θ	Theta.	ξ	Xi.	υ	Upsilon.
γ	Gamma.	ι	Iota.	ο	Omicron.	φ	Phi.
δ	Delta.	κ	Kappa.	π	Pi.	χ	Chi.
ε	Epsilon.	λ	Lambda.	ρ	Rho.	ψ	Psi.
ζ	Zeta.	μ	Mu.	σ	Sigma.	ω	Omega.

ASTRONOMY.

I. PRELIMINARY PRINCIPLES.

The Heavenly Bodies.

1. All space is filled with an imponderable substance that we call **ether.**

This substance constitutes the medium that transmits **light**, by means of which alone we derive all our knowledge of objects external to the earth.

Scattered through this boundless ocean of ether are myriads of bodies, of which our earth is one, and these are called the **heavenly bodies.**

Some of the heavenly bodies are larger than the earth, and some are smaller; some shine by their own light, and some by reflected light; some are solid, and some are gaseous; but we have reason to believe that they are all in motion. The most important of the heavenly bodies are: the **sun**; the **planets**, of which our earth is one; the **satellites**, of which the moon is one; the **comets**; the **fixed stars**; and the **nebulæ.**

The sun, the fixed stars, and the nebulæ are incandescent, and shine by their own light; the planets and the satellites are dark bodies, and shine by reflected light.

Definition of Astronomy.

2. **Astronomy** is the science that treats of the heavenly bodies.

Its object is to determine the distances, forms, and magnitudes of the heavenly bodies; to explain their motions, both real and apparent; and to investigate, as far as possible, their physical conditions. It also embraces an explanation of the methods of applying the principles of the science to the wants of society.

The Celestial Sphere.

3. All the heavenly bodies outside of our earth appear as though they were fixed on the concave surface of an immense hollow globe; this surface is called the **celestial sphere.**

The heavenly bodies are in reality at very different distances from us, and the places they seem to occupy are simply the points where visual rays drawn through them meet the celestial sphere. This surface, on which the heavenly bodies are projected by the eye, is purely imaginary, and it has been found convenient for the purposes of the astronomer, to regard its radius as *infinite.* This supposition enables us to consider the centre of the celestial sphere as being either at the centre of the earth, or at the centre of the sun, inasmuch as the distance of the sun from the earth is insignificant in comparison with the assumed radius of the celestial sphere.

It will be shown hereafter that the shape of the earth is ellipsoidal, but for the purposes of description we shall regard it as spherical, and in most cases we shall regard its centre as the centre of the celestial sphere.

Diurnal Motion.

4. The entire celestial sphere *appears* to revolve daily from *east to west,* turning around an axis that passes

through the centre of the earth. In consequence of this *apparent* rotation, each of the heavenly bodies *appears* to move in a circle whose centre is in the axis of revolution and whose plane is perpendicular to that axis. This *apparent* rotation of the heavens is called the **diurnal motion**; the line about which it appears to take place is called the **axis of the celestial sphere**; and the circles in which the heavenly bodies seem to revolve are called **diurnal circles.**

The diurnal motion, which is only *apparent*, is due to the actual rotation of the earth from west to east about an axis which always maintains a sensibly fixed direction in space. The axis of the celestial sphere is therefore the axis of the earth prolonged to the heavens. The points in which this line meets the surface of the earth are called the **poles of the earth**, and those in which it meets the heavens are called the **poles of the celestial sphere.** That pole, either of the earth or of the heavens, which is the nearer to an observer in this country is called the **north pole**, and the one opposite to it is called the **south pole.**

It is in consequence of the diurnal motion that the sun, moon, and stars appear to rise in the east and set in the west.

Definitions.

5. A **vertical line** is a line whose direction is indicated by a freely suspended plumb-line.

Every vertical line passes through the centre of the earth, and consequently no two vertical lines can be parallel.

The point in which the vertical line at any place when prolonged upward meets the celestial sphere is called the **zenith** of that place, and the point in which it meets the celestial sphere when prolonged downward is called the **nadir** of the place.

6. A **horizontal plane** is a plane that is perpendicular to a vertical line.

A horizontal plane through any place is called the **sensi-**

ble horizon of that place, and a plane parallel to it through the centre of the earth is called the **rational horizon** of the place.

Because the earth's radius is insignificant in comparison with that of the celestial sphere, the circles in which the sensible and the rational horizon meet the heavens may be regarded as coincident, and for most purposes either one may be taken as the **celestial horizon.**

7. A **vertical plane** is a plane that passes through a vertical line, and its intersection with the celestial sphere is called a **vertical circle.**

The vertical plane at any place which passes through the axis of the earth is called the **meridian plane** of that place; its intersection with the surface of the earth is called the **terrestrial meridian,** and its intersection with the heavens is called the **celestial meridian,** or simply the **meridian** of the place.

The terrestrial meridian of a place passes through the poles of the earth; the celestial meridian passes through the poles of the heavens and also through the *zenith* and the *nadir* of the place.

The vertical plane which is perpendicular to the meridian plane is called the **prime vertical.**

The intersection of the horizon by the meridian plane is a *north and south line;* the intersection of the horizon by the prime vertical is an *east and west line.*

8. The **altitude** of a heavenly body is its angular distance above the horizon, and its **azimuth** is the angle between the meridian and a vertical circle through the body.

The **zenith distance** of a body is its angular distance from the zenith. It is the *complement* of the altitude.

The altitude and the zenith distance of a body are measured on the vertical circle through the body; the azimuth is measured on the horizon, usually from the south point, around by the west through 360°.

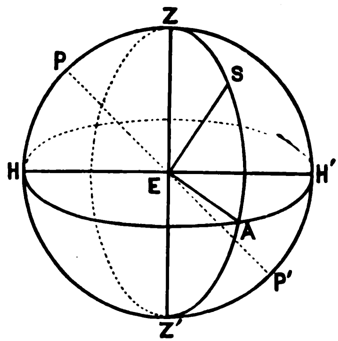

Fig. 1. Illustration of definitions.

EXPLANATION. In this figure E is the centre of the earth and of the celestial sphere; PP′ is the axis of the earth and of the celestial sphere; P and P′ are the poles of the heavens; EZ is a vertical line; Z is the zenith and Z′ is the nadir; HAH′ is the horizon; PH′P′ is the meridian; ZSZ′ is a vertical circle through S; the angle AES, measured by the arc AS, is the altitude of S; the angle H′EA, measured by the arc H′A, is the azimuth of S; and the angle ZES, measured by the arc ZS, is the zenith distance of S.

9. The **equator** is a great circle of the earth, whose plane is perpendicular to the axis. If the plane of the equator is extended in all directions, the great circle in which it meets the heavens is called the **equinoctial.**

The equinoctial is sometimes called the *equator of the heavens;* it is everywhere equally distant from the poles of the celestial sphere.

10. The **latitude** of a place on the earth is its angular distance from the equator.

The latitude of a place is measured on the meridian of that place, and is called **north** or **south** latitude according as the place is north or south of the equator. The latitude of a place is always equal to the angular distance of the zenith of the place from the plane of the equinoctial. The latitude of either pole is 90°.

A **parallel of latitude** is a small circle of the earth whose plane is parallel to the equator.

All places on the same parallel have the same latitude.

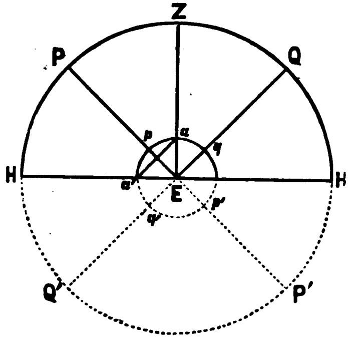

Fig. 2.

Explanation. Figure 2 represents the projection of the celestial sphere on the plane of the meridian of the place a; PP′ is the axis of the earth and of the heavens; EZ is the vertical at a; pqp' is the terrestrial meridian of the place a; PQP′ is the celestial meridian; qq' is the projection of the equator, and QQ′ that of the equinoctial; HH is the projection of the horizon; aa' is the projection of the parallel of latitude through a; qEa, equal to QEZ, is the latitude of a; and PEZ, equal $90° - $QEZ, is the co-latitude of a.

It is to be remembered that EZ is infinitely great in comparison with Ea, and consequently that HH is the celestial horizon of a.

The Sun's Apparent Motions.

11. The sun has an apparent diurnal motion like the fixed stars, and in addition it has an apparent motion *from west to east* amongst the stars by virtue of which it seems to complete an entire circuit of the heavens in a period we call a **year.** The apparent annual path of the sun amongst the stars, which is a great circle of the celestial sphere, is called the **ecliptic.**

The ecliptic retains a fixed position with respect to the stars, and cuts the equinoctial in two points called **equinoxes.** The point at which the sun passes *from the south to the north* side of the equinoctial is the **vernal equinox,** and the point at which it passes *from the north to the south* side of the equinoctial is the **autumnal equinox.** The sun is at the vernal equinox about the 21st of March, and at the autumnal equinox about the 22d of September.

The term *equinoxes* is applied, not only to the points as above defined, but also to the dates at which the sun passes them. A like application is made of the term solstices, yet to be defined.

The angle between the planes of the ecliptic and the equinoctial, which is about 23° 27′, is called the **obliquity of the ecliptic**, and the line in which these planes intersect is called the **line of equinoxes.**

The sun's *apparent* diurnal motion is due, as explained in Art. 4, to the earth's rotation on her axis. In like manner his *apparent* motion amongst the stars is due to an actual motion of the earth. The sun is the fixed body and the earth makes an annual revolution around him, moving from west to east in a path, or *orbit,* which determines the plane of the ecliptic. The sun's apparent place in the heavens is always on the prolongation of a visual ray drawn from the earth to the sun; hence, when the earth revolves around the sun from west to east, the prolongation of the visual ray revolves in the same way, that is, the sun *appears* to revolve in the same direction that the earth *actually* revolves, and with the same angular velocity. The ecliptic is therefore the great circle of the celestial sphere, in which the plane of the earth's orbit indefinitely extended meets the heavens.

It will often be found convenient to speak of the apparent motions of the sun, both diurnal and annual, as though they were real; and no error can result from this form of expression, if the explanations already given are carefully borne in mind.

Precession of the Equinoxes.

12. The equinoxes have a slow, but not quite uniform, motion from *east to west* along the ecliptic, that is, in a direction contrary to that of the sun in its annual path. This motion, which on an average is equal to 50″.2 a year, is called the **precession of the equinoxes.**

The precession of the equinoxes gives rise to a slow change in the direction of the earth's axis, by virtue of which the poles of the heavens circle around those of the ecliptic in an enormous cycle of more than 25,000 years.

The cause of the precession, and its effects on the aspect of the visible heavens, will be more fully treated of in a subsequent article.

Additional Definitions.

13. The **solstices** are the points of the ecliptic that are midway between the equinoxes. The one that is *north* of the equinoctial is called the **summer solstice**, and the one that is *south* of the equinoctial is called the **winter solstice.**

The solstices, which are 90° distant from the equinoxes, are the points of the sun's annual path that are farthest from the equinoctial. The sun is at the summer solstice about the 21st of June, and at the winter solstice about the 21st of December. In either case its angular distance from the equinoctial is equal to the *obliquity of the ecliptic*, that is, to about 23° 27′.

14. An **hour circle** is a great circle of the celestial sphere which passes through the poles of the heavens. It is also called a **declination circle.**

The hour circle that passes through the equinoxes is called the **equinoctial colure**, and the hour circle that passes through the solstices is called the **solstitial colure.**

The meridian of a place is an hour circle; that half of it which stretches from pole to pole and which passes through the zenith of the place is called its **upper branch,** and the remaining half is called its **lower branch.** When a heavenly body, in its diurnal motion, appears to cross the meridian of the place of the observer, it is said to **culminate.** The passage of a body over the upper branch of the meridian is called its **upper culmination,** or its **upper transit**; its passage over the lower branch is called its **lower culmination,** or its **lower transit.** The term *culmination,* when used by itself, is understood to mean the *upper culmination.*

The term *hour circle of a body* is frequently used in a limited sense to mean that half of the hour circle which extends from pole to pole and passes through the body. The context shows when the term is used in this sense. The term meridian is also used in the same sense.

15. The **hour angle** of a body is the angle between the meridian of the place and the hour circle of the body.

The hour angle is measured on the equinoctial. If the body is west of the upper branch of the meridian, its hour angle is *positive;* if the body is east of the meridian, its hour angle is *negative.* Thus, the hour angle of the sun is negative in the morning and positive in the afternoon.

EXPLANATION. The circle QRQ′ is the equinoctial; P and P′ are the poles of the heavens; KVK′ is the ecliptic and T,T′ are its poles; V is the vernal and A is the autumnal equinox; K is the summer and K′ is the winter solstice; the angle QEK measured by the arc QK is the obliquity of the ecliptic; PVP′A is the equinoctial colure; PQP′Q′ is the solstitial colure; PSR is part of the hour circle of the body S; and the angle QPR, measured by the arc QR, is the hour angle of S. The direction of the sun's apparent annual motion is indicated by the arrow. The solstitial colure passes through the poles of the heavens and also through the poles of the ecliptic. The arc PT is equal to 23° 27′.

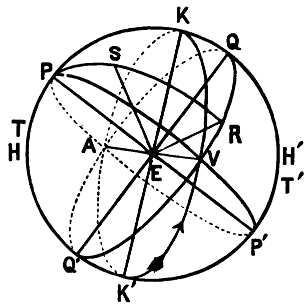

Fig. 3. Illustration of definitions.

Right Ascension and Declination.

16. The **right ascension** of a heavenly body is the arc of the equinoctial included between the vernal equinox and the hour circle of the body. Thus, in Fig. 3 the arc VR is the right ascension of the body S.

Right ascensions are reckoned from west to east, counting from the vernal equinox around through the entire circle of the equinoctial. They may be expressed in *degrees, minutes,* and *seconds* of angular measure, but for reasons yet to be explained it is found more convenient to express them in *hours, minutes*, and *seconds*, each hour corresponding to 15° of arc, each minute to 15′ of arc, and each second to 15″ of arc.

The **declination** of a heavenly body is its angular distance from the plane of the equinoctial. Thus, in Fig. 3, the angle RES, measured by the arc RS, is the declination of the body S.

Declinations are always expressed in degrees, minutes, and seconds of angular measure, and are reckoned on the hour circle that passes through the body in question. If the body is north of the equinoctial, its declination is regarded as *positive;* if it is south of the equinoctial, its declination is *negative.*

The **polar distance** of a body is its angular distance from the north pole of the heavens. Thus, in Fig. 3, PES, measured by the arc PS, is the polar distance of the body S.

The polar distance of a body is equal to 90° *minus* the body's declination. Thus, the polar distance of a body whose declination is +23° 27′ is 66° 33′, and the polar distance of a body whose declination is −23° 27′ is 113° 27′. From what has been explained it is obvious the sun's polar distance varies between the limits 66° 33′ and 113° 27′.

The right ascension and the declination of a body determine its position on the celestial sphere in the same way that the longitude and the latitude of a place determine its position on the surface of the earth. These elements of reference are determined by means of the *astronomical clock* and the *transit circle.*

Sidereal Time.

17. The interval between two successive culminations of the same star over the upper branch of the meridian of any place is called a **sidereal day**. The sidereal day is divided into 24 equal parts called **hours**, each hour is divided into

60 equal parts called **minutes**, and each minute is divided into 60 equal parts called **seconds**. Time reckoned in terms of these units is called **sidereal time**.

The *sidereal day*, which is assumed to be of invariable length, is the *fundamental unit* of astronomical time. The meridian of any place is carried from west to east with the earth as it turns on its axis, and setting out from any star its upper branch will sweep over every star of the heavens and return to its first position in the time required for the earth to turn once on its axis. Hence, the sidereal day is equal to the time required for the earth to revolve on its axis; it is also equal to the time required for any star to make a complete revolution in its diurnal circle.

The diurnal rotation of the earth takes place uniformly; hence, it turns through any fractional part of 360° in the same fractional part of a sidereal day. It will therefore revolve through an angle of 15° in a sidereal hour, through an angle of 15′ in a sidereal minute, or through an angle of 15″ in a sidereal second. This relation enables us to convert angular expressions into equivalent expressions in time, and the reverse, operations that are often required in astronomical computations.

The sidereal day used in *practical astronomy* begins when the vernal equinox is on the upper branch of the meridian of the place of observation. The practical sidereal day is therefore a trifle shorter than the sidereal day above described. For, while the meridian, starting from the vernal equinox, is moving eastward, the equinox itself is moving slowly toward the west in consequence of precession; consequently, the meridian will meet the equinox before it completes an entire revolution, that is, the sidereal day in actual use is a little less than the time required for the earth to make a complete revolution on its axis. The difference, which is less than a *hundredth part of a second*, is so small that it may be disregarded in a popular exposition of astronomical principles.

From what has been said above it is obvious that the sidereal time at which any body crosses the meridian is the same as the right ascension of the body expressed in time.

The Astronomical Clock.

18. An **astronomical clock** is a clock that is adjusted so as to keep accurate time. It differs but little from an ordinary clock except in nicety of construction. Its dial-plate, however, is usually divided into 24 equal parts, and its mechanism is such that the hour-hand turns around the dial once in 24 hours. The clock may be made to keep *sidereal* or *solar* time; when used as a *sidereal clock*, the pendulum is made of such length that the hour-hand shall make one revolution in a *sidereal day*. The most important parts of an astronomical clock are the *pendulum* and the *escapement*. The pendulum is compensating (Mech. Arts, 118–120), and the escapement is so constructed as to offer a minimum resistance to uniformity of motion.

It is not necessary that a sidereal clock should be set so as to indicate 0h. 0m. 0s. when the vernal equinox is on the meridian, provided we know its error, neither is it necessary that it should turn through exactly 24 hour spaces in a sidereal day, provided its *gain* or its *loss* in equal times is always the same.

The error of a clock at any given time, or **epoch**, *taken with its proper sign*, is called the **correction**; if the clock is fast, the correction is —; if slow, it is +. The amount that it gains or loses per day is called the *rate*; if it gains, the rate is —; if it loses, it is +.

Knowing the correction at a given time or epoch, and the rate, we may find the correction at any subsequent time by the following Rule:

Multiply the rate by the number of days and decimal parts of a day since the epoch, and apply the result, with its proper sign, to the given correction; the result will be the required correction.

EXAMPLE. At 12h. sidereal time, June 17th, a clock was 7m. 38s. fast, and it was losing 4s. a day; what was its error at 18h. sidereal time, June 29th?

OPERATION. – 7m. 38s. + 4s. × 12.25 = – 6m. 49s., *correction*; hence, 6m. 49s. must be *subtracted* from the reading of the clock to get the true time.

The Astronomical Telescope.

19. The ordinary **refracting telescope**, in its simplest form, consists of two lenses set in the opposite ends of a suitable tube. The larger lens, called the **objective**, receives the rays of light coming from a distant object, and so converges them as to form an *image* of that object; the smaller one, called the **eye-piece**, is used as a magnifier to view the image thus formed.

In modern telescopes the objective consists of two lenses placed close together; the outer one, which is of *crown* glass, is **convex**, that is, it is thicker at the middle than at the edge; the inner one, which is of *flint* glass, is **concave**, that is, it is thinner at the middle than at the edge. The curvatures of the surfaces of the two lenses are so chosen that the compound lens will give a distinct image *free from color;* in this case the objective is said to be **achromatic.**

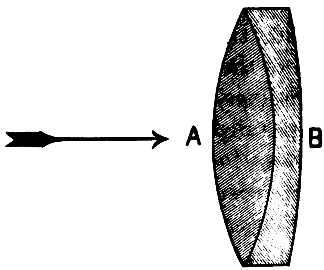

Fig. 4. Section of achromatic objective. A is a convex, and B is a concave lens, A being turned toward the object.

The eye-piece is composed of two convex lenses (usually plano-convex) placed a little distance apart; the one next the objective is called the **field-lens**, and the one next the eye is called the **eye-lens.** The lenses may be so arranged that the image of an object shall fall between the lenses, in which case the eye-piece is said to be **negative**; or they may be so placed that the image shall fall in front of the field-lens, that is, between it and the objective, in which case the eye-piece is said to be **positive**.

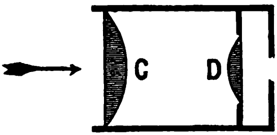

Fig. 5. Section of positive eye-piece. C is the field-lens, and D the eye-lens.

EXPLANATION. The lenses are of nearly equal focal lengths, and the distance between them is about $\frac{2}{3}$ the focal length of either. In this case the focal length of the combination is not far from $\frac{3}{4}$ the focal length of either lens.

When the telescope is used simply to view an object, the *negative* eye-piece is preferred; but when it is used to fix the exact direction of a body, the positive eye-piece is employed. The objective and the eye-piece should be so arranged in the tube that their axes shall coincide with each other and with the axis of the tube.

20. In a telescope to be used for measurements, the centre of the field of view is shown by the intersection of two fine lines, called **cross-hairs.** These lines are attached to a perforated diaphragm, provided with suitable adjusting screws for bringing the intersection of the cross-lines into its proper position. The line joining the optical centre of the objective with the intersection of the cross-hairs is the **line of collimation.** When the instrument is ready for use, the plane of the cross-hairs is at the common focus of the objective and the eye-piece. If the image of a star is seen at the intersection of the cross-hairs, the star itself must be in the prolongation of the line of collimation, for the ray of light that coincides with the line of collimation passes through the objective without deviation.

In the transit instrument, yet to be described, the diaphragm carries a system of hairs or wires, which is sometimes called a **reticle.** The manner in which the wires are arranged is shown in the figure. The wire *dc* is horizontal, and is sometimes double. The wires at right angles to *dc* are equidistant and usually either 5 or 7 in number, the middle one, *ab*, intersecting the horizontal one, *dc*, in the line of collimation. At whatever elevation the line of collimation may be set, the middle wire of the parallel system will be in the plane of the meridian, and the times required for a star to pass from wire to wire will be sensibly the same throughout the system.

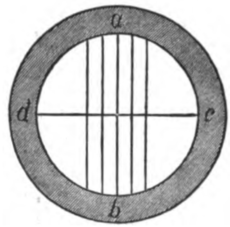

Fig. 6. The reticle.

The magnifying power of a telescope such as we have described is equal to *the focal length of the objective* divided by *the focal length of the eye-piece.* By using eye-pieces of different focal lengths, the magnifying power of the same telescope may be changed to meet the wishes of the observer.

The capacity of a telescope to bring faint objects into view depends upon the *size* of the objective. The quantity of light that falls upon the objective varies with the square of its diameter, and if none is lost either by absorption or from faulty construction, the quantity that enters the eye will be to the quantity that would enter it without the telescope as the square of the diameter of the objective is to the square of the diameter of the pupil of the eye.

The Reflecting Telescope.

21. Besides the kind of telescope already described, there is another class in which the image of the object to be viewed is formed by means of a curved mirror; these are called **reflecting telescopes.**

An example of this species of telescope is shown in Fig. 7, which represents the great silver-on-glass reflector at the Paris observatory. It consists of a tube about 25 feet long, at the bottom of which is a curved mirror nearly 4 feet in diameter. The reflected rays, which would come to a focus near the top of the tube, are turned in a lateral direction by a small plane mirror, and an image is formed that can be viewed by a suitable eye-piece as shown in the figure.

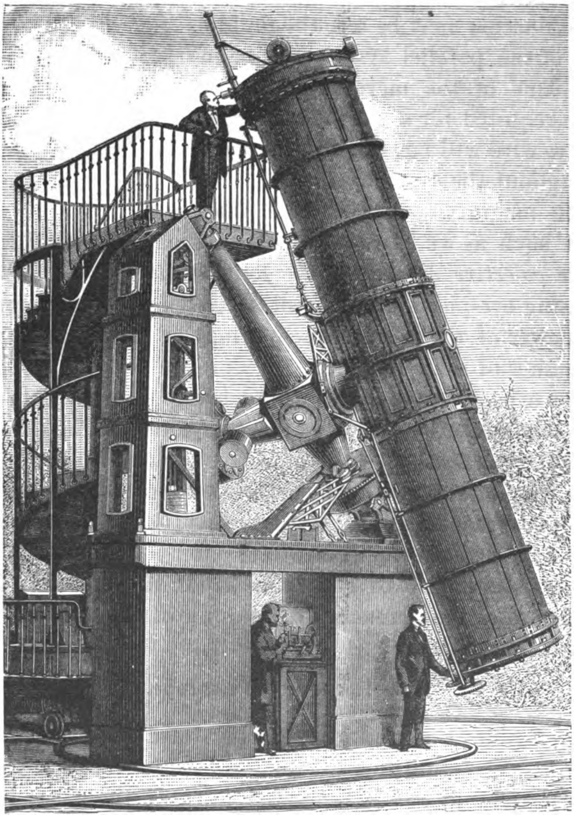

Fig. 7. Great silver-on-glass Reflector of the Paris Observatory.

This instrument is equatorially mounted, that is, it may be turned around either of two axes, one of which is parallel to the axis of the heavens, and the other to the plane of the equinoctial. The former, which is the principal axis shown in the figure, is called the **polar** and the latter is the **declination** axis of the instrument. By turning the instrument around its declination axis it may be set to the declination of any star, and then by turning it around the polar axis it may be made to follow the star in its diurnal motion. The latter motion is imparted by a train of clock-work.

The Transit Instrument.

22. A **transit instrument** is an instrument for determining when a heavenly body is on the meridian of a place.

It consists essentially of a telescope having an axis at right angles to its length, on which it can revolve in such manner that its line of collimation shall always be in the plane of the meridian. The telescope is provided with a reticle like that explained in Art. 20, which can be so adjusted as to make the line of collimation perpendicular to the axis of rotation, the wire *dc* being horizontal. The axis of rotation of the telescope is terminated at its extremities by two equal cylindrical pivots which rest in metallic pieces called **Y's**, and the Y's themselves are supported by two piers, between which the telescope revolves. One of the Y's can be moved *up and down*, and by means of a portable level the axis of rotation can be made horizontal; the other Y can be moved *north and south*, and by means of astronomical observation the axis can be placed due east and west.

When the axis of rotation is horizontal and also due east and west, it must be perpendicular to the plane of the meridian; then, if the line of collimation is perpendicular to the axis, it is obvious that this line will remain in the plane of the meridian when the instrument is revolved in the Y's. The line *dc* of the reticle being parallel to the horizon, the

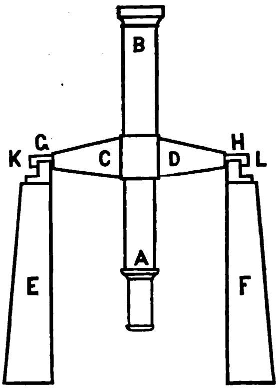

Fig. 8. The Transit Instrument.

remaining wires must be parallel to the plane of the meridian. When the image of a heavenly body is on the middle wire of the parallel system the body itself must be on the meridian of the place.

EXPLANATION. The projection of a transit instrument on a vertical plane perpendicular to the meridian. AB is the telescope; CD its axis of rotation; EF the supporting piers; GH the Y's; KL the pivots; the line of collimation revolves around KL, always remaining in the plane of the meridian.

Method of Finding Right Ascensions.

23. The right ascension of a heavenly body is found by means of a transit instrument and an astronomical clock. The operation consists in finding the exact sidereal time at which the body crosses the upper branch of the meridian.

The telescope of the transit instrument is turned around its axis of rotation till it has nearly the proper elevation, and when the body enters the field of view, the telescope is raised or depressed till the body appears to move along the horizontal wire. At the instant the body crosses each of the other wires, the reading of the clock is noted. The average of all these readings, corrected for the error and the rate of the clock, is the sidereal time that has elapsed since the vernal equinox was on the meridian, that is, it is the right ascension of the body expressed in time.

If the observation is made on a star when it is on the lower branch of the meridian, as it is when the star lies below the north pole of the heavens, the exact sidereal time of transit must be increased by 12 hours. If this result exceeds 24 hours, it must be diminished by that amount.

The Meridian Circle.

24. The **meridian circle** differs but little from the transit instrument, except in having a graduated circle attached to its axis of rotation whose centre is in that axis and whose plane is perpendicular to it. The telescope and the circle revolve together, and the angle through which the telescope turns is shown by the arc of the graduated circle that sweeps past a fixed index.

EXPLANATION. The figure represents the projection of a meridian circle on the plane of the meridian, the nearer or western pier being omitted. L is the rotation axis of the telescope AB; E is the remote or eastern pier; *ab* is the graduated circle firmly attached to the axis L; and *d* is the fixed index.

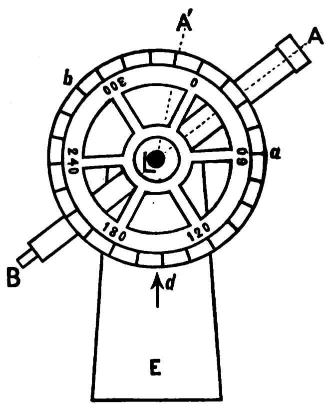

Fig. 9. The meridian circle.

If we first take the reading of the circle shown by the index *d* when the line of collimation has the position LA, and again take the reading of the circle shown by *d* after the telescope has been turned till its line of collimation has the position LA′, the former reading subtracted from the latter will give the length of the graduated arc that has swept past *d* during the motion, and this will be the measure of the angle ALA′.

Inasmuch as the circle and telescope turn together, the reading of the circle will always be the same when the telescope has the same direction. The reading when the telescope is directed toward the pole of the heavens, and which we may call the *polar reading*, can be found as follows: direct the line of collimation to a star that is very near the pole at the instant of its upper culmination, and take the reading of the circle; then, after an interval of 12 hours, direct the line of collimation to the same star at the instant of its lower culmination, and take the reading of the circle; the half sum of these readings (after both are corrected for atmospheric refraction) will be the *polar reading.*

If we subtract 90° from the polar reading we have what may be called the *equinoctial reading,* that is, the reading of the circle when the line of collimation is in the plane of the equinoctial.

Method of Finding Declinations.

25. The declination of a heavenly body is found by means of the meridian circle. The operation consists in finding the reading of the circle when the line of collimation of the telescope is directed to the body at the instant of its upper culmination.

As the body approaches the meridian, the telescope of the meridian circle is turned on its axis of rotation till the line of collimation has nearly the proper elevation, and when the body enters the field of view the instrument is elevated or depressed till the body seems to move along the horizontal wire. When the body reaches the middle vertical wire the reading of the circle is taken at the index d; this reading, corrected for atmospheric refraction, and then diminished by the equinoctial reading, is the required declination.

If the reading found is greater than the equinoctial reading, the difference will be *positive,* and the declination *north;* if the reading found is less than the equinoctial reading, the difference will be *negative,* and the declination *south.*

The descriptions given in this and in the preceding articles are only intended to impart a general notion of the instruments used, and of the methods employed in finding the right ascensions and declinations of the heavenly bodies; more detailed accounts belong to the subject of *practical astronomy.*

II. OF THE STARS.

Classification of Stars.

26. The fixed stars are divided into classes according to their apparent brightness; the brightest stars are said to be of the **first magnitude**, those next in order of brightness are said to be of the **second magnitude**, and so on down to the faintest that can be seen with the naked eye by the ordinary observer, which are usually classed as stars of the **sixth magnitude**. Still fainter stars are rendered visible by the aid of the telescope, and the same method of classification is continued to the **sixteenth magnitude**, beyond which it is seldom extended.

This method of classification is perfectly arbitrary, and astronomers are by no means agreed as to the classes to which certain stars are to be assigned. Amongst those of the same magnitude, also, very great differences of brightness exist, more even than between some that are classed in different magnitudes. The lines of division between the stars of the different magnitudes are the result of usage. According to Sir John Herschel there are 23 or 24 stars of the *first magnitude*, from 50 to 60 of the *second magnitude*, about 200 of the *third magnitude*, and so on, the numbers in each class increasing very rapidly as we descend in the scale of brightness. He estimates that the entire number of stars included in the first seven magnitudes is between 12,000 and 15,000. The number of stars in the remaining classes are counted by millions.

Astronomers are sometimes in doubt as to which class a star belongs, and in such cases it has been the practice to place it between two classes; thus, if a star is between the second and third magnitudes, it is numbered 2·3 or 3·2.

Both of these signs indicate that the star in question is between the second and third magnitudes, the former denoting that it is nearer the *second*, and the latter that it is nearer the *third* magnitude.

Catalogues of Stars.

27. A **catalogue of stars** is a tabular statement of the right ascensions and declinations of certain stars together with their several magnitudes.

Numerous star catalogues have been published, but the most extensive one is that of Argelander, which contains, approximately at least, the places of all the stars down to the ninth magnitude, and lying between the north pole of the heavens and a diurnal circle 2° south of the equinoctial. This catalogue has been extended in the southern hemisphere by Dr. Gould of the Cordova Observatory, in South America, and the entire catalogue now embraces more than half a million of stars. Catalogues like this are of great value to the astronomer, but others of greater accuracy, though containing fewer stars, are found to be more generally useful. Perhaps the most valuable one of the latter class is the British Association Catalogue, which gives the positions of more than 8,000 stars.

Star Maps and Celestial Globes.

28. When we know the right ascensions and declinations of the principal stars, we can show their relative positions and groupings by plotting them either on a plane surface or on the surface of a sphere. In the former case we have a **star map** and in the latter a **celestial globe**.

Star maps and celestial globes are constructed on the same general principles as terrestrial maps and globes, hour circles in the former corresponding to meridians in the latter, and diurnal circles in the former to parallels of latitude in the latter.

Terrestrial maps represent the relative positions of objects as seen from *above*, whereas star maps represent them as seen from below. Hence, for regions south of the pole the top of the map is *north*, and the right hand is *west;* for regions north of the pole the top of the map is *south*, and the right hand is *east*. In like manner a celestial globe represents the relative positions of the stars as they would appear to an observer at its centre and looking outward. In using a star map, therefore, we imagine it to be placed between the eye and that part of the heavens which it represents; in using a celestial globe, we suppose the eye to be placed at its centre.

The configurations of star groups are always the same, but in consequence of the motion of the observer the line joining any two stars is continually changing its apparent direction; hence it is impossible to point out the direction of one star from another in the same manner that we indicate the direction of one place from another on the surface of the earth. This is shown in Fig. 10, which represents the group of stars that is commonly called the *dipper* in different positions as it circles around the pole.

EXPLANATION. Figure 10 shows the positions of the dipper (a part of the great bear) as it appears at different seasons. A is its position at 9 o'clock on the 15th of May; B is its position at 9 o'clock on the 15th of August; C is its position at 9 o'clock on the 15th of November; and D is its position at 9 o'clock on the 15th of February.

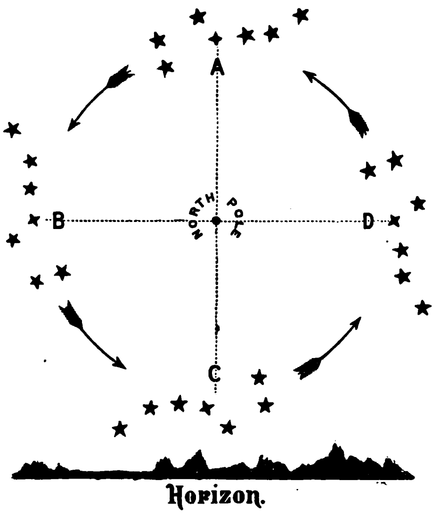

Fig. 10. Circumpolar stars.

Of two stars which are near together and on the same side of the pole, that is said to be most *northerly* which lies nearer the north pole; that which comes to the meridian first is said to *precede*, and the other one is said to *follow*. These terms are often used to describe the position of one star with respect to another;

thus, if we say that the star A is *south following* the star B, we mean that the star A is further from the north pole than the star B, and that A crosses the meridian after B.

Constellations.

29. The stars are not uniformly distributed over the heavens, but are aggregated in groups, whose boundaries are more or less distinctly outlined. These groups, which are called **constellations**, were recognized by the earliest astronomers, and many of them still bear names that were given to them as long ago as the time of Hipparchus.

The earlier star maps and globes were covered with rude figures of men and animals, each of which stood for a particular constellation; such figures are passing into disuse, and the names of the constellations are now used simply to indicate certain portions of the heavens. The boundaries of the constellations are usually laid down on the map or globe, and to a certain extent they afford a convenient means of referring to particular stars. In the same way that it is easier to describe Washington as the capital of the United States, than to say that its longitude is 5h. 8m. W. and its latitude is 38° 53′ N., so it is easier to describe Regulus as the principal star in the constellation Leo, than to say its right ascension is 10h. 2m. and its declination is 12° 33′ N.

Astronomers do not entirely agree as to the boundaries, nor even as to the number of the constellations. There were 48 ancient constellations, but these did not cover the entire celestial sphere, and others have been added in modern times; some of the latter have not been accepted by astronomers. According to Proctor there are now 84 recognized constellations, which may be divided into three classes, viz.: *zodiacal, northern,* and *southern* constellations. Of these, some are so near the south pole as to be either wholly or nearly invisible to an observer in the latitude of New York. Others are comparatively insignificant, either on account of their small size, or because of the faintness of the stars embraced within their limits.

Names and Designations of Stars.

30. The earlier astronomers gave particular names to the principal stars, and some of these are yet in general use. Thus, the principal star in the constellation *Canis Major* is called **Sirius**, the principal star in *Taurus* is **Aldebaran**, that in *Lyra* is **Vega**, and so on.

Bayer introduced the plan now in use, of designating the stars in each constellation by letters of the Greek alphabet, using Roman letters and numbers when the Greek letters were exhausted. The brightest star in each constellation is called α, the next brightest β, and so on. Thus, the brightest star in the constellation *Leo* is called α *Leonis*, the next brightest β *Leonis*, and so on. In some cases, however, the order of brightness is not indicated by the order of the letters employed.

The Zodiac and Zodiacal Constellations.

31. The **zodiac** is a zone or belt extending about 8° both north and south of the ecliptic. This belt is of importance only because it embraces the apparent paths of the sun, the moon, and the principal planets.

The ecliptic and the zodiac are divided into 12 equal parts called **signs**. The names of the signs, beginning at the vernal equinox and counting from west to east, together with their English equivalents and the characters by which they are denoted, are as follows: **Aries**, the *ram*, ♈; **Taurus**, the *bull*, ♉; **Gemini**, the *twins*, ♊; **Cancer**, the *crab*, ♋; **Leo**, the *lion*, ♌; **Virgo**, the *virgin*, ♍; **Libra**, the *balance*, ♎; **Scorpio**, the *scorpion*, ♏; **Sagittarius**, the *archer*, ♐; **Capricornus**, the *goat*, ♑; **Aquarius**, the *waterman*, ♒; and **Pisces**, the *fishes*, ♓.

The **zodiacal constellations** have the same names as the signs of the zodiac, but are not coincident with them. When the constellations were named it is probable that each coincided very nearly with the sign of the same name, but in consequence of the precession of the equinoxes the signs of the zodiac have fallen back with respect to the stars, till now, after the lapse of 2000 years, the *constellation* Aries has come to coincide very nearly with the *sign* Taurus, the *constellation* Taurus with the *sign* Gemini, and so on. This would seem to indicate that the zodiacal constellations were named more than a hundred years before the beginning of the Christian era.

Northern and Southern Constellations.

32. The **northern constellations** are those that lie between the zodiac and the north pole of the heavens. The most important of these are, **Ursa Major**, the *great bear;* **Ursa Minor**, the *little bear;* **Draco**, the *dragon;* **Cepheus**; **Cassiopeia**; **Camelopardus**, the *giraffe;* **Bootes**; **Corona Borealis**, the *northern crown;* **Hercules**; **Lyra**, the *lyre;* **Cygnus**, the *swan;* **Perseus**; **Auriga**, the *waggoner;* **Serpentarius** or **Ophiuchus**, the *serpent bearer;* **Serpens**, the *serpent;* **Aquila**, the *eagle;* **Delphinus**, the *dolphin;* **Pegasus**; and **Andromeda**.

The first six of the constellations above named are said to be *circumpolar*, that is, they circle around the pole without sinking below the horizon.

The **southern constellations** are those that lie between the zodiac and the south pole of the heavens. The most important of these, that are wholly or for the most part visible in the latitude of New York, are **Cetus**, the *whale;* **Orion**; **Canis Major**, the *great dog;* **Canis Minor**, the *little dog;* **Crater**, the *cup;* **Corvus**, the *crow;* **Eridanus**, the *river Eridanus;* and **Piscis Australis**, the *southern fish.* The principal constellations that are invisible in our latitude are **Argo Navis**, the *ship Argo;* **Hydra**; **Centaurus**, the *centaur;* **Lupus**, the *wolf;* **Corona Australis**, the *southern crown;* and **Crux Australis**, the *southern cross.*

The minor constellations, both northern and southern, may be found on any good celestial globe.

The student should familiarize himself with the location, and the names of the leading stars, of the principal constellations. This is most readily accomplished by the aid of a celestial globe.

The Star Maps.

33. A preliminary notion of the general location of some of the most important constellations may be obtained from the following miniature maps and the accompanying descriptions.

Method of Using the Maps.—Map I. is to be held so as to be perpendicular to a line from the eye to the pole star, and then turned around till the constellations on the map and in the heavens have corresponding positions with respect to the meridian. At 9 o'clock in the evening of May 15th the vertical line through the middle of the map will coincide very nearly with the meridian; at other times the map must be turned around till the middle vertical line passes through Polaris and γ Ursæ Majoris. Maps II., III., IV., and V. are to be held so that the middle vertical line of each shall coincide with an hour circle, the top of the map being toward the north. At 9 o'clock in the evening of the day named on any map the middle vertical will coincide with the meridian; at other times the map must be turned around till it corresponds in position with the stars that it represents. It is to be noted that the right hand side of each of the last *four* maps lies to the *west* and the left hand side to the *east,* just the reverse of what obtains in a terrestrial map.

Method of Tracing out the Constellations.

34. The great bear. The seven principal stars of this constellation form a group that is commonly known as the **Dipper.** This group circles around the north pole of the heavens, as shown in Fig. 10. The star nearest the pole is called α, and the other stars of the group, taken in order, are called β, γ, δ, ϵ, ζ, and η, as shown in Map I.

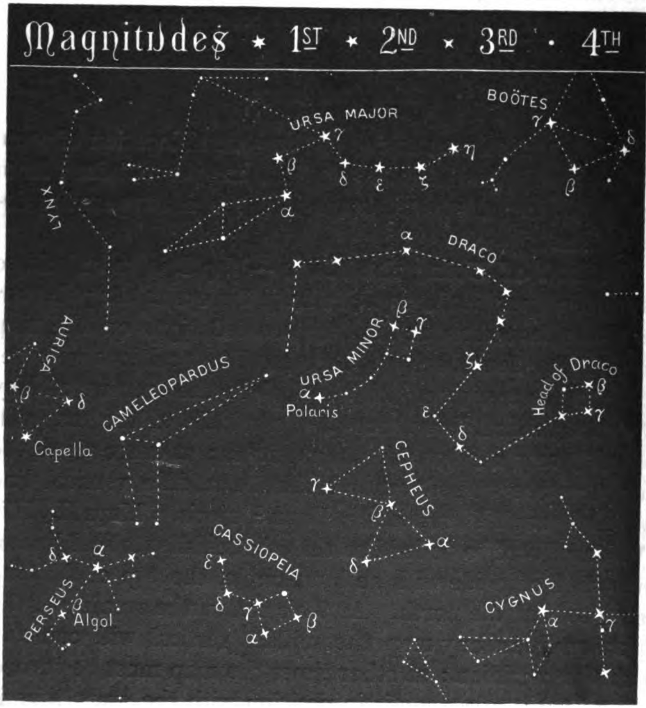

Fig. 11. MAP I., May 15th, 9 o'clock P.M.

This constellation gives us two convenient measures which are of continual use in estimating distances in the heavens: the distance from α to β is about 5°, and the distance from α to η, that is, the entire length of the dipper, is about 25°.

The little bear. The stars α and β of the great bear are called **pointers**, because the line from β to α, when prolonged about 30°, passes through the **pole star**, which is the principal star in the little bear. This star is called α Ursæ Minoris, or more commonly **Polaris**, and it is the star around which all the other stars appear to revolve. The seven principal stars of this constellation also form the figure of a dipper, but its handle is curved in a different way from that of the other dipper, as shown in **Map I.**

The handles of the two dippers, which correspond to the tails of the two bears, are turned toward opposite points of the heavens.

Cassiopeia. A line from δ Ursæ Majoris to the pole star, and then prolonged as much farther, goes to the star β in Cassiopeia. The five principal stars of this constellation form a figure shaped like a wide W, having its top toward the pole. The Greek letters that designate these stars, taken in order, form the word $\beta\alpha\gamma\delta\varepsilon$, as shown on Map I.

Cepheus. A line drawn from α to β Cassiopeiæ, and then prolonged about four times its own length, goes to the principal star in Cepheus, which is called α Cephei; β Cephei is on a line from α toward Polaris, and is about 7° from the former; δ Cephei lies at the vertex of a nearly equilateral triangle, whose other vertices are α and β. The other stars of this constellation may be learned from the map.

Draco. A line from δ Cassiopeiæ to β Cephei, when prolonged a distance equal to itself, goes to the **Head of** the Dragon, which is marked by 4 stars arranged in the form of a lozenge. Starting from the head, the remaining principal stars form a figure shaped somewhat like the letter Z and enclosing the constellation Ursa Minor. The lower line of the Z lies midway between the two bears, and is parallel to the tail of the great bear.

Andromeda. If a line is drawn from Polaris to β Cassiopeiæ, and prolonged an equal distance, it will go to α Andromedæ, and in like manner if a line is drawn from Polaris to ε Cassiopeiæ, and prolonged an equal distance, it goes to γ Andromedæ. The star β lies nearly midway between α and γ. Knowing then these, the other stars of the constellation may be found by means of Map II.

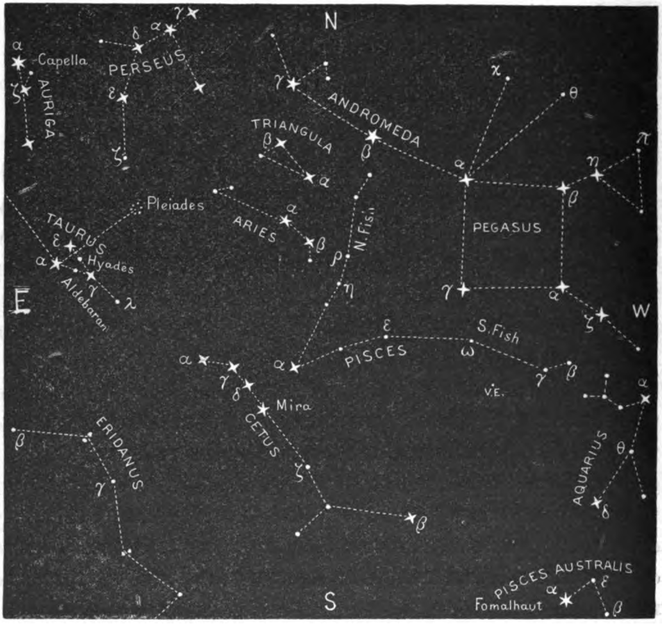

Fig. 12. MAP II., 9 o'clock P.M., December 1st.

Perseus. A line from β to γ Andromedæ, when prolonged an equal distance, reaches α Persei. At a distance of about 10° nearly south of α is β Persei, or *Algol*, a noted variable star. The stars α and β Persei with γ Andromedæ form a triangle, right-angled at β Persei. The other principal stars of Perseus may be found from the map.

Auriga. If we draw a perpendicular to the line joining Polaris and α Cassiopeiæ at its middle point, and prolong it on the side of Perseus, it will pass through Capella, the brightest star of Auriga. This star is about 45° from the pole. If the line from δ Persei to α Aurigæ is prolonged it goes to β Aurigæ, a star of the second magnitude. The other stars of this constellation can be found by the aid of Maps III and I.

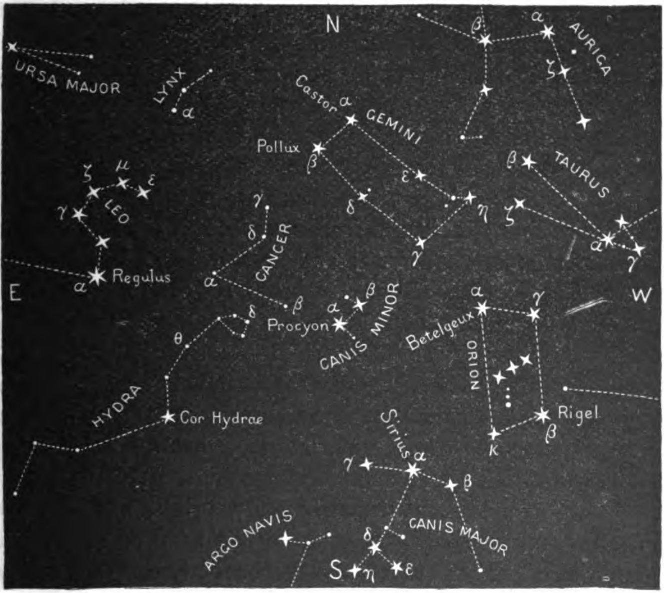

Fig. 13. Map III., 9 P.M., March 1st.

Taurus. Aldebaran, the brightest star in Taurus, together with Capella and Algol, form an isosceles and nearly equilateral triangle, Aldebaran being at the vertex farthest from the pole. Aldebaran is a red star, and with four other, but smaller ones, it forms a letter V with its opening turned towards Capella. This V-shaped cluster is called the **Hyades**. If the bottom of the V is joined with a fourth magnitude star called λ Tauri, the V is converted into a Y. A smaller and more compact cluster, called the **Pleiades**, 15° northwest of the Hyades, is a prominent object. The stars β and ζ Tauri, which form the tips of the bull's horns, are easily found by the aid of Map III.

The Ram and the Fishes. A line from ε Cassiopeiæ to γ Andromedæ when prolonged passes through α Areitis and α Piscium, the four stars dividing the line into nearly equal parts. The star β Arietis lies about 5° southwest of α Arietis, and is a trifle fainter than that star. The other stars of these constellations are unimportant, but may be traced by means of Map II.

The Whale. If the stem of the Y, described in speaking of the Hyades, is prolonged it will pass through α Ceti, which lies at the vertex of an isosceles triangle, whose base is the line joining the Hyades and the Pleiades. About one-third of the way from α Ceti to α Piscium we find the star γ Ceti, and at about 10° southwest of γ Ceti is the noted *variable* star called **Mira**. The other principal stars can be found by the aid of Map II.

The Twins. If a line is drawn from α Persei to a point midway between α and β Aurigæ and then prolonged an equal distance it goes to two bright stars in Gemini. The northernmost of them is named Castor and the southernmost Pollux. Both Castor and Pollux are bright stars of the second magnitude, and each marks the head of one of the twins. The general direction of the body of each of the twins is southwest, and is marked by a row of stars. These rows which mark the bodies of the twins form a well marked and conspicuous rectangle whose breadth is about 5° and whose length is more than 20°.

Orion. This is the most magnificent of all the constellations. It comes to the meridian about 9 o'clock on the 1st of February, being about 25° southeast of the Hyades. It is marked by four brilliant stars which form a trapezoid, whose greatest diagonal is nearly 20° in length. The stars at the extremities of this diagonal, called Betelgeux and Rigel, are both of the first magnitude, and the line joining them is nearly bisected by a line of three stars of the third magnitude, which form what is called the **belt of Orion.** The extreme stars of the belt are 3° apart, and the middle one bisects this distance. Just below them is a line of small stars running north and south which form the **Sword of Orion.** The belt points to Aldebaran on the northwest and to Sirius on the southeast.

The Great Dog. The star Sirius, which is the principal star of Canis Major, and the most brilliant one in the heavens, lies as has been said in the prolongation of the belt of Orion to the southeast; it also lies in the prolongation of a line from β to κ Orionis. This star, which cannot be mistaken for any other, enables us to trace out the constellation to which it belongs.

The Little Dog. The principal star in Canis Minor is called Procyon. It lies to the eastward of Betelgeux, and is at one vertex of a nearly equilateral triangle whose other vertices are Betelgeux and Sirius.

The Lion and the Crab. Regulus, the principal star in the Lion, is at the eastern vertex of an isosceles triangle, whose base is formed by joining Procyon and Pollux. The equal sides of this triangle are about 35° in length. The triangle just described includes the principal stars of the constellation Cancer. Regulus is very near the line formed by prolonging the line from α to β of the Great Bear. The star η Leonis is about 5° due north of Regulus and, taking the line joining them as a handle, the stars γ, ζ, μ, and ϵ form the blade of a sickle, whose cutting edge is turned to the west. The bright star β can easily be found by referring it to the stars in the Sickle.

Hydra. The principal star of this constellation is called Cor Hydræ. It lies south of a line joining Regulus and Procyon, and is so placed as to form with them a nearly equilateral triangle.

Bootes. If the line from ζ to η Ursæ Majoris is prolonged and slightly curved away from the pole, it will go to Arcturus the principal star in Boötes. Arcturus is a star of the first magnitude, and is easily recognized. The other principal stars can be found by the aid of Maps I. and IV.

Virgo and Libra. The principal star of Virgo, called Spica, is of the first magnitude and about 30° southward of

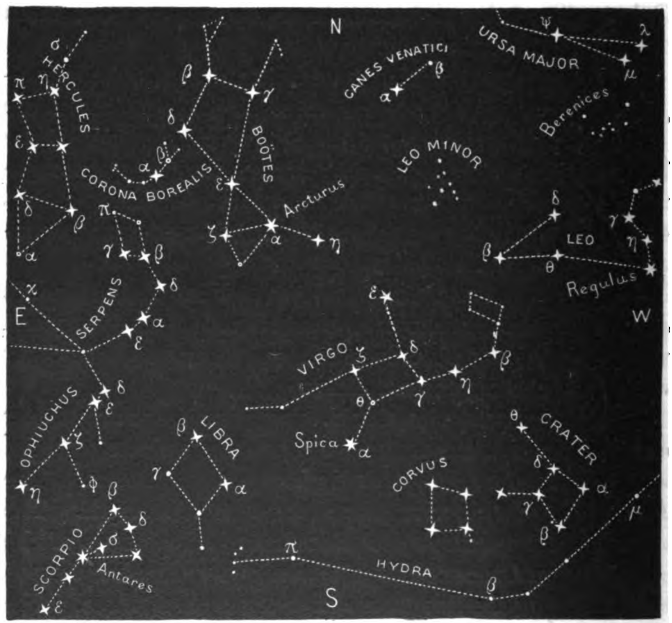

Fig. 14. Map IV., 9 P. M., June 1st.

Arcturus. The other important stars of this constellation lie to the north and west of Spica, and are easily traced. The four principal stars of Libra form a small quadrilateral, whose longest diagonal lies north and south. The upper star in the quadrilateral is about 20° nearly west of Spica.

The Crown, Ophiuchus, the Serpent, and Her-

cules. The line from ε to ζ of the Great Bear if prolonged about 35° goes to the Crown, and if prolonged about 10° further it goes to the head of the Serpent, which is marked by the four stars β, γ, κ, and π Serpentis. The constellation of the Crown is easily recognized, as it consists chiefly of a number of stars very close together, and arranged in an arc of a circle whose concavity is turned

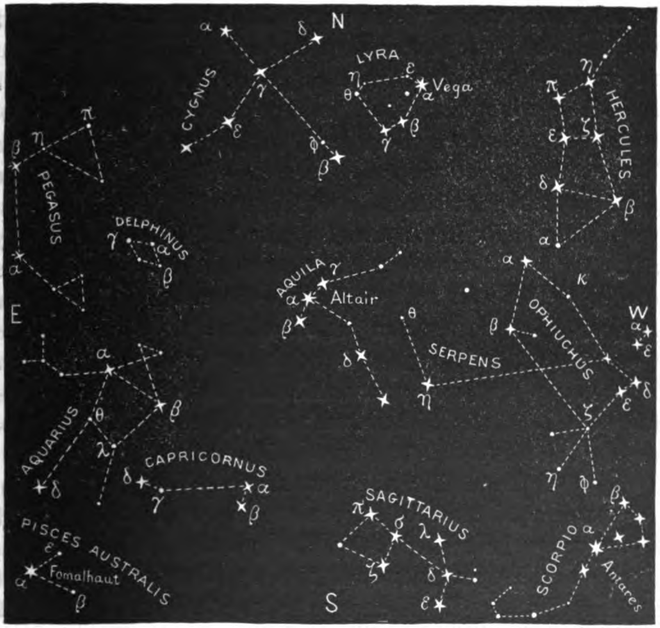

Fig. 15. Map V., 9 o'clock P. M., September 1st.

towards the north pole. Ophiuchus, or the *serpent bearer*, is represented with his head at the star marked *a* and with his feet on Scorpio, and holding in his grasp a huge serpent whose general direction is shown on maps V. and IV. A line from γ to ε of the Great Bear when prolonged passes through a quadrilateral formed by the stars ε, η, ζ, and π, in what is called the **girdle of Hercules.** Hercules is represented as standing with his head at *a*, his girdle as just explained, and his feet reaching nearly to the Dragon.

The Lyre, the Swan, and the Eagle. The star Vega, which is the principal star in the Lyre, and which is the brightest star in the northern hemisphere is at the vertex of a large and nearly right-angled triangle, whose hypothenuse is a line joining Arcturus and Polaris. It cannot be mistaken for any other star. Two small stars towards the west and very near Vega form with it a small equilateral triangle. The upper one is ϵ, a remarkable double star. Below and to the eastward are two other stars called β and γ, between which there is a remarkable ring nebula. The swan is to the east of Lyra, and its four principal stars form a very distinct cross whose length is along the milky way. The body of the cross is formed by the stars α, γ, and β, and it is completed by the stars δ and ϵ, which are nearly in a line through γ. Altair, the principal star in the Eagle, is at the southern vertex of an isosceles triangle, whose base is formed by a line joining Vega and γ Cygni. Two small stars, one above and one below Altair, at distances of 2° and 3°, form with it an arc slightly curved toward the west.

Pegasus, the Dolphin, and the Waterman. The three principal stars of Pegasus, namely α, β, and γ, with the star α Andromedæ, form a square called the **great square of Pegasus,** whose sides are about 15° in length as shown in Map I. The four principal stars of the Dolphin form a beautiful lozenge, which is nearly south of α Cygni. It is also on the prolongation of the line from α Andromedæ to β Pegasi. If that diagonal of the great square of Pegasus which passes through α Pegasi is prolonged a distance equal to its own length, it will go to α Aquarii. To the eastward of α are four stars forming a letter Y with its opening turned toward γ Pegasi.

The Scorpion. The line from Regulus to Spica, when prolonged to a distance nearly equal to that between the stars named, goes to Antares the principal star in the Scorpion. This is a red star of the first magnitude, and cannot easily be mistaken for any other star. Antares is the middle one of three stars, forming an arc whose concavity is toward the south. At right angles with this, and to the westward, is a second arc of three stars, having its concavity toward the star *α* Scorpii. If we imagine this to be the bow of a kite, the remaining stars commencing with *α* form the tail, as shown in Map V.

When the student has become familiar with the leading stars of the heavens he can trace out the minor ones by the aid of more detailed maps, such as are to be found in Proctor's Star Atlas.

The Milky Way.

35. The **Milky Way**, or the **Galaxy**, as it is often called, is a luminous belt, or zone, extending entirely around the heavens. It is not everywhere of uniform width, is somewhat irregular in its boundary, and it often presents deviations, branches, and gaps; on the whole, however, its middle line does not differ materially from a great circle of the sphere, its inclination to the equinoctial being about 63°. It comes nearest to the north pole in the constellation Cassiopeia, and to the south pole in the neighborhood of the Southern Cross. It is seen most favorably during the early evening in the month of September, at which time it presents the appearance of a magnificent arch, passing through the zenith and running from northeast to southwest.

The telescope shows that this remarkable belt is made up of a countless multitude of stars, so far distant from us as to be invisible to the naked eye, and so close together as to give it the appearance of an almost uniformly luminous cloud. It has been estimated that the milky way contains more than 20,000,000 of stars that can be seen with the largest telescopes.

Double and Multiple Stars.

36. Many stars that seem *single* to the naked eye, or with small telescopes, are in reality **double**, that is, when viewed with more powerful telescopes they are seen to consist of a pair of stars, separated from each other by only a few *seconds* of arc. When very powerful telescopes are directed to such stars, they are sometimes found to consist of *three, four,* and even *more than four* components, closely grouped together; such groups are called respectively *triple, quadruple,* and *multiple* stars.

Herschel limits the class of double stars to those whose components are less than 32″ apart. The whole number of double stars within this limit, so far as known, is more than 6000. The components of some of these can be seen as separate stars with telescopes of moderate power, others require for their separation instruments of the highest degree of excellence. The stars Castor, β Scorpionis, ζ Ursæ Majoris, and γ Leonis are familiar examples of double stars that are easily separated; Sirius is a double star that can only be separated by a powerful telescope.

The components of a double star may happen to lie in nearly the same direction from the observer, and yet be so far apart as to have no appreciable physical connection; such stars are said to be **optically double.** Again, the components of a double star may revolve around their common centre of gravity in regular orbits; these stars, which are said to be physically connected, are called **binary stars,** to distinguish them from those that are optically double. It is highly probable that a great majority of double stars belong to the binary class.

The star ε Lyræ is a striking example of a *double binary.* With a small telescope this star is seen as a widely separated but simple double; with a more powerful instrument each component is seen to be double. Observation shows that the two pairs revolve around their common centre of inertia, in an immensely long period, while each of the pairs revolves about its own centre of inertia in a very much shorter period.

The star θ Orionis, which is situated in the midst of a great nebulæ, presents the appearance of four brilliant stars, forming a trapezium whose longest diagonal is about 21″; these are accompanied by two exceedingly minute stars, the whole forming a sextuple star, or a multiple star of six components. This group forms a test object for telescopes of from 4 to 5 inches aperture.

Clusters and Nebulæ.

37. In many parts of the heavens great numbers of stars are crowded together in masses that are called **clusters**. The Pleiades afford an example of this kind of aggregation; in this cluster no more than *six* or *seven* stars are usually visible to the naked eye, but when viewed with a telescope of moderate power the number is increased to *sixty* or *seventy*. The cluster in Cancer called Præsepe, and the cluster in Perseus, are barely visible with the naked eye, but when viewed with a telescope they are shown to contain hundreds of closely compacted stars. The telescopic appearance of the latter is shown in Fig. 16. It is on a line from δ Cassiopeia to α Persei at about one-third of the distance from the former.

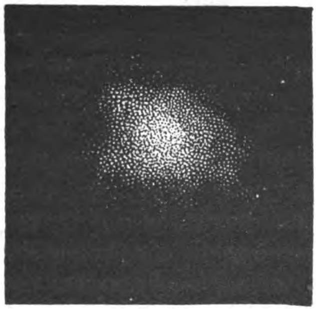

Fig. 16. Cluster in Perseus.

The globular cluster in Hercules is another example of an object which is barely discernible with the naked eye, but which is shown in the telescope as a grand assemblage of glittering stars. Its telescopic appearance is shown in Fig. 17

Fig. 17. Cluster in Hercules.

In some regions of the heavens the stars, without being grouped in regular clusters, are so closely compacted that for every star visible to the naked eye there are hundreds that are only discernible with the telescope. Fig. 18 gives a telescopic view of a small portion of the constellation Gemini, within which there are no more than six or seven stars that can be seen with the naked eye.

The term **nebula** has been used to designate any of those cloud-like patches of faintly luminous matter, of which thousands are seen by the telescope to be scattered over the dark background of the heavens.

It has been shown by the spectroscope that some of these objects are extended masses of incandescent gases or vapors; these are the true nebulæ.

It is difficult to draw a line of division between clusters of stars and nebulæ, for many objects that appear to be

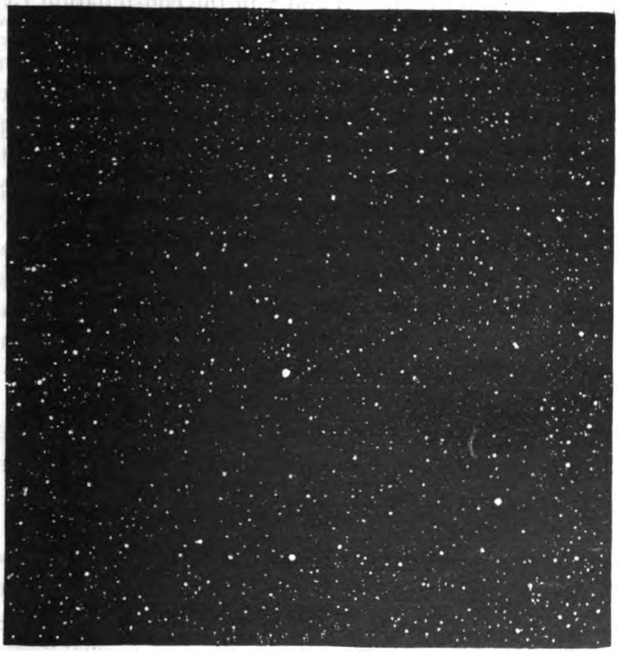

Fig. 18. Star map of a small area in the constellation Gemini.

nebulæ when seen with small telescopes are found to be clusters of stars when viewed with instruments of higher power. For this reason it has been found convenient to call all of these objects nebulæ, and then to designate the two classes as *resolvable* and *irresolvable*.

Nearly all of the nebulæ are exceedingly irregular in form; a few, however, are so nearly regular in shape as to admit of a species of classification. The most noteworthy of these classes are the following;

1°. **The annular nebulæ.** These are shaped like a ring, which may be either circular or elliptical. Only four such nebulæ are known; the most remarkable of these is situated between the stars β and γ in the constellation Lyra, and may be seen with a telescope of moderate power. The nebulous ring is of an elliptical form, and its interior seems to be filled with a faintly luminous matter, so that the entire nebula appears like a tenuous veil stretched on a hoop.

2°. **The elliptical nebulæ.** These have an elongated form, approaching to that of an ellipse. The best example of this class is the great nebula of Andromeda. It is faintly visible to the naked eye; when viewed with a small telescope, its form is that of an extremely elongated ellipse; but under higher powers, its boundaries are greatly extended, it loses much of its elliptical form, and presents two remarkable black streaks or rifts extending from end to end.

3°. **The planetary nebulæ.** These are nearly circular in shape, resembling somewhat the disks of the planets. About twenty nebulæ of this class are known, some of which are double.

4°. **Spiral nebulæ.** These are but few in number, and for the most part can only be seen with telescopes of the highest excellence. They appear to be made up of irregular spiral bands which spring from a central nucleus or eye. The nebula known as 51 Messier, situated in the constellation Canes Venatici, is now ranked with the spiral nebulæ. Sir John Herschel says that in an 18-inch reflector it presents the appearance of a large globular nebula surrounded by a ring which is divided, through two-fifths of its circumference, into two laminæ. Outside of the ring is a bright round nebulous mass. In the great 6-foot reflector of Lord Rosse, the principal centre of condensation is seen to be the origin of a great number of spiral whorls, the denser portions of which correspond to the ring. These curious whorls extend out as far as the secondary centre, which also seems to be the origin of a minor set of spiral tongues.

This nebula affords an example of the different appearances presented by the same object under different degrees of magnifying power.

Among the more irregular nebulæ some are named from their apparent form. Of these we may note the *crab nebula*

Fig. 19. The Crab Nebula.

in the constellation Taurus, of which a drawing is given in Fig. 19. In ordinary telescopes it has an elliptical outline, but in Lord Rosse's telescope "it is transformed into a closely crowded cluster, with branches streaming off from the oval boundary, like claws, so as to give it an appearance that in a measure justifies the name by which it is distinguished."

Fig. 20 represents the central parts of the great nebula of Orion as drawn by Trouvelot. It is the most brilliant and also the most complicated in form of all the nebulæ which are visible in our latitudes. It contains in its brightest part a multiple star, θ Orionis. This star consists of four components, arranged in the form of a trapezium, visible in a moderately good telescope. It is supposed by some that this nebula is variable, that is, its brilliancy is not always

Fig. 20. Central part of the Great Nebula in Orion as drawn by Trouvelot.

the same. Another remarkable nebula surrounds the star η Argûs, in the southern hemisphere.

Fig. 21 is a drawing made by Sir John Herschel. It covers an area of the heavens equal to five times that covered by the full moon. Sir John Herschel studied it with an 18-inch reflector, but was unable to discover any indication of its being resolvable into stars.

Nebulæ are not distributed uniformly over the heavens.

In some regions there are but few, and, again, in other regions their number is very great. They are particularly numerous in the constellations Leo, Virgo, and Ursa Major.

Fig. 21. Nebula in Argûs.

As a general rule, they increase in number as we recede from the milky way, being most numerous near the poles of the great circle which marks the general direction of that belt.

Colors and Varying Brightness of Stars.

38. The color of a great majority of the stars is white like the sun, but there are some stars of a yellowish tint, some are orange, and not a few are red. Secchi, who bases his statement on the evidence of the spectroscope, says that "the tints of the stars called white are for the most part blue; from this color there is a passage by insensible degrees to true white, then to yellow, then to orange red, and finally to blood red. Sirius, Vega, Castor, and Regulus are *blue;* Procyon and Altair, *white;* Capella, Pollux, and *a* Ceti, *yellow;* Aldebaran, Arcturus, and Betelgeux, *orange;* Arcturus and *a* Hercules, *red;* the blood red stars are small."

The components of double stars are frequently colored, and in some instances the colors of the two components are complementary, that is, colors whose combination would form white. In other cases the components have different, but not complementary, colors. The components of η Cassiopeiæ are *yellow* and *purple;* those of γ Andromedæ are *orange* and *green;* those of β Cygni are *yellow* and *blue;* those of ε Boōtis are *orange* and *green;* and those of *a* Piscium are *pale green* and *blue.*

The stars do not always retain the same degree of brightness; in fact, many of them experience a remarkable change of brilliancy; these are called **variable stars.** Secchi says that it is probable that all the stars undergo a greater or less change in brilliancy. This change is particularly marked in those stars whose colors are orange, red, or yellow. In some cases the change is well marked and periodical; in other cases the change is less distinctly manifest, and the periodicity is not established. The star *o* Ceti, commonly called Mira, is one of the most remarkable of the variable stars. Newcomb says, "during most of the time this star is entirely invisible to the naked eye, but at intervals of about eleven months it shines forth with the brilliancy of a star of the second or third magnitude. It is, on the average, about forty days from the time it first becomes visible until it attains its greatest brightness, and it then requires about two months to become invisible; so that it comes into sight more rapidly than it fades away." Another noted variable star is called Algol, or β Persei. It is ordinarily of the second magnitude, and retains this degree of brightness for about 2d. 13h., when it begins to decline in brilliancy, and at such a rate as to become of the fourth magnitude in 3½ hours, and then in about the same time it regains its original brightness. The total period of this star is 2d. 20h. 48m. 55s.

A class of stars very closely connected with variables comprises those which are called **temporary**. The most remarkable star of this class made its appearance in 1572, in the time of Tycho Brahe. It was situated in the constellation Cassiopeia, where it was visible for nearly seventeen months, the greater part of which time it was as brilliant as Venus; it finally disappeared after passing from white to yellow and then to red. In 1670 a star appeared in the constellation of the Swan, which remained visible for two years. In 1848 Hind saw a star in Ophiuchus which suddenly became of the fourth magnitude, and is now visible as a star of the eleventh magnitude. In 1866 a star in the northern crown blazed up to the second magnitude, having previously been of the eighth magnitude, and gradually subsided to its original brilliancy. It is remarkable that the spectrum of this star showed the bright lines of incandescent hydrogen, a fact which gave rise to the theory that the increase in brilliancy of this star was due to the sudden development of an immense volume of this gas.

Aspects of the Heavens.

39. The celestial sphere presents different aspects to observers in different latitudes, that is, the diurnal circles are differently situated with respect to the horizon.

First Aspect.—The **right sphere.** At the equator the horizon of the observer coincides with an hour circle, and consequently in the course of a sidereal day it sweeps over the entire heavens. The diurnal circles are all perpendicular to the horizon, and are bisected by it; hence, all the heavenly bodies rise and set in lines perpendicular to the horizon, and are as long above the horizon as they are below it. A body on the equinoctial rises due east, culminates at the zenith, and sets due west. A body that is not on the equinoctial rises, culminates, and sets at points whose distances from the east point of the horizon, the zenith, and the west point of the horizon, are respectively equal to the *declination* of the body.

On account of the obliquity of the ecliptic, the sun is sometimes on the north side and sometimes on the south side of the equinoctial. At either equinox the sun culminates at the zenith; from the vernal to the autumnal equinox it culminates to the north of the zenith, reaching its northern limit at the summer solstice when it culminates 23° 27′ north of the zenith; from the autumnal to the vernal equinox it culminates to the south of the zenith, reaching its southern limit at the winter solstice, when it culminates 23° 27′ south of the zenith. The days and nights are equal throughout the year.

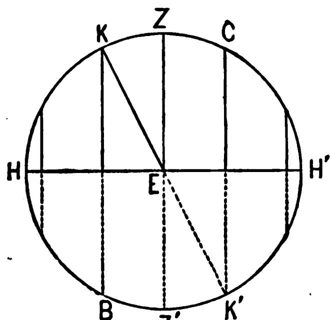

Fig. 22. The Right Sphere.

EXPLANATION. Fig. 22 shows the right sphere projected on the plane of the solstitial colure, the equinoxes being in the horizon; HH′ is the projection of the horizon; ZZ′ is the projection of the prime vertical; and KK′ is the projection of the ecliptic; KB is the projection of the sun's diurnal circle at the summer solstice; and CK′ is the projection of its diurnal circle at the winter solstice.

Second Aspect.—The **parallel sphere.** At either pole, say the north pole, the horizon of the observer coincides with the equator, and always remains fixed in position. The diurnal circles are all parallel to the equator. The fixed stars neither rise nor set, but circle around, remaining always at distances from the horizon equal to their respective declinations. Those north of the equinoctial are always above the horizon, and those south of the equinoctial are always below the horizon.

The sun is in the horizon, or *rises*, at the vernal equinox;

it then ascends slowly till the summer solstice, when its distance above the horizon is 23° 27′; from that time it descends till the time of the autumnal equinox, when it is again in the horizon, or *sets*. From this time till the next vernal equinox it remains below the horizon. Hence, we say that the days and nights at the pole are six months in length.

EXPLANATION. The figure represents the parallel sphere projected on the plane of the equinoctial; EAQV is the equinoctial; V is the vernal equinox; A is the autumnal equinox; and VA is the line of equinoxes; VSA is the projection of that half of the ecliptic which lies north of the equinoctial, S being the projection of the summer solstice; SBS′ is the projection of the sun's diurnal circle on the day of the summer solstice.

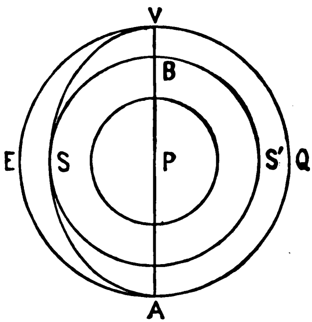

Fig. 23. The Parallel Sphere.

Third Aspect.—The oblique sphere. To an observer at any point between the equator and either pole, say at a point between the equator and the north pole, the horizon is oblique to the axis of the earth, the angle of inclination being equal to the latitude of the place. The diurnal circles are all oblique to the horizon, the angle of inclination counted from the south point being equal to the *complement of the latitude*, that is, to the *co-latitude* of the place; all of these circles except the equinoctial itself are unequally divided by the horizon. For bodies south of the equinoctial the part above the horizon is *less* than the part below, and for bodies north of the equinoctial the part above the horizon is *greater* than the part below; hence, a body whose declination is south is longer below than it is above the horizon, and a body whose declination is north is longer above the horizon than it is below.

A circle described about the north pole, with a spherical radius equal to the latitude of the place, is called the **circle of perpetual apparition**, and a circle about the south pole with an equal radius is called the **circle of perpetual occultation.**

All bodies north of the circle of perpetual apparition are always above the horizon, and all bodies south of the circle of perpetual occultation are always below the horizon, that is, they are perpetually invisible.

If a body's declination is less than the latitude of the place, it culminates south of the zenith; if its declination is equal to the latitude, it culminates at the zenith; and if its declination is greater than the latitude it culminates north of the zenith.

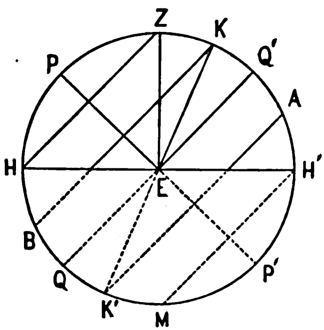

Fig. 24. The Oblique Sphere.

Explanation. The figure represents the projection of the oblique sphere on the plane of the solstitial colure, the equinoxes being in the horizon; PP' is the axis of the heavens; Z is the zenith of the place (supposed to be in north latitude); HH' is the projection of the horizon; QQ' is the projection of the equinoctial; KK' is the projection of the ecliptic; K being the summer and K' the winter solstice; KB is the projection of the sun's diurnal circle on the 21st of June; AK' is the projection of the sun's diurnal circle on the 21st of December; HZ is the projection of the circle of *perpetual apparition;* and H'M is the projection of the circle of perpetual occultation. The latitude of the place is equal to the angle Q'EZ, or to the angle HEP.

When the sun is at either equinox it rises due east, culminates at a point whose distance south of the zenith is equal to the latitude of the place, and sets due west. At these times the days and nights are equal. When the sun is south of the equinoctial, that is, from the autumnal to the vernal equinox, it rises to the south of east, and sets to the south of west, the days being shorter than the nights. When the sun is north of the equinoctial, that is, from the vernal to the autumnal equinox, it rises to the north of east and sets to the north of west, the days being longer than the nights. When the sun is at the winter solstice the days are shortest and the nights longest; when the sun is at the summer solstice the days are longest and the nights are shortest.

From what has been said above, we see that the difference between the lengths of the days and nights depends upon the latitude of the place and the position of the sun in its apparent path amongst the stars.

Additional Definitions.

40. The diurnal circles of the sun, when at the solstices, are called **Tropics**, the northern one being the **Tropic of Cancer**, and the southern one being the **Tropic of Capricorn.**

The diurnal circles through the poles of the ecliptic are called **Polar Circles**, the northern one being the **Arctic Circle**, and the southern one being the **Antarctic Circle.**

Corresponding circles on the surface of the earth are called by corresponding names.

At the tropics the inequality in the lengths of days and nights varies from 0 to 2h. 54m.; between the tropics and polar circles it varies from 0 to 24 hours; and within the polar circles it varies from 0 to 6 months.

Varying Inclination of the Ecliptic to the Horizon.

41. The ecliptic being oblique to the axis of the heavens, its inclination, with respect to the horizon, will be variable. It makes the greatest angle with the horizon when the vernal equinox is at the west point of the horizon; this angle is equal to the co-latitude of the place *plus* the inclination of the ecliptic. It makes the least angle with the horizon when the vernal equinox is at the east point of the horizon;

this angle is equal to the co-latitude of the place, *minus* the inclination of the ecliptic.

At a place whose latitude is 40°, the co-latitude is 50°, the greatest inclination of the ecliptic to the horizon is 73° 27′, and the least inclination is 26° 33′. The inclination may have any value between these limits.

Proper Motion of the Stars.

42. The bodies heretofore considered, that is, the *stars* and *nebulæ*, though regarded as **fixed**, are really in motion, but on account of their enormous distances from us and from each other their motions are scarcely perceptible; they are indeed so slight that thousands of years would be required to produce a change of relative position that would be apparent to the naked eye. Of the stars that are found to have a **proper motion**, that is, a motion with respect to the other stars, only a few move more than a single second of arc in a year, whilst by far the greater number move but a few seconds in a century. A part of what is usually called the *proper motion* of the stars is due to the motion of the sun, which belongs to the same class of bodies as the stars, and which, like them, is undoubtedly moving through space, carrying the planets and their satellites with it.

The bodies we are next to consider are much nearer to us than the stars, and for this reason their motions are more obvious.

III. THE SOLAR SYSTEM.

Bodies that Constitute the Solar System.

43. We have already seen that the **sun** appears to have a progressive motion from west to east, completing the circuit of the heavens in a period that we call a **year.**

The **moon** also has a progressive motion from west to east among the stars, advancing at an average rate of a little more than 13° a day, completing the circuit of the heavens in about 27⅓ days. In her eastward motion she gains on the sun a little more than 12° per day, so that if the two bodies have the same right ascension, at any time, their right ascensions will again be the same after a period of about 29½ days, which period is called a **lunar month.**

Besides the sun and moon, whose eastward motion is progressive and comparatively regular, there are other bodies that move irregularly among the stars, sometimes **advancing,** that is, moving from *west to east,* and sometimes **retrograding,** that is, moving from *east to west.* The arcs through which they advance are always greater than those through which they retrograde, so that they ultimately complete the entire circuit of the heavens, which they do in periods ranging from a little less than 3 months up to more than 164 years. The principal bodies of this class are called **planets,** and the minor ones **planetoids.**

Many of the planets are accompanied by secondary bodies that revolve around them as centres in the same way that they themselves revolve around the sun. These bodies are called **satellites**; thus, the moon is a satellite of the earth.

If to these we add **comets,** which occasionally appear in the heavens and **meteoric streams,** which seem to be closely allied to comets, we have all the bodies whose motions can readily be observed.

The bodies above enumerated, including our earth, which is a planet, constitute a closely connected group called the **solar system.**

Plan of the Solar System.

44. 1°. The **sun** is the central body of the system. As already stated, the sun belongs to the same class of bodies as the stars; like them it has its own proper motion through space, but this motion is so small that it may be disregarded in a general view of the heavens; we may therefore regard its position as *fixed.*

2°. The **planets,** of which *eight* are now known, revolve around the sun from west to east in orbits that are nearly circular, and whose planes are but slightly inclined to each other. These orbits are really ellipses, each of which has one focus at the sun.

The names of the planets, in the order of their distances from the sun, and the signs by which they are designated, are as follows: 1st. Mercury, ☿; 2d. Venus, ♀; 3d. Earth, ⊕; 4th. Mars, ♂; 5th. Jupiter, ♃; 6th. Saturn, ♄; 7th. Uranus, ♅ or ⛢; and 8th. Neptune, ♆. Mercury and Venus, being nearer to the sun than the earth, are called **inferior planets**; Mars, Jupiter, Saturn, Uranus, and Neptune are called **superior planets.**

The orbits of the planets are so little inclined to each other that they are all included within a cylindrical disk, whose diameter is twice the greatest distance of Neptune from the sun, and whose height, or thickness, is considerably less than $\frac{1}{80}$ of its diameter. This disk, whose bases are symmetrically situated with respect to the ecliptic, is thinner in proportion to its diameter than the thinnest of our government coins, and it has been found by observation that it always retains a fixed position with respect to the stars. Hence, for the ordinary purposes of description we may regard the planets as revolving in orbits which lie in the plane of the ecliptic.

3°. The **planetoids**, of which more than 230 are now known, revolve around the sun from west to east in elliptical orbits, each of which has one of its foci at the sun.

The planetoids differ from the planets in several particulars, the most noticeable of which are the following: 1st, they are vastly smaller than the smallest planet; 2dly, their orbits are much more excentric; and 3dly, the planes of their orbits are generally much more inclined to the ecliptic.

4°. The **satellites**, of which 20 are now known, revolve around their *primaries*, that is, around the planets to which they belong, and at the same time they accompany these planets in their journey around the sun.

Of the known satellites, the earth has 1, Mars 2, Jupiter 4, Saturn 8, Uranus 4, and Neptune 1. Of these, the first 15 revolve around their primaries in the same direction that the planets revolve around the sun, that is, their motions are *direct*; the remaining 5 revolve around their primaries in an opposite direction, that is, their motions are *retrograde.*

5°. The **comets** which appear from time to time, revolve around the sun in orbits that are *always* more excentric, and *frequently* more inclined to the ecliptic, than those of the planetoids. In some cases their motions are *direct,* and in some cases they are *retrograde.*

The orbit of a comet may be an *ellipse,* a *parabola,* or an *hyperbola,* but it always has one of its foci at the sun. Those comets which are permanent members of our system move in extremely elongated ellipses.

6°. The **meteoric streams,** which consist of myriads of minute bodies scattered over immense spaces, revolve around the sun in orbits that resemble those of the permanent comets of our system, with some of which they appear to be closely connected.

Definitions and Principles.

45. Because the orbits of the planets are ellipses, each having one of its foci at the sun, the distance of any planet from the sun is continually changing; when nearest the sun it is said to be in **perihelion**, and when farthest from the sun it is said to be in **aphelion.**

The perihelion and the aphelion points of any orbit are the vertices of its **transverse**, or *major axis;* the former is sometimes called the **lower**, and the latter the **upper apsis**, and in this case the transverse axis itself is called the **line of apsides.**

A line from either focus of an ellipse to any point of the curve is called a **radius-vector**; it is shown in analytical geometry that the **mean** or *average value* of all the radii-vectores that can be drawn from either focus of an ellipse to the curve, is equal to the semitransverse axis of that ellipse. Hence, the **mean distance** of any planet from the sun is equal to half the sum of its perihelion and aphelion distances.

The **excentricity** of an ellipse is *the distance from its centre to either focus* divided by *the semitransverse axis,* or what is the same thing, it is equal *to the distance between its foci* divided by *its transverse axis.* Hence, the excentricity of the orbit of a planet is equal to *the difference between its aphelion and perihelion distances,* divided by *the sum of those distances.*

Dimensions of the Planetary Orbits.

46. The mean distance of the earth from the sun, in terms of which the mean distances of all the other planets are expressed, is itself dependent on the **solar parallax,** that is, on the semi-angle subtended by the earth as seen from the sun. The determination of this angle has occupied much of the attention of astronomers for a long period of time, and Prof. Newcomb, in summing up the results deduced from all the different methods that have been used, but not including those of the various expeditions that were sent out to observe the transits of Venus in 1874 and 1882, says that its value is probably between 8″.82 and 8″.86. If we take the mean of them, or 8″.84, as the true value of

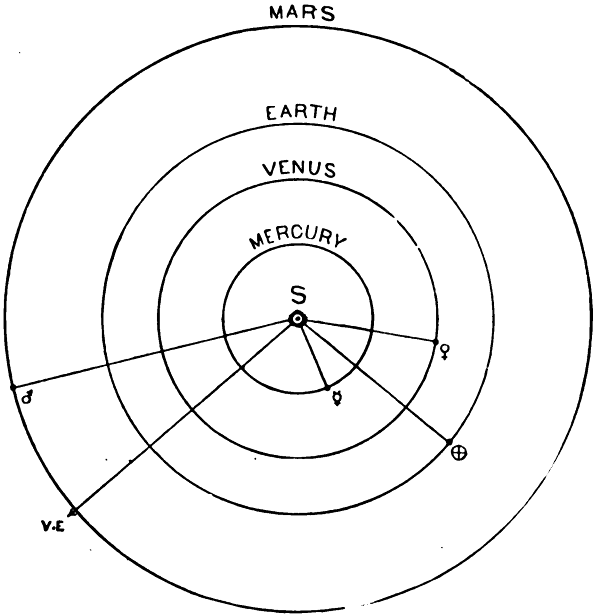

Fig. 25. Diagram of the orbits of the four interior planets.

EXPLANATION. The scale of the diagram is one inch to 92½ millions of miles. The sun being at S, the direction of V-E from S, is that of the vernal equinox; and the perihelion point of each orbit is shown by the place of the sign, that designates the corresponding planet.

the parallax, the mean distance of the earth from the sun is nearly 92½ millions of miles. Assuming this as the correct distance of the earth from the sun, the mean distances of all the planets, to the nearest *quarter of a million of miles*, are given in Table I. The same table gives the excentricity of each of the planetary orbits with the corresponding perihelion and aphelion distances, to the nearest quarter of a million of miles.

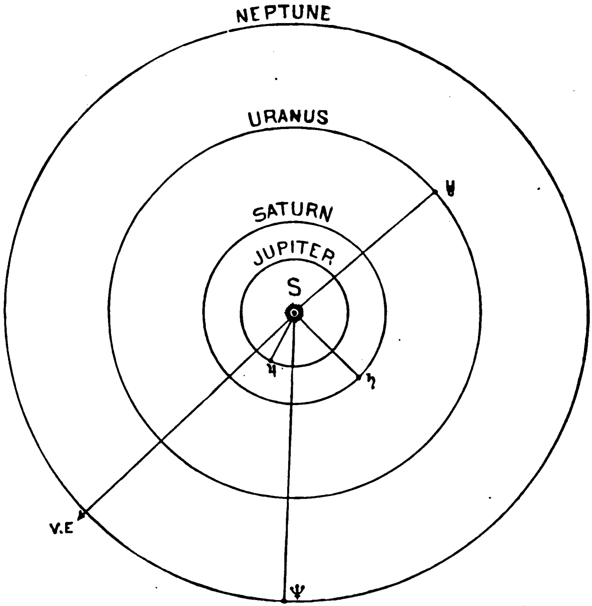

Fig. 26. Diagram of the orbits of the four exterior planets on a smaller scale.

EXPLANATION. The scale of the diagram is $\frac{1}{10}$ of an inch to 92½ millions of miles. In order that it may be compared with the preceding diagram, it must be enlarged 20 times in all directions; S is the place of the sun; the direction from S to V-E is that of the vernal equinox; and the perihelion points of the different orbits are denoted by the places of the signs that designate the corresponding planets.

The orbits of the planetoids are situated between those of Mars and Jupiter, the mean distances of the planetoids being greater than 200 millions of miles, and less than 330 millions of miles. The excentricities of the orbits of the planetoids range from .0229 up to .3468, the average value being about 2½ times as great as that of the planetary orbits.

TABLE I.

Name of Planet.	Mean distance in millions of miles.	Excentricity of orbit.	Perihelion distance.	Aphelion distance.
Mercury.....	35¾	.2056	28½	43
Venus......	66¾	.0068	66¼	67¼
Earth.......	92½	.0168	91	94
Mars........	141	.0933	128	154
Jupiter.....	480	.0483	457	503
Saturn	881	.0560	832	930
Uranus......	1771	.0464	1689	1853
Neptune....	2775	.0090	2750	2800

NOTE.—Prof. YOUNG, in his recent work on the sun, is inclined to adopt 8″.8 as the most probable value of the solar parallax. This would make the earth's mean distance from the sun nearly *one-half of one per cent. greater* than that given in Table I., and would require a proportional change in all the other distances in the table. It would also require a corresponding change in the values of the quantities given in Table II.

Distribution of Volumes and Masses.

47. It has been shown from geodesic surveys that the earth has the shape of an **oblate spheroid**, that is, of a sphere flattened at the poles, its equatorial diameter being about 7925.6 miles and its polar diameter about 7899.2 miles. It has been found by astronomical observation that Mars, Jupiter, and Saturn are also oblate spheroids, but evidences of flattening have not been discovered in any of the remaining planets. The diameter of the sun and the greatest and least diameters of each of the planets are given in Table II.; that table also contains the volumes of these bodies in terms of the earth's volume, which is taken as a unit. This table has been computed on the supposition that the solar parallax is 8″.84; should any correction be made in this element, it would require a corresponding correction in the table. The relative diameters of the planets are shown in Fig. 27.

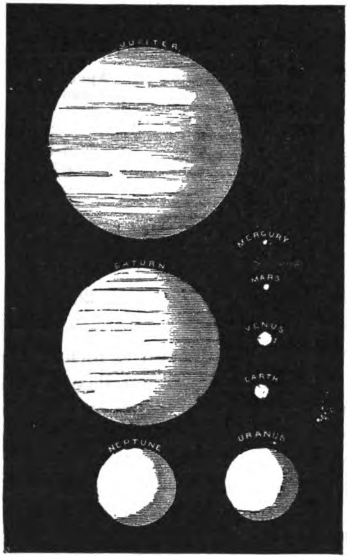

Fig. 27. Diagram showing the relative sizes of the planets.

The masses of the planets, by which we mean the quantities of matter they contain, are the same as those given by Prof. Newcomb, except that the earth has been taken as a unit instead of the sun. He says that the masses of many of the planets are still very uncertain, for the reason that exact observations have not as yet been continued long enough to admit of their satisfactory determination. He also says that the diameters are uncertain in many cases, but especially in those of the outer planets, Uranus and Neptune.

TABLE II.

Body.	Diameter in miles.		Volume Earth=1.	Mass Earth=1.
	Greatest.	Least.		
Sun	860,000	860,000	1,281,900	326,800
Mercury	2,990	2,990	.054	.065
Venus	7,660	7,660	.9058	.769
Earth	7,925	7,899	1	1
Mars	4,220	4,196	.1506	.11
Jupiter	87,770	82,570	1,282	312
Saturn	72,980	65,580	704	93
Uranus	31,690	31,690	64	14
Neptune	34,800	34,800	85	17

It will be seen from the table that the volume of the sun is more than 600 times the aggregate of the volumes of all the planets, and that the mass of the sun is more than 700 times the combined masses of all the planets.

Popular Illustrations.

48. To illustrate the relative magnitudes and distances of the sun and planets, take an ordinary 36-inch globe to represent the sun and pass a horizontal plane through its centre to represent the ecliptic in which we suppose all the planets to move. Then, on the same scale, Mercury will be represented by a globule whose diameter is $\frac{1}{8}$ of an inch, and its orbit will be represented by a circle whose diameter is 250 feet; the diameters of Venus and the Earth will each be about $\frac{1}{3}$ of an inch, the orbit of the former having a diameter of 468 feet, and that of the latter a diameter of 646 feet; Mars will be represented by a globule $\frac{1}{6}$ of an inch in diameter, and its orbit will have a diameter of 984 feet; Jupiter, the "giant planet" of the system, will have a diameter of $3\frac{1}{2}$ inches, and its orbit will be 3,360 feet across; Saturn will be represented by a ball 3 inches in diameter, and its orbit will have a diameter of 6,160 feet; Uranus and Neptune will be represented by balls whose respective diameters are $1\frac{1}{3}$ and $1\frac{1}{2}$ inches, the former moving in a circle whose diameter is 13,390 feet, and the latter in one whose diameter is 19,380 feet, or more than $3\frac{1}{2}$ miles.

Some idea may be formed of the enormous distance from the sun to Neptune if we recollect that a railway train whose speed is 38 miles an hour would require *three years* to accomplish a *million of miles.* A body traveling at this rate would require more than 8,000 years to traverse the distance from the sun to Neptune, and more than 50,000 years to accomplish the entire circuit passed over by Neptune in his journey around the sun. And yet these distances, which are almost inconceivably great, dwindle into insignificance in comparison with the still greater distances that separate the sun from the nearest of the fixed stars.

Definitions and Principles.

49. In determining the relative positions of the bodies belonging to the solar system, it is often convenient to refer them to the ecliptic instead of to the equinoctial. In this case the elements of reference are called *celestial latitude* and *celestial longitude.*

The **celestial latitude** of a body is its angular distance from the ecliptic; it is measured on the arc of a great circle passing through the body and perpendicular to the ecliptic. It is positive when the body is *north* of the ecliptic, and negative when the body is *south* of the ecliptic.

The **celestial longitude** of a body is the angular distance from the vernal equinox to the foot of an arc passing through the body and perpendicular to the ecliptic. It is reckoned from the vernal equinox around to the east through 360°, and is always *positive.*

Sometimes the place of a body is referred to the centre of the earth, and sometimes to the centre of the sun; in the former case it is said to be **geocentric**, and in the latter it is **heliocentric**. Thus, the *geocentric* longitude of a heavenly body is its longitude as seen from the centre of the earth, and its *heliocentric* longitude is its longitude as seen from the centre of the sun.

When the terms latitude and longitude are used without qualification they are to be understood as meaning *geocentric* latitude and longitude. Latitudes and longitudes of the heavenly bodies cannot be found by direct observation, but when we know the obliquity of the ecliptic, together with the right ascension and declination of a body, we can compute its latitude and longitude.

EXPLANATION. V is the vernal equinox; VR an arc of the equinoctial; VD an arc of the ecliptic; P the place of a body; QP, perpendicular to VR, is the declination, and VQ the right ascension of P; CP, perpendicular to VD, is the latitude, and VC the longitude of P; and PV is an arc of a great circle.

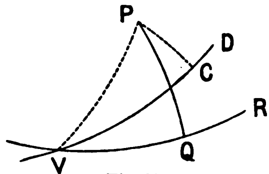

Fig. 28.

When we know QV and QP in the right-angled triangle VQP, we can find, by the principles of trigonometry, the angle QVP and the arc VP. In the right-angled triangle VPC the angle CVP is equal to the difference between QVP and the obliquity RVD, and consequently we can find CP and VC, the latitude and the longitude of P.

50. Two bodies are **in conjunction** (☌) when they have the same longitude; they are **in opposition** (☍) when their longitudes differ by 180°; and they are **in quadrature** (□) when their longitudes differ by 90°, or by 270°.

When two bodies have the same right ascension they are said to be *in conjunction in right ascension*, and when their right ascensions differ by 12h. they are said to be *in opposition in right ascension.*

The terms conjunction and opposition are used in the former sense when the places of the bodies are given by longitudes and latitudes, and in the latter sense when their places are given by right ascensions and declinations. In determining the times of new and full moon it is customary to use these terms in the former sense, but in the computation of eclipses and occultations it is found to be more convenient to use them in the latter sense.

An inferior planet has two kinds of conjunction with the sun: it is in **inferior conjunction** when it is between the earth and the sun, and in **superior conjunction** when the sun is between it and the earth.

The **elongation** of a body is its angular distance from the sun. The elongation may be reckoned on the great circle passing through the body and the sun, but more commonly it is reckoned on the ecliptic, in which case it is equal to the difference between the longitude of the body and that of the sun.

A superior planet may have any elongation from 0°, when it is in conjunction, up to 180°, when it is in opposition. The elongation of Mercury is never greater than about 29°, and that of Venus is never more than 48°. When a planet is in eastern elongation it sets after the sun and is called an **evening star**; when in western elongation it rises before the sun and is called a **morning star.**

51. The **periodic time** of a planet is the time required for the planet to make a complete revolution around the sun.

The **synodic period** of a planet is the interval between two successive conjunctions of the planet with the sun, or between two successive oppositions of the planet and the sun.

It will be shown hereafter that the periodic time of a planet can be found when we know its synodic period and the periodic time of the earth.

The **inclination of the orbit** of a planet is the angle between the plane of the orbit and the plane of the ecliptic.

The **nodes** of a planet are the points in which the orbit of the planet intersects the plane of the ecliptic. The **ascending node** is the point at which the planet passes from the south to the north side of the ecliptic, and it is often designated by the sign ☊; the **descending node** is the point at which the planet passes from the north to the south side of the ecliptic, and it is designated by the sign ☋.

The **line of nodes** is the line joining the ascending and the descending node; it is the intersection of the plane of the planet's orbit with that of the ecliptic.

TABLE III.

Body.	Periodic time.		Synodic period in days.	Inclination of orbit.	Heliocentric Long. of Perihelion.	Heliocentric Long. of As. node.
	In days.	In years.				
Mercury..	87.97	0.24	115.9	7°.00	75°.12	46°.55
Venus....	224.70	0.62	583.9	3°.39	129°.45	75°.33
Earth ..	365.25	1.00	....	....	100°.36	....
Mars.....	686.98	1.88	779.8	1°.85	333°.30	48°.40
Jupiter...	4,332.58	11.86	398.8	1°.31	11°.92	98°.94
Saturn...	10,759.22	29.46	378.0	2°.49	90°.07	112°.35
Uranus...	30,686.82	84.01	369.7	0°.77	170°.65	73°.24
Neptune..	60,126.71	164.62	367.5	1°.78	49°.15	130°.12

Kepler's Laws and the Newtonian Law.

52. Early in the 17th century Kepler announced three laws of planetary motion, which have since been known as **Kepler's laws.** They are as follows:

1°. The orbit of each planet is an ellipse, one focus of which is at the sun.

2°. As the planet revolves around the sun its radius-vector sweeps over equal areas in equal times.

3°. The squares of the times of revolution of the planets are proportional to the cubes of their mean distances from the sun.

These three laws would be rigorously true if the planets were material points, but in consequence of the mutual attraction of the planets upon each other the laws require slight corrections. These corrections, or rather the changes that call for the corrections, are called **perturbations.**

Sir Isaac Newton showed that Kepler's laws were simple consequences of a more general law, which is known as **Newton's law of universal gravitation.** This law may be enunciated as follows:

Every particle of matter in the solar system attracts every other particle, with a force that varies directly as the mass of the attracting particle, and inversely as the square of the distance between the particles.

The attraction between two bodies is *mutual*, that is, each particle in one acts upon every particle of the other according to the above law. If, therefore, we take the mutual attraction of two units of mass at a unit's distance from each other as the *unit of attraction*, and call it 1, the mutual attraction of two bodies whose masses are m and m' at the unit's distance will be $m \times m'$, and at the distance d it will be $m \times m'$ *divided by* d^2. Hence, the measure of the mutual attraction of two bodies is equal to the *product of their masses* divided by the *square of the distance between them.*

It is certain that the Newtonian law extends throughout the solar system, and it is extremely probable that it holds good throughout the physical universe.

IV. THE EARTH.

Astronomical Importance of the Earth.

53. The Earth is one of the smallest of the planets, but from an astronomical point of view it is the most important of them all. Its **distance from the sun** is the primary **unit** in terms of which we measure the dimensions of the solar system; its **mass** is the **unit** employed in measuring the masses of all the other bodies of the system; the **period required for it to revolve on its axis** gives us one ultimate **unit** of time; and finally, it is the **standpoint** from which we observe all the phenomena of the heavens.

These relations seem to indicate that its study should precede that of the other bodies of the solar system.

General Form of the Earth.

54. By the **general form** of the earth we mean the form that it would present to an observer at a distance so great as to render inappreciable the irregularities of hill and dale that roughen its surface. That this form is **globular** may be inferred from the following considerations:

1°. *From its appearance as seen from different points.* Its apparent form is best seen at sea. If we stand on the deck of a vessel out of sight of land, or if we ascend to the mast-head, the visible part of the ocean seems to be limited by the circumference of a circle. In like manner if we view the earth from a mountain-top, or from a balloon, its outline always seems circular. Inasmuch as a globe is the only body that appears circular from every point of view, we are led to infer that the earth is *globular.*

Universal experience shows that the more elevated the point of view, the more extended is the visible part of the earth's surface, and consequently the more elevated an object is, the greater the distance from which it is visible. Thus, at sea an approaching vessel first shows the tops of her masts, then her principal sails, and finally her hull comes in sight; also, when a receding vessel has entirely disappeared from the view of an observer on deck, she again becomes visible if he ascends to the mast-head.

2°. *From analogy.* Observation shows us that all the other bodies of the solar system are *globular*, and we may infer from analogy that the earth does not differ from them in form.

3°. *From actual measurement.* Actual measurement of arcs of meridians and circles of latitude show that the earth is *globular*, but not quite *spherical.* Its real form is that of a sphere flattened at the poles, but the flattening is so slight that we may, for the purposes of descriptive astronomy, regard it as truly *spherical.*

Comparative Roughness of the Earth's Surface.

55. The loftiest mountain on the surface of the earth hardly exceeds 5 miles in height, which is only $\frac{1}{1600}$ of the earth's diameter. On a 16-inch globe such a mountain would be represented by an elevation of $\frac{1}{100}$ of an inch, which is about the thickness of ordinary drawing-paper. But the *average* elevation of even the most mountainous countries does not amount to the fifth part of this, so we may truly say that the inequalities of hill and valley are insignificant in comparison with the entire earth. The greatest depths of the ocean are not much more than 5 miles, and its average depth is very much less than this, so that the depth of the ocean is also insignificant in comparison with the diameter of the earth.

Dimensions of the Earth.

56. Having ascertained that the earth is globular, an approximate value for its diameter may be found as follows :

A meridian line of suitable length is laid out by the aid of a portable transit instrument and its two ends are marked by signals. The length of the line is then determined by geodesic survey, and the latitudes of its extreme points are found by one of the methods yet to be explained. Assuming the earth to be an exact sphere and the measured arc to lie wholly on one side of the equator, the difference between the latitudes found will be the angle subtended by the arc as seen from the centre of the earth. The length of the entire circumference, or the length of a single degree, may then be found by means of the geometrical principle that the length of any arc of a circumference is proportional to the angle that it subtends.

Denoting the length of the measured arc by l, the corresponding angle at the centre by $n°$, and the circumference of the earth by c, we have the proportion, $n° : l :: 360° : c$; $\therefore c = \frac{360}{n} \times l$.

The diameter is equal to the circumference divided by π, that is, by 3.1416; it is found to be a little more than 7,900 miles.

Again, if we denote the length of 1° of the meridian by d, we have the proportion $n° : l :: 1° : d$; $\therefore d = \frac{l}{n}$.

Explanation. AC is the measured arc, l; Q′EA is the latitude of A; and Q′EC is the latitude of C.

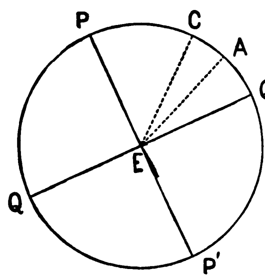

Fig. 29. Diagram.

When the lengths of a degree of the meridian are measured in different latitudes it is found that they are longer the nearer they are to the pole, from which it is to be inferred that the meridians become *less curved,* that is, they *grow flatter* as they approach the poles. From a great number of arcs measured in different latitudes and on different meridians it has been shown that the true form of the earth is that of an oblate spheroid, that is, of a volume generated by revolving an ellipse around its shorter axis. Prof. Airy showed by a process of the higher mathematics that the longer axis of this ellipse, or, in other words, the **equatorial diameter of the earth**, is equal to 7925.648 miles, and that the shorter axis, or the **polar diameter of the earth**, is 7899.17 miles in length. If we define the **mean diameter** of the earth to be the diameter of a sphere whose volume is equal to the actual volume of the earth, we can easily show that it is equal to 7916.81 miles; hence we say in round numbers that the mean diameter of the earth is equal to 7917 miles.

Its Ellipticity and the Equatorial Protuberance.

57. The **ellipticity** of an oblate spheroid is measured by *the difference between its greatest and least diameters* divided by *its greatest diameter.*

The difference between the greatest and least diameters of the earth is 26.478 miles; hence its ellipticity is equal to $\frac{26.478}{7925.648}$ or to $\frac{1}{299.33}$.

If we imagine a sphere to be described on the polar diameter of the earth, that portion of the earth which lies without the sphere is called the **equatorial protuberance.**

The equatorial protuberance is 13.239 miles thick at the equator, and grows thinner as it approaches the poles, where its thickness is 0. The volume of the equatorial protuberance is about $\frac{1}{150}$ of the entire volume of the earth, although its mass is probably not more than $\frac{1}{300}$ of the entire mass of the earth.

Probable Cause of the Earth's Spheroidal Form.

58. The earth's rotation gives rise to a centrifugal force in each of its particles whose direction is perpendicular to the axis and whose intensity is equal to the continued product of *the mass* of the particle, *the square of its angular velocity*, and *its distance from the axis*. If the centrifugal force acting on each particle is resolved into two components, one in the direction of the vertical through the particle and the other perpendicular to it, the former will always act to diminish the apparent weight of the particle, and the latter will tend to draw it toward the equator. The general effect of these two components is to heap up the matter of the earth in the neighborhood of the equator, and this action must go on till an equilibrium takes place between all the forces acting on each particle, (Peck's Elementary Mechanics, Art. 128). Now, it has been shown, by means of the higher analysis, that the form of equilibrium of a plastic body, whose matter is distributed as we have reason to suppose is the case in our earth, is that of an *oblate spheroid* whose shape is that which our earth has been shown to have. We therefore infer that the earth was probably once in a plastic condition, and that its present form is due to the combined action of gravity and the centrifugal forces upon each of its particles.

This inference is strengthened by the fact that other planets are flattened at the poles, and that those which revolve more rapidly than the earth are still more flattened than it.

It is to be noted that the amount of flattening of a rotating mass will depend not only on the rapidity with which the body rotates, but also on the relative distribution of its matter with respect to density.

The Torsion Balance.

59. The **torsion balance** is a species of horizontal pendulum used to measure small horizontal forces. It consists of a slender rod of homogeneous material terminating in two equal metallic balls and suspended at its middle point by a delicate wire. The upper end of the wire is attached to a fixed support and the rod is so placed that it can revolve freely in a horizontal plane.

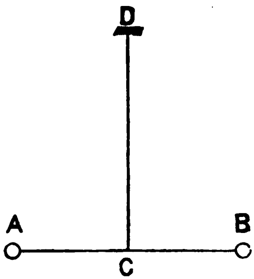

Fig. 30. Torsion balance.

Explanation. A and B in Fig. 30 are spherical balls of metal; DC is a suspending fibre or wire; and AB is a horizontal rod of wood or other homogeneous substance.

The wire DC is firmly attached to a fixed ceiling at D.

When this wire is twisted by turning the rod in azimuth, its elasticity is called into play, and when the rod is set free, it is forced back to its original position, which it reaches with a living force sufficient to carry it as far to the other side; a force of torsion is thus developed in an opposite sense, which causes the pendulum again to return, and so on indefinitely. The vibration thus set up is in all respects similar to that of an ordinary pendulum, and when we know the time of a single vibration (which is independent of the length of the arc of vibration), it is a simple matter to compute the value of the force that must be applied to either ball to turn the rod through a unit of angular measure. Again, knowing this force, we can easily compute the force that would be necessary to turn the rod through any other angle; for, the force necessary to turn it through an angle n is equal to n times the force necessary to turn it through the angle 1.

When equal and opposite horizontal forces are applied to the two balls they both tend to turn the rod in the same direction, and consequently the angle through which the rod is turned will be the same as though a single force equal to the sum of the two had been applied to one of the balls.

Mass and Density of the Earth.

60. Several methods have been employed to determine the **mass of the earth,** all of which depend upon finding the relation between the attraction exerted by an object of known mass on a given body, and the attraction exerted by the earth on the same body. Of these, the simplest, and perhaps the most reliable, is that known as the **method of Cavendish.**

By this method the attractions exerted by two leaden balls is measured by means of a torsion balance, and the resulting acceleration is then compared with that of gravity.

EXPLANATION. A and B are heavy leaden balls; CD is a horizontal swinging bar; and EF is a vertical axis around which the balls may be made to revolve by means of the pulley G and the driving-belt GH.

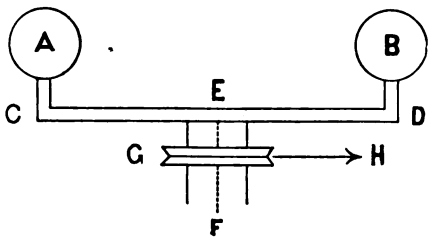

Fig. 31. Part of the Cavendish apparatus.

The essential parts of the Cavendish apparatus are a *torsion balance* and *two heavy leaden balls* mounted on a horizontal bar so that they can be turned around an axis whose direction coincides with the suspending wire of the balance. The manner in which the leaden balls are mounted and the method of turning them in azimuth are shown in Fig. 31. A horizontal plan of the apparatus is shown in Fig. 32.

In using the apparatus the leaden balls are first brought to the positions P″, Q″, in which case they have no tendency to move the balance, and the readings of the scales K and L are noted. The balls are next brought into the positions P′, Q′, in which case they act to turn the balance in the direction indicated by the arrow heads, and when the instrument comes to rest, the readings of the scales are again noted. From these readings we can find the corresponding angle of torsion, that is, the angle through which the balance is turned by the attraction of the leaden balls.

The swinging bar is then turned so that the heavy balls shall occupy the positions P, Q, symmetrical with Q′, P′; in this case the forces of attraction turn the balance in an opposite direction, and in the same manner as before the value of the new angle of torsion is found.

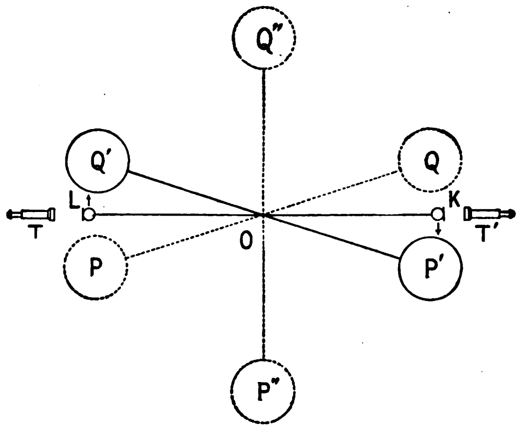

Fig. 32. Plan of the Cavendish apparatus.

EXPLANATION. KL is the horizontal projection of the torsion balance, O being the projection of the suspending wire; at K and L are two scales of equal parts attached to the balls of the balance and perpendicular to KL; T and T′ are two fixed telescopes for reading the scales; P and Q are the leaden balls, which can be so turned as to occupy either of the positions P′Q′, or P″Q″.

From these values of the angles of torsion we can, in accordance with the principle referred to in the preceding article, find the force of attraction exerted by each of the leaden balls upon the corresponding ball of the balance. The distance, d, between the large and the small ball in each case, is known from the relation between the parts of the apparatus.

If we denote the acceleration due to the attraction of a leaden ball at the distance d by f, the acceleration due to the earth's attraction at the distance R by g, the mass of the leaden ball by m, and the mass of the earth by M, we shall have by the *Newtonian law*

$$f : g :: \frac{m}{d^2} : \frac{M}{R^2}; \therefore \ M = m \times \frac{g}{f} \times \frac{R^2}{d^2}.$$

All the quantities in the second member of this equation are known, and consequently the mass of the earth is known in terms of the mass of the leaden ball.

Knowing the relative masses of the ball and the earth, and also their respective volumes, the average or *mean density* of the earth can be found.

As the result of 17 experiments, Cavendish found the mean density of the earth to be 5.48 times that of water; Reich of Freiburg repeated Cavendish's experiments in 1836, using but one leaden ball instead of two, and found the mean density of the earth to be 5.438 times that of water; Sir Francis Baily, however, executed the most complete set of observations that has ever been made, in 1838–42, from which the mean density of the earth was found equal to 5.66 times that of water.

The observations made by Dr. Maskelyne, who compared the attraction of Mt. Schehallien in Scotland with the attraction of the earth, made the density of the earth equal to 4.71, and those of Prof. Airy, who compared the attraction of a shell of the earth with that of the entire earth, made the earth 's density equal to 6.56.

From all of these results it is inferred that the mean density of the earth is not far from $5\frac{2}{3}$ times that of water.

Motions of the Earth and the Seasons.

61. We have already seen that the earth has two principal motions: 1°, it rotates on an axis which maintains a fixed direction in space; and 2°, it revolves around the sun in an elliptical orbit that differs but little from a circle.

It is in consequence of the latter motion that the sun *appears* to revolve around the earth in an elliptical orbit.

The line joining the centres of the earth and sun actually revolves about the common centre of gravity of the earth and the sun. Now, whether we regard the sun's *apparent* motion as seen from the earth, or the earth's *real* motion as seen from the sun, the general effect is the same, the only difference being that the earth as seen from the sun is always 180° in advance of the sun as seen from the earth, both being referred to the stars. We may therefore speak of the sun as revolving around the earth, if it is understood that we only refer to *apparent* motion.

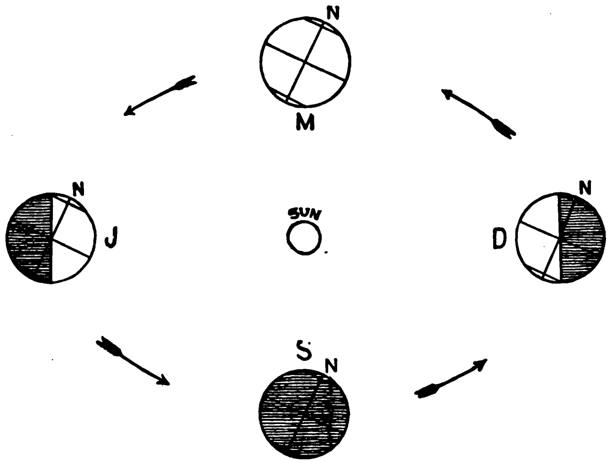

Fig. 33. Parallelism of the Earth's axis.

EXPLANATION. M is the earth's position March 21st; J is its position June 21st; S is its position September 22d; and D is its position December 21st. In each case N marks the position of the north pole, and also indicates the direction of the earth's axis.

Besides these motions of rotation and revolution, the earth is subject to certain slight motions due to the disturbing influence of the other bodies of the solar system. These irregular motions, which are called **perturbations**, are so small that they may be disregarded in a general view of the system.

The axis of the earth is inclined to the plane of the ecliptic, that is, to the plane of the earth's orbit, in an angle of about 66° 33′, and in the course of a year this axis prolonged describes an oblique cylinder whose base is the earth's orbit and whose axis passes through the centre of the sun and the poles of the heavens. The plane of the equator being always perpendicular to the axis of this cylinder, will sometimes pass through the sun, sometimes above the sun, and sometimes below it.

The varying position of the equator with respect to the ecliptic gives rise to the changes in light and heat which are known as the **changes of the seasons**. At the equinoxes, that is, on the 21st of March and the 22d of September, the plane of the equator passes through the sun and consequently the sun is on the equinoctial. From the 21st of March to the 22d of September the plane of the equator passes below the sun and consequently the sun is north of the equinoctial, or in north declination. From the 22d of September to the 21st of March the plane of the equator passes above the sun, and consequently the sun is south of the equator, or in south declination. The sun is farthest north at the summer solstice, or on the 21st of June, and farthest south at the winter solstice, or on the 21st of December.

We have seen that the horizon of a place, not on the equator, divides all the diurnal circles, except the equinoctial, unequally. If the place is north of the equator, say in the United States, the greater part of the diurnal circle will be above the horizon when the circle is north of the equinoctial, and below the horizon when the circle is south of the equinoctial. Hence, at any place in the United States the days and nights are equal at the equinoxes; the days are longer than the nights from March 21st to September 22d ; and the nights are longer than the days from September 22d to March 21st. The difference between the lengths of the days and nights is greatest at the solstices.

The astronomical year is divided into four nearly equal parts called **seasons**: the period from March 21st to June 21st is called **spring**; that from June 21st to September 22d is called **summer**; that from September 22d to December 21st is called **autumn**; and that from December 21st to March 21st is called **winter.**

It has been found by observation that the average annual temperature of any place on the surface of the earth is *nearly* constant; hence, we infer that all the heat which the place receives from the sun in the course of a year is radiated into space in the same period. During the day the place is both receiving and radiating heat, the amount received being greater than the amount radiated; during the night there is no heat received, but radiation still goes on. The processes of receiving and radiating are so adjusted as to balance each other at the end of the year.

In spring and summer the days are *longer* than the nights, and consequently more heat is received during the day than is radiated during the day and the night; hence, there is a continual *accumulation* of heat, the accumulation being slight at the beginning of spring and at the end of summer.

In autumn and winter the days are *shorter* than the nights and consequently less heat is received during the day than is radiated during the day and the night; hence, there is a continual diminution of heat, the diminution being slight at the beginning of autumn and at the end of winter.

We ought, therefore, to have our hottest weather in the latter part of summer, and our coldest weather in the latter part of winter. This would undoubtedly be the case were it not for the modifying effects of aerial and oceanic currents.

In studying the subject of *change of temperature,* we must take into account the obliquity of the sun's rays: during spring and summer the rays of the sun are, on an average, more nearly perpendicular to the horizon, and consequently more efficient in their heating effect, than they are during the autumn and winter.

For reasons analogous to those set forth above, the hottest part of the day should be some time after noon and the coldest part of the night should be some time after midnight.

Refraction.

62. If a ray of light passes obliquely from one medium into another, it experiences a change of direction at the common surface of the two media, and this change of direction or bending is called **refraction.**

In Fig. 34, AB represents the surface that separates the two media P and Q ; CD is the path of a ray in the medium P, and DE is its path in the medium Q, FG being normal, or perpendicular, to AB at D. The angle CDF is called the *angle of incidence*, EDG is the *angle of refraction*, and KDE is the *refraction*, or the amount of bending. It has been shown, both by theory and by experiment, that under ordinary circumstances the sine of the angle of incidence is equal to the sine of the angle of refraction *multiplied* by a constant quantity, no matter what may be the value of the angle of incidence. If we denote the angle of refraction by ϕ' and the angle of incidence by ϕ, we shall have the equation

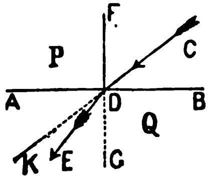

Fig. 34. Diagram illustrating refraction.

$$\sin \phi = m \sin \phi'$$

in which m is called the index of refraction. The value of m is constant for the same two media at the same temperature, but it is different for different pairs of media and also for the same two media at different temperatures; m is greater than 1 when light passes from a rarer to a denser medium, and less than 1 when it passes from a denser to a rarer medium, or, what is the same thing, light is bent *toward* the normal in passing from a rarer to a denser medium, and *from* the normal in passing from a denser to a rarer medium.

The *refraction*, denoted by r, for the same two media increases with an increase of the angle of incidence, that is, the more obliquely the ray strikes the deviating surface the more will it be bent from its course.

The Atmosphere and Atmospheric Refraction.

63. The **atmosphere** is a gaseous envelope surrounding the earth and extending upward to a distance of 60 or 80 miles, perhaps even to a greater height. It is a mixture of oxygen and nitrogen gases, together with small, but varying, quantities of carbonic acid and watery vapor. Its density is greatest at the surface of the earth, where it is about $\frac{1}{773}$ as dense as water, and the density continually diminishes as we ascend. For the purpose of illustration we may regard it as arranged in layers concentric with the surface of the earth, each of which is more dense than the one next above it, and consequently capable of producing a greater amount of refraction. A ray of light falling obliquely on the surface of the upper stratum is bent downward, and this bending is continually increased as the ray passes from stratum to stratum till it finally reaches the eye of the observer; its path through the atmosphere is therefore a curved line, as shown in Fig. 35, and the apparent direction of the body from which the light comes is that of the tangent PE to the curve at the point where it enters the eye. Hence, the effect of refraction is to *increase* the apparent altitudes of the heavenly bodies, or, what is the same thing, to *diminish* their apparent zenith distances.

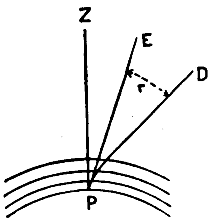

Fig. 35. Atmospheric refraction.

The strata into which we have supposed the atmosphere to be divided are concentric with the surface of the earth, and because the height of the atmosphere is very small in comparison with the earth's radius, we may, without sensible error, regard the surfaces of the several strata as horizontal planes.

It is to be observed that the path of a ray in passing through the atmosphere is usually situated in a vertical plane: hence, refraction produces no lateral displacement of the apparent position of a body, except in extraordinary cases.

Tables of Refraction.

64. Refraction for a given zenith distance varies with the pressure, or tension, of the atmosphere, and also with its temperature; it *increases* with an increase of pressure, and it *decreases* with an increase of temperature. Hence, in order to find the refraction corresponding to any observed zenith distance we must know the readings both of the barometer and of the thermometer at the time of observation. The refraction may then be found by means of tables called **tables of refraction.**

Several different formulas have been deduced for determining the amount of refraction corresponding to any observed zenith distance, or altitude, but they are all somewhat complex.

A complete set of Bessel's tables, with full directions for using, is to be found in Loomis' Practical Astronomy, to which work the student is referred for further information.

It is to be observed that the tables are not very reliable when the apparent zenith distance exceeds 80° ; beyond this limit the irregularities of refraction are too great to be brought within the scope of any formula. These irregularities increase as we approach the horizon, and it is within the narrow zone near the horizon that we are to look for lateral refraction and other disturbances which sometimes result in peculiar distortions of the disks of the sun and moon.

Some Effects of Refraction.

65. The general effect of refraction is to throw all the heavenly bodies toward the zenith, and this effect is increased as we approach the horizon.

One of the most notable consequences of refraction is a *lengthening of the amount of sunlight* at any place. Refraction at the horizon is nearly 35′; hence, the sun appears to rise earlier and to set later than it would were it not for the atmosphere. This increase, at the equator, amounts to more than 4 minutes per day. On an average over the entire globe the *increase* amounts to about $\frac{1}{100}$ part of the whole period of sunlight.

Another effect is to distort the forms of the disks of the sun and the full moon when near the horizon. The refraction being greater at the lower than at the upper limbs of these bodies, the lower limbs are thrown up more than the upper ones, and thus gives the bodies an oval shape, which is very obvious at all times, but occasionally, in consequence of extraordinary refraction, the flattening is peculiarly striking.

Twilight.

66. After sunset and before sunrise the solar rays illuminate a part of the earth's atmosphere, giving rise to a diffused light that we call **twilight**. Evening twilight begins at sunset and gradually grows fainter till it finally becomes extinct when the sun has descended to about 18° below the horizon; morning twilight begins when the sun has risen to within 18° of the horizon and gradually grows brighter till sunrise.

The length of twilight varies in different latitudes, and also in the same latitude at different seasons of the year, but the length of the evening twilight is always equal to that of the succeeding morning twilight.

The length of evening twilight at the equator does not differ much from 1¼ hours, and is nearly constant through the year; in the latitude of New York it varies from 1½ to 2 hours, the shortest twilight being in winter and the longest in summer; at all places north of latitude 49°, as, for example, in all parts of Great Britain, the sun does not descend as much as 18° below the horizon at the time of the summer solstice, so that morning twilight begins before evening twilight ends, and consequently twilight lasts all night; at the north pole evening twilight begins about the 22d of September, when the sun passes below the horizon, and lasts till about the 12th of November, at which time the sun is 18° south of the equinoctial, that is, it lasts for more than 50 days, and the morning twilight has a corresponding duration.

The cause of the variation in the length of twilight is found in the different degrees of obliquity of the sun's diurnal path to the horizon. When the sun sets, or rises, obliquely to the horizon, a longer time is occupied in descending or ascending through a vertical distance of 18° than when it sets perpendicularly to the horizon.

Parallax.

67. Parallax is a change in the *apparent* direction of a body due to an *actual* change in the position of the point from which the body is observed.

An idea of what is meant by *parallactic displacement* may be obtained as follows: let the student hold a pencil vertically between his face and a vertical wall which is ten or twelve feet distant; then, without changing the position either of his head or of the pencil, let him first close the right eye and note the apparent place of the pencil on the wall as seen by the left eye; again, closing the left eye and opening the right one, let him note the apparent place of the pencil on the wall; the pencil will appear to have moved from right to left along the wall. This *apparent* change of place is the parallactic displacement of the pencil, due to a change in the position of the point of observation from one eye to the other.

68. Geocentric parallax is the change that the apparent direction of a body would experience if the point of observation were changed from the surface of the earth to its centre.

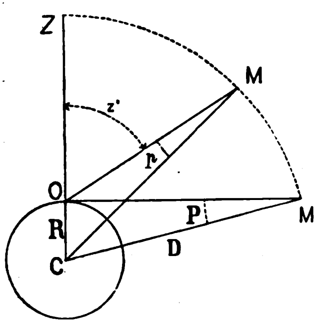

Fig. 36. Geocentric Parallax.

EXPLANATION. O is the point from which the body M is observed; C is the centre of the earth; Z is the zenith of O, and ZOM, equal to z', is the observed zenith distance of M; and OMC, equal to p, is the geocentric parallax of M.

In Fig. 36 the body M as seen from O appears to lie in the direction OM, but if seen from C it would appear to be in the direction CM. The angle OMC is therefore the geocentric parallax of M, and it is obviously equal to the angle subtended by the radius OC, at the body M.

It is plain, from the figure, that the zenith distance of a body seen from the surface of the earth is greater than it would be if seen from the centre, the difference being equal to its geocentric parallax.

The geocentric parallax of a body depends upon its apparent zenith distance, and also upon its actual distance from the centre of the earth. To deduce the law of variation, let us denote ZOM by z', OMC by p, or CM by D and OC by R; then, because the sides of a triangle are proportional to the sines of their opposite angles, and because the sine of the angle COM is equal to the sine of z', we have

$$D : R :: \sin z' : \sin p; \text{ whence, } \sin p = \frac{R}{D} \sin z' \ldots\ldots (1).$$

Hence, we see that *the sine of the parallax varies directly as the sine of the apparent zenith distance of the body, and inversely as its actual distance from the centre of the earth.*

The parallax of a body is zero at the zenith and it is greatest at the horizon; in the latter case it is called the *horizontal parallax;* in all other cases it is called *parallax in altitude.*

If we make $z' = 90°$ in equation (1) and denote the corresponding value of p by P, we have

$$\sin P = \frac{R}{D} \ldots\ldots\ldots (2); \text{ whence } D = \frac{R}{\sin P} \ldots\ldots\ldots\ldots (3).$$

From equation (2) we see that P depends on both R and D; if R is the equatorial radius of the earth, and if D is the mean distance of the body from the earth, the corresponding value of P is called the *mean equatorial parallax.* In speaking of the sun, this angle is usually designated by the simpler term *solar parallax.*

Equation (3) enables us to find the mean distance of a body from the earth when we know its mean equatorial parallax and the radius of the earth.

69. Heliocentric parallax is the change that the apparent direction of a body would experience, if the point of observation were transferred from the centre of the earth to the centre of the sun.

In Fig. 37, EM is the direction of the body M as seen from E, and SM is its direction as seen from S; hence, EMS, which is equal to KEM *minus* KSM, is the heliocentric parallax of M, and it is obviously equal to the angle subtended by the earth's radius-vector SE as seen from M.

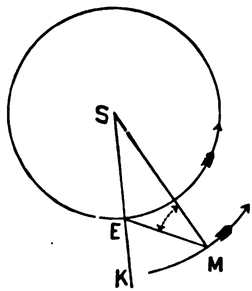

Fig. 37. Heliocentric Parallax.

EXPLANATION. E represents the centre of the earth, S that of the sun, and M that of a heavenly body, say Mars. The directions in which the earth and Mars are moving are represented by the arrow heads.

The use of the heliocentric parallax of a body is to determine the motion of a body as it would appear from the sun.

The angle KEM, which is the supplement of SEM, is found by observation. The angle EMS, or the heliocentric parallax, is found from the formula

$$\sin \text{EMS} = \frac{\text{SE}}{\text{SM}} \sin \text{KEM} \ldots . (4),$$

which is deduced in the same manner as formula (1) in the preceding article. The angle KSM is then found by subtracting the angle EMS from the angle KEM.

70. The **annual parallax** of a star is the apparent displacement of the star due to the earth's annual revolution around the sun.

If we conceive a straight line to be drawn from the earth passing through a star, this line will in the course of a year generate the surface of a cone whose vertex is the star and whose base is the earth's orbit; the axis of this cone will in general be oblique to plane of the earth's orbit. If we suppose all the elements of the cone to be prolonged to the celestial sphere they will meet it in an ellipse which will be the apparent path of the star due to parallax; the centre of the ellipse will be the position of the star as seen from the sun. If the axis of the cone is perpendicular to the plane of the ecliptic, the ellipse becomes a *circle;* if the axis lies in the plane of the ecliptic, the ellipse becomes a straight line.

The angle at the earth subtended by the semi-transverse axis of the ellipse, which is equal to the angle at the star subtended by that semi-diameter of the earth's orbit which is perpendicular to the axis of the parallactic cone, is called the **stellar parallax.** When this angle can be found, we can immediately compute the distance of the star from the sun or from the earth.

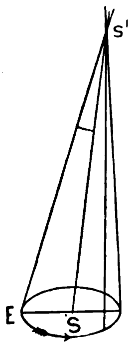

Fig. 38. Annual or Stellar Parallax.

EXPLANATION. S represents the sun; E the earth in its orbit; and S′ the star. SS′ is the axis of the parallactic cone; SE is the radius-vector of the earth's orbit which is perpendicular to SS′: and ES′S is the stellar parallax, denoted by p.

In the right-angled triangle SS′E we have, since ES′S is a very minute angle,

$$SS' = \frac{SE}{p} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5).$$

Many attempts have been made to find the stellar parallax, but, except in the case of a few stars, they have been unsatisfactory. The largest stellar parallax that has been found is that of *α* Centauri, a southern star. Its parallax is a little less than 1″ of arc, which corresponds to a distance of about 20 *millions of millions* of miles. This almost inconceivable distance is so great that light traveling at the rate of 186,360 miles a second would require more than 3 years to traverse the space that separates the star from the earth. The distance of *α* Centauri from the sun is, according to Newcomb, about 221,000 times as great as that of the earth from the sun.

Newcomb says, "the recent researches of various observers have resulted in showing that there are about a dozen stars visible in our latitudes of which the parallax ranges from a tenth to a half second." The corresponding times required for light to come from these stars to the earth would therefore range from 30 down to 6 years. The bright star *α* Lyræ has, according to Dr. Brünnow, a parallax of about one-fifth of a second, which corresponds to a distance which is more than a million of times as great as that of the earth from the sun.

All attempts to find any appreciable parallax for the stars which are visible to the naked eye, except in a few instances, have totally failed, and we are permitted to assert that their distances from us are not measurable. What then shall be said of the countless millions of stars that are revealed to us by our powerful telescopes? It has been conjectured that some of these bodies are so far distant that their light can only reach us after a flight of hundreds, perhaps thousands, of years.

Aberration.

71. Aberration is a displacement in the apparent place of a body due to the combined motion of the observer and of light.

It is analogous in effect to the combined motion of an observer in a railway car and that of a falling drop of rain. If a shower of rain is falling on a still day, and if the observer is at rest, he will see the drops descend in vertical lines; but if he is moving in a rapidly advancing car, he will see the drops descend obliquely, and as though they had come from a point in advance of his position.

EXPLANATION. DA represents the velocity of a ray of light and the direction of its motion; OA represents the velocity of the observer and the direction of his motion; and DC is equal and parallel to AO.

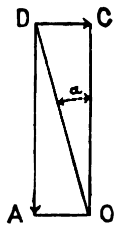

Fig. 39. Aberration.

In accordance with the law of *relative motion*, the apparent path of the rain-drop is the same that it would be if the observer were at rest and the drop were, in addition to its actual motion, endowed with a motion equal and directly opposite to that of the observer.

In like manner the combined motion of the observer and of a ray of light causes a body to appear as if thrown slightly forward in the direction of the observer's motion. If in

Fig. 39 we suppose the observer O to be at rest and the light to move with the combined velocities DA and DC, it will reach O in the direction of the diagonal of the parallelogram described on DA and DC. The body from which the light comes will appear to be thrown forward, the displacement being equal to the angle COD. The angle COD is called the aberration, and its value will be the greatest possible when DA is perpendicular to OA.

If we denote the aberration in this case by a, we have from the right-angled triangle OCD

$$\tan a = \frac{DC}{CO};$$

or because the angle a is very small, we have the formula

$$a = \frac{v}{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In which v is the velocity of the observer and V the velocity of light. Hence, *the maximum value of aberration is equal to the velocity of the earth in its orbit divided by the velocity of light.* This value, which has recently been found to be equal to $20''.49$, is sometimes called the *constant of aberration.*

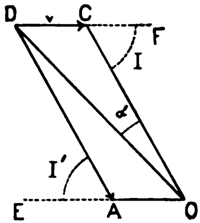

Fig. 40. Aberration.

EXPLANATION. Same as before, except that the direction of light is inclined to that of the observer's motion in an angle EAD denoted by I′, equal to I.

In Fig. 40, the angle CDO is equal FCO − a'; but a' is so small that we may regard CDO equal to FCO or to I. We then have from the triangle OCD the proportion

$$v : V :: \sin a' : \sin I \quad . \quad . \quad (2)$$

If we replace $\sin a'$ by a' and $\frac{v}{V}$ by $20''.49$, we have, from (2)

$$a' = 20''.49 \sin I \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Hence, the general value of *aberration varies as the sine of the inclination of the direction of light to the direction of the observer's motion.*

When the observer is moving directly toward or directly from a body the aberration is *zero;* when he is moving at right angles to the motion of light the aberration is 20″.49; in all other cases the aberration lies between these limits.

EXPLANATION. S is the sun; ACDF is the orbit of the earth; *s* is a star at the pole of the ecliptic; and *acdf* is the annual curve of aberration.

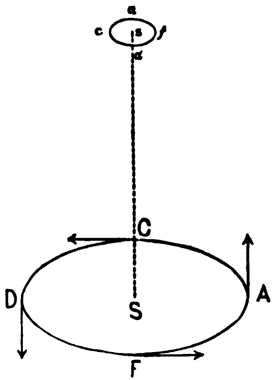

Fig. 41. Aberration at the pole of the Ecliptic.

In Fig. 41, let *s* be the true place of a star, at the pole of the ecliptic. When the earth is at A the star is thrown forward in the direction *sa*, parallel to the earth's motion, and to a distance equal to 20″.49; when the earth is at C the star is apparently at *c*, *sc* being equal to 20″.49; when the earth is at D the apparent place of the star is *d*; and when the earth is at F the apparent place of the star is at *f*. Hence, we see that the star appears, in consequence of aberration, to describe a circle around its true place; the time of description being a year, and the spherical radius of the circle being equal to 20″.49.

If the star is obliquely situated with respect to the ecliptic it will appear to describe an ellipse whose semi-transverse axis is 20″.49 and whose semi-conjugate axis is 20″.49 *multiplied by the sine of its celestial latitude.*

If the star is in the plane of the ecliptic it will oscillate back and forth along a line in the ecliptic whose middle point is the true position of the star, and whose length is 40″.98.

In all cases the true position of the star is at the centre of its apparent annual path.

The sun at every instant appears to be moving in space in exactly the opposite direction to that of the earth's actual motion; hence, the effect of aberration is to cause the sun to appear 20″.49 behind its true place.

Precession and Nutation.

72. It has been stated (Art. 12) that the equinoxes have a slow motion from east to west along the ecliptic, which is called the **precession of the equinoxes.** This motion, averaging 50″.2 a year, is produced by the unequal attractions of the sun and of the moon on the different parts of the *equatorial protuberance* (Art. 57). Most of the matter of this protuberance lies in the equatorial regions, and for the purposes of explanation we may regard it as a *ring* whose central plane coincides with the plane of the equator.

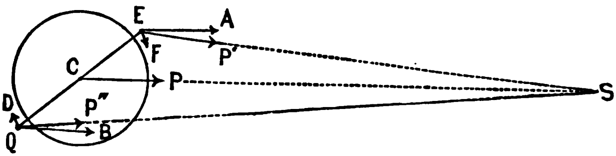

Fig. 42. Precession of the Equinoxes.

Explanation. In this figure the plane of the paper passes through the centres of the sun and earth, and is perpendicular to the plane of the ring. CS is in the projection of the ecliptic, S being the centre of the sun; EQ is the projection of the ring, C being the centre of the earth; CP is the acceleration due to the sun's attraction at C; EP′ is that due to the sun's attraction at E; and QP″ is that due to the sun's attraction at Q.

Because E is nearer to the sun than C is, EP′ is greater than CP; for a like reason CP is greater than QP″. If we resolve EP′ into two components, one of which, EA, is equal and parallel to CP, the other one will have the direction EF parallel to the line joining A and P′ (Peck's Mechanics, Art. 26); in like manner if we resolve QP″ into two components, one of which, QB, is equal and parallel to CP, the other will have a direction, QD, parallel to the line joining B and P″. Now, the forces CP, EA, and QB, being parallel and equal, it is obvious that their effect is simply to draw the masses C, E, and Q in parallel lines toward S. The remaining forces EF and QD, which are small in comparison with CP, will act to produce rotation of the ring, and consequently of the whole earth, around an axis perpendicular to the plane ECS at C. This rotation, combined with the earth's rotation on its axis, produces a retrograde motion of the line of equinoxes, in accordance with the law of composition of rotations (Mech., Arts. 142–3). The attraction of the moon on the ring acts in like manner, but with greater effect, to produce a retrogradation of the equinoxes, and a very slight effect of the same kind is also produced by the action of the planets The action of the sun in producing precession is variable, in consequence of the different aspects of the ring as seen from the sun: it is greatest about the times of the solstices, and least about the times of the equinoxes, going through all its changes in a year. The action of the moon is still more variable. It goes through its principal changes in a nodical period, but, as we shall see hereafter, the plane of the moon's orbit is continually changing its position with reference to that of the equinoctial, completing its cycle of change in about 18.6 years. There is therefore an inequality in the precession extending over this cycle, during which the pole of the heavens recedes from and approaches the pole of the ecliptic, the entire arc of oscillation amounting to about 19″. This inequality is known as the *nutation* of the earth's axis.

In consequence of the combined effects of precession and nutation, for they are always considered together, the pole of the heavens retrogrades around the fixed pole of the ecliptic in a slightly waving line, that may for our purposes be regarded as a circle, whose spherical radius is about 23° 27′. The cycle of a complete revolution of the axis of the earth about that of the ecliptic is 25,800 years.

Effects of Precession and Nutation.

73. The effect of precession and nutation is to produce a continual change in the right ascensions and declinations of the stars. This change is caused by the displacement of the equinoctial and of the vernal equinox, to which the positions of the stars are referred. When we know the right ascension and declination of a star at a given epoch, we can find these elements at any other time by means of formulæ and tables constructed for the purpose.

The continued change in the right ascensions and declinations of the stars produces a slow but progressive change in the aspect of the heavens; the north pole of the heavens, continually changing place, comes successively into the neighborhood of new stars, which in turn become *pole-stars.* The diurnal circles of all the stars gradually change to conform to the new position of the pole, and the positions of the constellations with respect to the poles of the heavens experience a corresponding change.

After the lapse of about 12,000 years, according to Herschel, the bright star *α* Lyræ will be within 5° of the pole, and will therefore be the *pole-star*, and at that time the present *north-star* will be more than 40° from the new pole.

About 4000 years ago, that is, about the time of the building of the pyramids of Egypt, the north pole of the heavens was about $3\frac{3}{4}°$ from the bright star α Draconis, which was at that time the *pole-star*. In this connection we condense from Sir John Herschel the following curious facts relating to the pyramids of Gizeh. The latitude of Gizeh being 30° N., the star in question must have had its lower culmination at an altitude of about $26\frac{1}{4}°$. The explorations of Col. Vyse show that of the *nine* pyramids still existing at Gizeh, six (including the largest) have the narrow passages by which alone they can be entered (opening on the northern faces) inclined downward at angles varying from 26° 2′ to 28°, the average inclination being about 26° 47′. "At the bottom of every one of these passages, therefore, the *then* pole-star must have have been visible at its lower culmination, a circumstance which can hardly be supposed to have been unintentional, and was doubtless connected (perhaps superstitiously) with the astronomical observation of that star, of whose proximity to the pole at the epoch of the erection of these wonderful structures, we are thus furnished with a monumental record of the most imperishable nature."

Micrometers.

74. The **filar micrometer** is a contrivance for measuring the angular distance between two objects, both of which are in the field of view of the telescope. When an additional arrangement is made for measuring the angle included between the line that joins the two objects and the hour circle passing through one of them, the instrument is called a **position micrometer**.

The simple *filar micrometer* consists essentially of two parallel wires, or spider lines, placed at the common focus of the objective and the eye piece, and so mounted that they can be moved at right angles to their lengths by means of two delicate screws of uniform pitch, called **micrometer screws.** The interval between the wires, in terms of the distance between two consecutive threads of the screw can be read off by means of a suitable scale, and from this the angular distance between them can be found by a simple computation.

In the *position micrometer* the part just described is mounted so that it can be revolved around the line of collimation as an axis, and a graduated circle with an index is introduced for measuring the angle through which it is turned.

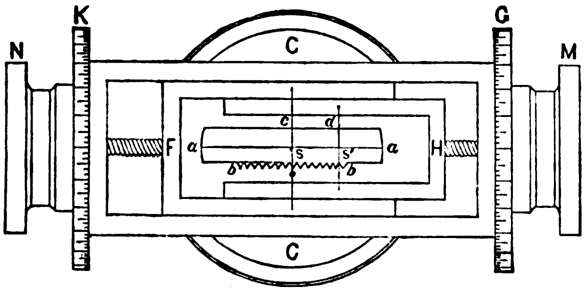

Fig. 43. The Position Micrometer.

DESCRIPTION. In Fig. 43, *aa* is a longitudinal wire attached to the perforated diaphragm of the instrument in such manner that it always intersects the line of collimation at right angles. The parallel wires *c* and *d* are perpendicular to *aa*, the former being attached to the sliding fork F, and the latter to the sliding fork H. These forks terminate in screws, and may be moved to and fro by the nuts, or *screw heads*, M and N, which are so arranged as to admit of rotary motion only; the number of entire turns of either screw head is shown by a serrated scale, *bb*, at the bottom of the opening of the diaphragm, each notch of which corresponds to one turn. The circular, or flange-like, projections G and K, are each divided on their circumferences into 100 equal parts, and by means of suitable indices they indicate the number of hundredths of a turn. The middle of the serrated scale is indicated by a small hole, and when either of the parallel wires bisects it, that wire intersects *aa* in the line of collimation; thus, in the figure the point *s* is in the line of collimation.

The circle CC, whose graduation is not shown, is called the *position circle;* when the instrument is revolved about the line of collimation the point *s* remains fixed, and the arc of the position circle which passes by the index determines the angle through which the line *aa* is revolved.

Before using the position micrometer we must know the *polar reading* of the position circle and the *angular value* of one turn of the screw head.

To find the polar reading, the telescope is directed to an equatorial star and the micrometer is revolved in the direction of the graduation till the star appears to move along the longitudinal wire *aa*; the corresponding reading diminished by 90° is the polar reading, that is, it is the reading of the position circle when *aa* coincides with an hour circle. To find the angular value of one turn, set the wires *c* and *d* so that they shall be at a distance apart equal to say 20 notches; then turn the telescope to an equatorial star and note the sidereal time required for it to pass from one wire to the other; convert this time into angular measure and divide by 20; the quotient will be the angular value of one turn.

As an example of the use of the instrument, let it be required to measure the distance from the star *s* to the star *s'*, and the inclination of *ss'* to the hour circle through *s*. Having brought the wire *c* to the zero of the scale *bb*, direct the telescope so the star *s* shall be at the intersection of *c* and *aa*; turn the micrometer on its axis till *aa* passes through *s'*; then move the wire *d* till it coincides with *s'*. To the number of entire turns indicated on the scale *bb*, add the hundredths of a turn as shown by the graduation on the screw head, and multiply the result by the angular value of one turn; the result will be the angular distance *ss'*.

From the reading of the position circle (increased by 360° if necessary) subtract the polar reading of the instrument; the remainder will be the angle between the hour circle and the line *ss'*.

The Zenith Telescope.

75. A **zenith telescope** is a telescope arranged for measuring small differences between the meridian zenith distances of two stars. It consists of a telescope, having a filar micrometer at the common focus of its objective and eye piece, and so mounted that it can be turned around either a vertical or a horizontal axis. In the form now used on the U. S. Coast Survey, the mounting is similar to that of the portable transit, which permits the instrument to be used in place of a transit. The mounting differs however from that of a simple transit in the fact that the piers which carry the horizontal axis, instead of resting on a solid support, are attached to a horizontal plate which can be turned in azimuth upon a second horizontal plate, much as the vernier plate of a theodolite is turned on the horizontal limb. The telescope is provided with a circle and level by means of which its line of collimation may be set so as to make any angle with the vertical, and the revolving horizontal plate has a clamp and tangent screw by means of which the instrument can be brought into the plane of the meridian. This plate has also two movable stops which can be set at the opposite ends of a diameter. When the stops are set, the instrument can be *reversed*, that is, it can be turned 180° in azimuth, without the trouble of reading the circle at each reversal.

To explain the use of this instrument, let E be the place of the observer; Z his zenith; HZH′ the meridian of E; *s* and *s′* the points of culmination of two stars, whose right ascensions differ by only a few minutes of time. We also suppose that the distances Z*s* and Z*s′* to be approximately known, and that they differ but little from each other.

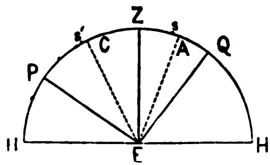

Fig. 44. Method of using the Zenith Telescope.

The instrument having been placed in the meridian and the stops set, the telescope is directed so that its line of collimation shall incline towards the south and make an angle with the vertical equal to the mean of the assumed zenith distances of *s* and *s′*. Suppose EA to be the position of the line of collimation when the instrument is turned towards the south, and EC to be its position when turned towards the north; also suppose that s culminates a few minutes before s'. The micrometer having been placed so that its longitudinal wire shall be in the plane of the meridian, the angle As is measured at the instant s crosses the meridian; the instrument is then reversed and when s' crosses the meridian the angle Cs' is measured, both measurements being made as explained in Art. 74.

Denoting the angle ZEA or its equal ZEC by ϕ, the meridian zenith distance of s by z, and that of s' by z', we have from the figure,

$$z = \phi - \mathrm{A}s, \text{ and } z' = \phi + \mathrm{C}s' \quad . \quad . \quad . \quad . \quad (1)$$

whence, by subtraction,

$$z' - z = \mathrm{C}s' + \mathrm{A}s \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

but in practice it is customary to call distances estimated from a star toward the zenith *positive*, in which case those estimated in a contrary direction are *negative*. Adopting this notation the arc Cs' is essentially negative, and equation (2) takes the form

$$z' - z = \mathrm{A}s - \mathrm{C}s' \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If one of the parallel wires is set to mark the point of culmination of s and the other to mark the point of culmination of s' the angular distance between them will be the value of $z' - z$.

Different Methods of Finding Latitude.

76. In Art. 10 the *latitude of a place* is defined to be its angular distance from the equator. Referring to the figure and accompanying explanation in that article, we see that the latitude of the place a is equal to QEZ, which is the complement of PEZ; but HEZ being a right angle, HEP is also the complement of PEZ; and consequently HEP is equal to QEZ. Hence, the latitude of a place is equal either to the *declination of its zenith*, or to the *altitude of the elevated pole*, that is, of the pole which is above the horizon. The methods of finding the latitude of a place are simply methods of finding one or the other of these two angles. Some of these methods are given below.

First method. Let E be the place of the observer; HZH′ the upper branch of his meridian; P the elevated pole; EQ the projection of the equinoctial on the meridian; and let s'' and s''' be the points of upper and lower culmination of a star which is near the pole.

The altitudes Hs'' and Hs''' are measured with some suitable instrument, and both are corrected for refraction. Then, because the distance of the star from the pole is the same for each observation, HP, or the latitude, is equal to the half sum of the corrected altitudes.

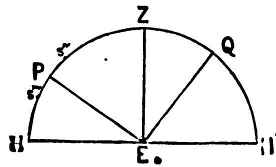

Fig. 45. Method of finding Latitude.

If the polar distance of the star, Ps'' or Ps''', is known, the latitude may be found by a single observation.

Second method. Let E be the place of the observer; Z his zenith; HZH his meridian; S the place of a star whose declination is known; ZSB a vertical circle through S; and PS an hour circle. Also, let HBH be the celestial horizon of the observer at E. The altitude BS is measured and the sidereal time of observation is noted. The measured altitude is first corrected for refraction, and the result taken from 90°; this gives the arc ZS; the difference between the sidereal time of observation and the right ascension of S gives the hour angle ZPS; the declination of S being subtracted from 90°, gives the value of PS. In the spherical triangle ZPS we therefore know the sides ZS, PS, and the angle ZPS; hence the side PZ may be computed. But, PZ is the complement of the latitude; the latitude may therefore be found by subtracting PZ from 90°.

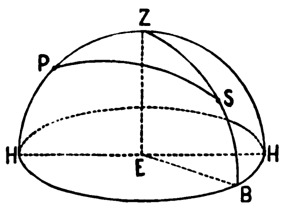

Fig. 46. Determination of Latitude.

The spherical triangle ZPS, in which S is any star, is often called **the astronomical triangle**, on account of its importance in astronomical computations. In it, PZ is the *co-latitude* of the place of observation; ZS is the *zenith distance* of the star; PS is the star's *polar distance;* ZPS is the *hour angle* of the star; PZS is the *azimuth* of the star counted from the direction of the elevated pole; and PSZ is called the *position angle* of the zenith. When any three of these elements of the triangle are known, all the others may be found by computation.

Third method. This method was first employed by Capt. Talcott, of the U. S. Army, and is generally known as **Talcott's method.** It is the simplest and the most accurate of all the methods, but it is only applicable when an approximate value of the latitude is already known.

EXPLANATION. An approximate value of the latitude being known, we select from a catalogue two stars which culminate within a few minutes of each other and whose meridian zenith distances are nearly equal. Let s and s', Fig. 44, be the points at which these stars culminate, EQ being the projection of the equinoctial and Z being the zenith of the place whose latitude is to be determined.

Denote QZ, which is equal to the latitude, by l; Qs, Qs', which are the declinations of the stars, by d and d': and Zs, Zs', which are the meridian zenith distances of s and s', by z and z'. We then have, from the figure,

$$l = d + z; \text{ and } l = d' - z' \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Adding equations (1), member to member, and dividing by 2, we have

$$l = \tfrac{1}{2}(d + d') - \tfrac{1}{2}(z' - z) \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The value of $d + d'$ is found from the star catalogue, the value of $z' - z$ is found by the method explained in Art. 75, and these values substituted in equation (2) give the latitude required.

Geocentric Latitude.

77. The latitude determined by any of the preceding methods is called the **geographic latitude,** and is equal to the angle between the normal at the place and the plane of the equator. The **geocentric latitude** is the angle between the radius of the earth at the place and the plane of the equator. The angle between the normal and the radius is called the **reduction**; this is zero at the equator and at the poles, and is a maximum when the latitude is 45°, where it is about 11′ 30″.

EXPLANATION. The ellipse PMQE is the meridian of the place M; EQ, the equator; MA, the normal at M; MC, the radius at M; QAM, the geographic latitude of M; QCM, its geocentric latitude; and AMC, the reduction.

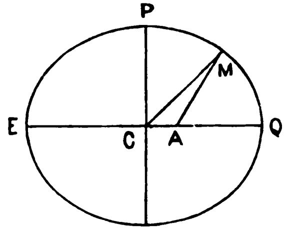

Fig. 47. Geocentric Latitude.

Apparent and Mean Solar Time.

78. An **apparent solar day** is the interval between two successive transits of the sun over the upper branch of the same meridian; time reckoned in terms of this unit is called **apparent solar time.**

This species of time is not adapted to the wants of astronomy because it is not uniform. The sun's motion along the ecliptic is variable, and furthermore, the direction of its motion with respect to the equinoctial is continually changing; for these reasons the sun's advance in right ascension is not uniform, and consequently the lengths of apparent solar days are not equal to each other.

To secure the desired uniformity, astronomers have adopted the device of an *imaginary sun,* moving uniformly along the equinoctial and making the circuit of the heavens in the same time as the real sun; this imaginary body is called the **mean sun.** The interval between two consecutive transits of the mean sun over the upper branch of the same meridian is called a **mean solar day**, and time reckoned in terms of this unit is called **mean solar time.**

The manner in which the motion of the mean sun is connected with that of the true sun may be explained as follows. We first suppose a *fictitious sun* to move uniformly along the ecliptic, its rate of motion being equal to the real sun's average motion in longitude. This fictitious sun coincides with the real sun when the earth is in perihelion and when it is in aphelion, but at no other time. The longitude of this imaginary body is called the **sun's mean longitude**, and its angular motion with respect to the earth is called the **sun's mean motion in longitude.** When this fictitious sun reaches the vernal equinox, a *second fictitious sun* is supposed to start from that point and to move uniformly along the equinoctial with the same angular velocity as the first; the two fictitious suns are together at the equinoxes, but at no other times. This second fictitious sun is the **mean sun** of astronomy.

Because the longitude of the first fictitious sun is zero when it is at the vernal equinox, and because the two imaginary suns have the same angular velocity, it is obvious that the *right ascension of the mean sun* is always equal to the *sun's mean longitude.*

The Equation of Time.

79. The **equation of time** is the difference between *apparent* and *mean* solar time at any instant.

The equation of time is used to convert *apparent* into *mean* solar time; it is also used to convert *mean* into *apparent* solar time. When the mean sun is *west* of the true sun it comes to the meridian before the true sun and the equation of time is *positive,* that is, it must be added to apparent time to get mean time; when the mean sun is *east* of the true sun it comes to the meridian after the true sun and the equation of time is *negative,* that is, it must be subtracted from apparent time to get mean time.

The value of the equation of time for every day in the year, with the rule for using it, is given in the Nautical Almanac. It is equal to *zero* four times a year; viz.: on the 15th of April, on the 14th of June, on the 1st of September, and on the 24th of December. It has its greatest *positive* value on the 11th of February, at which time it amounts to more than 14 minutes, and its greatest negative value on the 2d of November, when it amounts to more than 16 minutes. At the former time the forenoons are nearly half an hour shorter than the afternoons, and at the latter time the afternoons are more than half an hour shorter than the forenoons. These irregularities take place when the days, in the northern hemisphere, are very short, and for this reason they are particularly noticeable.

EXPLANATION. The figure represents the projection of a part of the celestial sphere on the plane of the meridian HZH; P is the elevated pole; EQ is the projection of the equinoctial; VS is the projection of the ecliptic; PS′ and PM are projections of hour circles, the former passing through the true sun S, and the latter through the mean sun M, both being west of the meridian.

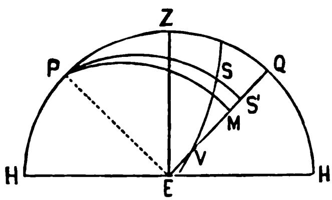

Fig. 48. Apparent and Mean Time.

The nature of the equation of time and the method of applying it will be understood after a careful study of Fig. 48. The hour angle QPS, measured by the arc QS′, is the angle between the meridian and the hour circle through the true sun; hence, QS′ divided by 15° is the *apparent time* at the instant in question. The hour angle QPM, measured by the arc QM, is the angle between the meridian and the hour circle through the mean sun; hence, QM divided by 15° is the *mean time* at the instant in question. The difference between QS′ and QM, that is, the arc S′M divided by 15° is the *equation of time*. In the case considered the equation of time is positive, and it is obvious from the figure that the mean time is equal to the apparent time *plus* the equation of time.

The arc VS′ is the right ascension of the true sun, and the arc VM which is the right ascension of the mean sun is, from Art. 78, the sun's mean longitude. Hence, *the equation of time is the difference between the sun's true right ascension and his mean longitude.*

Comparison of Sidereal and Mean Solar Time.

80. The meridian plane of any place is carried eastward by the earth's rotation, sweeping uniformly over the heavens, and indicating the lapse of time by its progress amongst the stars. In a sidereal day it turns through an angle of 360°, but in a mean solar day it turns through an angle which is greater than 360° by an amount which is equal to the angular motion of the mean sun in that time.

From what has preceded it is plain that the number of sidereal days in the interval between two successive returns of the sun to the vernal equinox is greater by 1 than the number of solar days in the same period. This interval is called a tropical year, and as we shall see hereafter it contains 365.2422 mean solar days; hence, it must contain 366.2422 sidereal days.

The quotient of 366.2422 by 365.2422 is 1.002738 *nearly*, and the quotient of 365.2422 by 366.2422 is .99727 *nearly*. Hence, a mean solar day is equal to 24 hours, 3 minutes, 56.56 seconds of sidereal time, and a sidereal day is equal to 23 hours, 56 minutes, 4.13 seconds of solar time.

The solar day exceeds the sidereal day by 3 minutes, 56.56 seconds of sidereal time, or by 3 minutes, 55.9 seconds of solar time.

In practice intervals of solar time are converted into corresponding intervals of sidereal time, and the reverse, by means of tables constructed in accordance with the preceding principles.

Astronomical Dates.

81. The time at which the apparent sun crosses the upper branch of the meridian of any place is called **apparent noon**, and the time at which the mean sun crosses the meridian is called **mean noon.** The **astronomical day** begins at one mean noon and ends at the next mean noon, the interval being divided into *hours, minutes,* and *seconds* as already explained (Art. 17). The date of any astronomical day is the same as that of the civil day on which it begins; its hours are numbered continuously up to 24. Thus, the day that begins at noon on the 22d of December ends at noon on the 23d of December, and, in astronomical language, this interval is styled the 22d of December. The astronomical date December 22d, 6 hours 15 minutes, corresponds to the civil date December 22d, 6 hours 13 minutes, P. M.; the astronomical date December 22d, 18 hours 13 minutes, corresponds to the civil date December 23d, 6 hours 13 minutes, A. M.

It is the custom for each astronomer to reckon time from the instant when the mean sun crosses his own meridian; time thus reckoned is said to be **local time**. It is obvious that the absolute instant of time at which a phenomenon is observed may bear different dates at different places. In order, therefore, that we may compare the observations of different astronomers, we must not only know the local dates, but also the relative positions of the places of observation.

The Chronometer.

82. In many cases it would be inconvenient to use an astronomical clock (Art. 18), and in some cases, especially at sea, its use would be impossible. In these cases a chronometer may be employed.

A chronometer is simply a nicely constructed watch. To guard as far as possible against the irregularities that would arise from change of temperature, the balance wheel is *compensated*, the compensation being made in such manner as to neutralize the irregularities, not only of the balance wheel itself, but of the hair-spring. Particular attention is given to the escapement and also to the winding arrangement.

To secure uniformity of rate it is necessary that the chronometer should remain, as nearly as possible, in a fixed position. For this reason the instrument is suspended by a sort of *universal joint*, and in such manner that its face shall always be horizontal.

Error of a Clock, or Chronometer.

83. There are several methods of finding the error of a clock or chronometer with respect to mean time.

1°. **By a transit of the sun.** In this method we note the reading of the clock, or chronometer, at the instant when the advancing *limb* or *edge* of the sun crosses the meridian, and also when the following limb crosses it; the half sum of these is the clock reading at apparent noon, from which we have at once the *apparent* error of the time-piece; this result corrected for the equation of time is the *error* required.

2°. **By measuring the altitude of the sun.** In this method we are supposed to know the latitude of the place and the declination of the sun. We measure the altitude of the sun's lower limb, and at the same time we note the reading of the chronometer. This altitude, after being corrected for refraction, semi-diameter, and parallax, gives the true altitude of the sun's centre. Subtracting the altitude of the sun's centre from 90°, we have the side ZS of the astronomical triangle (Art. 76); subtracting the latitude of the place from 90°, we have the side PZ; and subtracting the sun's declination from 90° we have the side PS. We may therefore compute the hour angle ZPS, which gives the apparent time at the instant of observation; from this we can find the corresponding mean time, and consequently the error of the chronometer.

By finding the error of the chronometer at two instants sufficiently remote from each other, we can find the rate (Art. 18).

The error of a clock or watch may also be determined by means of observations made upon a star either when *on* or *off* the meridian. When either the sun, or a star, is observed off the meridian, it is better to make two observations, one when the body is east and the other when it is west of the meridian, and these should be made at nearly equal times before and after culmination.

Relation of Longitude and Time.

84. The **longitude** of a place is the angular distance of the meridian of that place from some fixed meridian. It is reckoned from the fixed meridian toward the west, and may be expressed either in units of angular measure or in units of time. Longitude is generally reckoned from the meridian of Greenwich, England, but it may be reckoned from any other meridian; thus, in the United States longitude is often reckoned from the meridian of Washington. To avoid confusion we shall always regard the meridian of Greenwich as the *fixed* or **prime meridian.**

It has been stated already that we may either suppose the earth to revolve from west to east carrying the meridians of different places with it, or that we may conceive the earth to be at rest and the heavens to revolve with an equal angular velocity from east to west, inasmuch as the apparent motions of the heavenly bodies will be the same in either case. In showing the relation of longitude and time the latter idea will be adopted, not only because it is simpler, but because the motions to be considered will then correspond to the direction in which longitude is reckoned.

Let us first consider the apparent motion of the vernal equinox, calling the time at which it is on the meridian of any place **sidereal noon.** Setting out from the meridian of Greenwich the equinox travels westward at the rate of 15° in a *sidereal* hour; hence, when it is sidereal noon at a place on any other meridian the sidereal time at Greenwich, *in hours*, is equal to the number of degrees in the longitude of the place divided by 15, that is, the longitude of any place, expressed in time, is the difference between the sidereal time at the place, and at Greenwich.

For example, the longitude of New York is 74°, and consequently the time required for the equinox to travel from the meridian of Greenwich to that of New York is $\frac{74}{15}$ of an hour, or 4 hours 56 minutes; hence, when it is sidereal noon in New York, the sidereal time at Greenwich is 4 hours 56 minutes; when the sidereal time at New York is 1 hour, the sidereal time at Greenwich is 5 hours 56 minutes; when the sidereal time at New York is 2 hours the sidereal time at Greenwich is 6 hours 56 minutes, and so on. The longitude of New York, expressed in time at the rate of 15° to the hour, is, therefore,

equal to the difference of the local sidereal times at New York and at Greenwich.

Again, let us consider the apparent motion of the mean sun. Setting out from Greenwich the mean sun travels uniformly toward the west, returning to that meridian at the end of 24 mean solar hours; hence, it travels westward *with respect to any meridian* at the rate of 15° in a mean solar hour. Consequently, when it is mean noon at a place on any other meridian the mean solar time at Greenwich, *in hours,* is equal to the number of degrees in the longitude of the place divided by 15, that is, the longitude of a place, expressed in time, is equal to the difference between the mean solar time at the place, and at Greenwich.

From what precedes, we infer that *the difference between the longitudes of any two places,* expressed in time, *is equal to the difference of the local times at the two places* at the same instant, and this whether the time considered is sidereal, or mean solar. Conversely, the difference of local time at any two places is equal to their difference of longitude *expressed in time.*

The Chronograph.

85. A **chronograph** is a contrivance for recording the times of astronomical observations by means of the electric current.

The recording part of the apparatus consists of a **revolving cylinder** and a suitable **recording pen.** The cylinder, which carries a sheet of paper wrapped around it, is made to revolve on its axis at the rate of one turn per minute, and at the same time the recording pen is made to advance in the direction of the axis of the cylinder at the rate of about $\frac{1}{8}$ of an inch per minute. The pen is moved *to* and *from* the revolving paper by means of an electro-magnet and a counteracting spring. When the electric circuit is *completed* the pen is pressed against the paper and a **signal** is recorded; when the circuit is broken the pen is thrown back by the spring.

The recording apparatus is connected with the clock in such a manner that the circuit is completed, and a signal recorded, at each beat of the pendulum; it is also connected with a key by means of which the circuit may be completed, and a signal recorded, at the pleasure of the observer. By a simple mechanical arrangement the pen is slightly displaced at each beat of the pendulum, so that a peculiar form is given to the clock-signals, which distinguishes them from those made by means of the key. An arrangement is often made by which the record of the last second of each *minute* is omitted; this facilitates the operation of determining the time that corresponds to any signal.

When the instrument is in use the clock-signals are registered automatically, and it only remains to connect them with the reading of the clock; this is done by writing the clock time at the beginning of any minute over the corresponding signal on the revolving paper. In registering the transit of a star the observer holds the key in his hand, closing it briskly when the star crosses a line of the reticle. The time corresponding to each of these signals can be determined by its distance from the adjacent clock-signals.

It is to be noted that the recording apparatus need not be near the observer; it may even be hundreds of miles from the place of observation.

Methods of Determining Longitude.

86. The operation of finding the difference of longitude of two places consists in finding the difference of the local times of the places at any given instant (Art. 84). The following are some of the methods employed:

1°. **By chronometer.** In this method the observer is provided with a chronometer whose error with respect to Greenwich time at a given epoch, and whose rate are known. From these data the observer can compute the local Greenwich time at any instant. By one of the methods explained in Art. 83 he can determine his local time at the same instant. The difference between these local times is the required longitude.

This is the method which is generally used at sea, and by travelers. It is somewhat uncertain on account of the liability of a chronometer to change its rate. The accuracy of the determination may be increased by using two or more chronometers.

2°. **By signals.** This method requires two observers, each provided with a chronometer, whose error and rate are known. The observers are stationed at the places whose difference of longitude is to be determined, and at a time agreed upon a signal is made which can be seen from both stations. The chronometer time of the signal, which may be a flash of gunpowder, the bursting of a rocket, or something of the kind, is noted by both observers, and each determines his corresponding local time. The difference of these local times is the difference of longitude between the two stations.

3°. **By the eclipses of Jupiter's satellites.** The eclipses of Jupiter's satellites, as we shall see hereafter, are of frequent occurrence; the times at which they take place are computed in advance and laid down in the Nautical Almanac. If an observer knows his longitude approximately, he can find the approximate local time at which an eclipse is to be looked for, and when it happens he has only to note the reading of his chronometer; from this he can find the correct local time of the phenomenon. The difference between the local time thus found and the corresponding Greenwich time, taken from the almanac, is the longitude of the place of observation.

4°. **By lunar distances.** It will be seen hereafter that the moon moves eastward among the stars at the rate of a little more than half a degree per hour; it is therefore continually approaching those stars that lie to the east, and continually receding from those that lie to the west. The angular distances between the moon and certain bright stars as seen from the centre of the earth are computed for every three hours and laid down in the Nautical Almanac.

In order to find the longitude of a place the observer determines, by observation and computation, the geocentric angle subtended by the moon and a suitable star at any instant; he then finds from data given in the almanac the Greenwich time at which the bodies subtend this angle. The difference between the local time of observation and the corresponding Greenwich time is the required longitude.

5°. **By the electric telegraph.** When two places are in telegraphic communication the best method of determining their difference of longitude is by means of electric signals. This method requires two observers, each provided with a transit instrument, a clock or chronometer, and a chronograph. The error and rate of each clock having been carefully determined, both clocks are connected with one of the chronographs and allowed to record their beats for a few minutes; both clocks are then connected with the other chronograph and again allowed to record their beats for an equal time. From these records and the known errors of the clocks at the corresponding times, the difference between the local times at the two stations can be deduced and this is the required longitude.

A single set of chronographic observations would be sufficient to determine the difference of local times, were it not for the fact that a certain period of time is required for the electric current to pass from one station to the other. In finding the difference of local times we have to subtract the time at the western station from that at the eastern station. But when both clocks are connected with the eastern chronograph, the recorded time of the western clock will be too great by the period required for electricity to travel over the distance between the stations, and consequently the recorded difference of local times will be too small by that amount. Again, when the clocks are connected with the western chronograph the recorded time of the eastern clock will be too great by the time required for electricity to travel over the distance between the stations, and consequently the recorded difference of local times will be too great by that amount. Hence, if we determine the differences of the local times as recorded upon both chronographs, the half sum of these differences will be the required difference of times, corrected for the time required for electricity to travel from station to station.

As an illustration, let E be an eastern and W a western observer, and suppose that it requires 0.4 second for the current to pass from one to the other. At 12 o'clock, E sends a signal to W which is received, say at 11 hours 46 minutes 42.9 seconds, giving an apparent difference of local times equal to 13 minutes 17.1 seconds; again at 12 o'clock, W sends a signal which is received by E at 12 hours 13 minutes 17.9 seconds, giving an apparent difference of local times equal to 13 minutes 17.9 seconds. The half sum of these differences, which is 13 minutes 17.5 seconds, is the required difference of longitude.

V. THE MOON.

The Moon's Actual Path in Space.

87. The **moon** is a satellite of the earth, revolving around it and at the same time accompanying it in its annual journey around the sun.

During the earth's revolution around the sun the plane of the lunar orbit is carried along with it, and because this plane is always inclined to the earth's orbit it follows that the moon's real path in space is a species of flattened spiral winding once around the earth's orbit in each revolution of the moon, but never returning into itself.

In what follows we shall only consider the moon's motion with respect to the earth, that is, we shall disregard that part of her motion which is due to the common revolution of the earth and moon around the sun.

Definitions and Explanations.

88. The moon's **orbit is an ellipse**, one focus of which is at the centre of the earth, or, more strictly speaking, at the common centre of gravity of the earth and the moon, a point that is always within the body of the earth. She moves along this orbit in such a manner that her **radius-vector**, that is, the line from the earth to the moon, **sweeps over equal areas in equal times.** Her motion is from west to east, and her velocity is such that she travels from any given star completely around the heavens back to the same star in about $27\frac{1}{3}$ days; this time is called her **sidereal period.**

The point of the moon's orbit which is nearest the earth is called **perigee**, that which is farthest from the earth is called **apogee**, and the line joining them is called the **line of apsides**; in consequence of the *law of equable description of areas* the moon's angular velocity is a maximum at perigee and a minimum at apogee.

The plane of the moon's orbit is inclined to that of the ecliptic in an angle that is slightly variable, but whose mean value is 5° 8′ 30″; the points in which the orbit intersects the plane of the ecliptic are called **nodes**, and the line joining them is called the **line of nodes**. The point at which the moon passes from the south to the north side of the ecliptic is the **ascending node**, and the point at which she passes from the north to the south side of the ecliptic is the **descending node**.

Mean Distance and Horizontal Parallax.

89. The moon's mean distance from the earth is a little less than 239,000 miles, and the corresponding value of her equatorial horizontal parallax is about 57′. The excentricity of the orbit is variable, its mean value being 0.055; hence, the moon's average distance when in perigee is about 226,000 miles, and when in apogee about 252,000 miles. Of course the horizontal parallax varies with the varying distance of the moon. The distance and corresponding value of the parallax may be found by the following method.

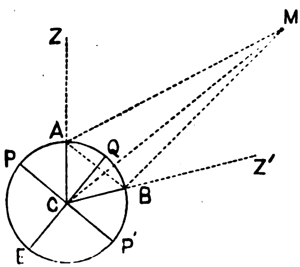

Fig. 49. Method of finding Distance of Moon.

Explanation. The curve PQP′E represents a meridian section of the earth; EQ, the equator; A, B, two stations on the meridian; and M, the apparent place of the moon when on the meridian.

The geocentric latitudes of A and B being given, the radii CA and CB are known from the properties of an ellipse, and consequently the angle ACB; hence, the chord AB and the angles CAB, CBA can be computed. The supplement of the zenith distance ZAM, diminished by CAB, gives BAM; and in like manner we have MBA; hence, the angle AMB and the distance AM can be found. Knowing CA, AM, and the angle CAM, we can compute CM, which is the *moon's distance*, and CMA, which is the parallax corresponding to the apparent zenith distance ZAM. From these elements we can easily deduce the horizontal parallax for the radius CA, and thence the horizontal parallax for the equatorial radius, that is, the *moon's equatorial horizontal parallax* corresponding to the distance CM.

The elements given in this and the preceding articles are subject to the disturbing influence of the sun and planets, which act to draw the moon slowly but continuously from its normal orbit. We may, however, continue to regard her orbit as elliptical if we suppose the ellipse to vary slightly at each instant both in its position and in its form. A complete discussion of this subject is beyond the scope of the present work, but some of the changes that take place will be pointed out in the following article.

Irregularities in the Moon's Motion.

90. The following are some of the most important of the changes that take place in the lunar orbit in consequence of the disturbing influence of the sun, and the smaller perturbations due to the action of the planets.

1°. The **inclination** of the plane of the lunar orbit is subject to an alternate increase and decrease; its least value is about 4° 57′, and its greatest value is about 5° 20′, giving for the *mean* or *average* inclination about 5° 8′ 30″.

This change is equivalent to a rocking or vibratory motion of the orbital plane about the line of nodes.

2°. The **line of nodes** has a *retrograde* motion in the plane of the ecliptic; that is, a motion from east to west, by virtue of which it performs a complete revolution with respect to the stars in about 18.6 years.

This change is equivalent to a revolution of the plane of the moon's orbit around an axis passing through the centre of the earth, and perpendicular to the plane of the ecliptic; that is, making an angle with the plane of the orbit whose average value is 84° 51′ 30″.

3°. The **line of apsides**, which is the same thing as the transverse axis of the orbit, has a *direct* motion by virtue of which it performs a complete revolution from west to east in a little less than 9 years.

This change is equivalent to a revolution of the orbit in its own plane around an axis passing through the centre of the earth, and perpendicular to the plane of the orbit.

4°. The **excentricity** of the orbit is subject to an alternate increase and diminution, either of which may amount to more than $\frac{1}{5}$ of the mean value of the entire excentricity, which is about 0.055. The *minimum* value of the excentricity may therefore become less than .044, and its *maximum* value may become greater than .066.

This change produces a corresponding change in the difference between the apogean and the perigean distances of the moon, the difference being about 21,000 miles when the excentricity is a minimum, and about 31,000 miles when the excentricity is a maximum.

5°. The **mean distance**, which is the same thing as the semi-transverse axis of the orbit, is subject to a secular change; that is, a change that extends through an immensely long period. At present the mean distance is *diminishing.*

These changes are taking place simultaneously, and all of them are more or less irregular; hence, the operation of computing the moon's place in the heavens is extremely tedious. The place of the moon, determined by tables constructed for the purpose, is laid down in the Nautical Almanac for every hour of the day throughout the year.

Angular Diameter of the Moon.

91. The **angular diameter** of the moon varies inversely as her distance from the observer; when she is at her mean *distance*, her angular diameter as seen from the centre of the earth is 31′ 7″.

One-half of the angular diameter of the moon is called the moon's **apparent semi-diameter.**

Because the moon is farther from the centre of the earth than she is from any point on the surface from which the moon is visible, the apparent semi-diameter of the moon when seen from the surface is greater than it would be if seen from the centre. This excess, which is called the *augmentation of the moon's semi-diameter*, obviously increases as she approaches the zenith of the observer. The mean distance of the moon from the centre of the earth is a little more than 60 times the terrestrial radius; hence, her mean distance from that point of the surface which lies directly between the centres of the earth and moon is a little more than 59 terrestrial radii. At this point, therefore, the augmentation of the moon's semi-diameter is about $\frac{1}{60}$ of its entire value; that is, it amounts to nearly 16″.

Magnitude, Mass, and Density of the Moon.

92. The **semi-diameter** of the moon in miles is found by multiplying her distance from the earth by the sine of her *apparent semi-diameter*. In this way we find that her semi-diameter is equal to 1080 miles, and consequently her **diameter** is 2160 miles. From this we infer that the **volume** of the moon is about $\frac{1}{50}$th that of the earth.

The **mass** of the moon, as found by the methods of physical astronomy, is about $\frac{1}{80}$th that of the earth. The **density** of the moon is therefore about $\frac{5}{8}$ths that of the earth, or about $3\frac{1}{2}$ times that of water.

Synodic Period.—Phases.

93. The moon's **synodic period**, which is the same as a **lunar month**, is the interval between two consecutive conjunctions of the sun and moon. In consequence of irregularities in the motions of both of these bodies, the length of the synodic period is somewhat variable; its average length, however, is found to be about 29.53 days. For the ordinary purposes of description its length is taken as $29\frac{1}{2}$ days.

During a lunar month the bright part of the moon assumes a succession of different forms called **phases**; these are due to a continual change in the position of the observer with respect to the sun and the moon.

The *illuminated* half of the moon is turned toward the sun and the line that separates it from the *unilluminated* part is called the **terminator**. The plane of the terminator, except at conjunction and opposition, is oblique to the observer's line of vision; hence, its projection on the moon's disk is elliptical. The bright part of the moon's disk is therefore bounded on one side by a semicircle, and on the other side by a semi-ellipse.

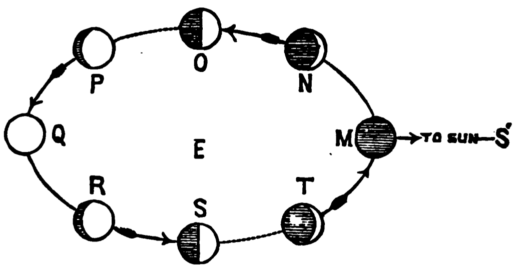

Fig. 50. Phases of the Moon.

EXPLANATION. E is the position of the earth; ES′ is the direction from E to the sun; MOQS is the moon's orbit, supposed to lie in the plane of the ecliptic; M, N, O, P, etc., are the representations of the moon's phases when her elongations from the sun are 0°, 45°, 90°, 135°, etc.; and the arrow-heads show the direction of the moon's motion.

The different phases of the moon and their order of succession are shown in Fig. 50. When the moon is at M, that is, when she is in conjunction with the sun, her illuminated face is turned away from the earth, and is therefore invisible; the moon is then said to be **new**. After passing M a portion of the illuminated face comes into view, and this portion continues to increase until she reaches Q, when her entire illuminated face is turned toward the earth; the moon is then said to be **full**. After passing Q the visible portion of her illuminated face begins to diminish, and this diminution goes on until she returns to M, when she again becomes invisible. When the moon is at O she is said to be in her **first quarter**, and when at S she is said to be in her **third quarter**.

Between M and O, and between S and M, the moon's phase as shown at N and T is said to be **crescent**; between O and Q, and between Q and S, her phase as shown at P and R is said to be **gibbous**; at O and at S her phase is said to be **dichotomous**.

In all its changing forms the circular portion of the moon's apparent outline is turned toward the sun; hence, from new moon to full moon the western limb is circular, and from full moon to new moon the eastern limb is circular.

The earth, as seen from the moon, goes through a succession of phases which are always complementary to those of the moon as seen from the earth, that is, when the moon has a *crescent* phase the earth has a *gibbous* phase, and the reverse.

For a few days before and after new moon the dark part of the moon is faintly visible; this is due to light twice reflected. The earth being nearly full at that time, as seen from the moon, reflects a sufficient amount of sunlight to render the entire disk of the moon faintly visible to a terrestrial observer.

It is noticeable at this time that the semicircle that bounds the bright limb appears perceptibly larger than that which bounds the dark limb; this is an optical delusion due to irradiation. It is an established principle of optics that a bright circular disk appears larger than a dark one of the same size; hence, the phenomenon in question.

Other Lunar Periods.

94. Besides the sidereal and the synodic periods already referred to, the moon has two other periods frequently used by astronomers, the *nodical* and the *anomalistic* periods. The **nodical period** is the interval between two successive returns of the moon to the *ascending node;* and the **anomalistic period** is the interval between two successive returns of the moon to *perigee.*

Because the ascending node has a *retrograde* motion, the arc passed over by the moon in a nodical revolution is less than a complete circumference by the arc that is passed over by the node in that time; hence, the nodical period is less than the sidereal period. Again, because the perigee has a *direct* motion, the arc passed over by the moon in an anomalistic period is greater than a complete circumference by the arc passed over by the perigee in the same time; hence, the anomalistic period is greater than the sidereal period.

For convenience of reference the average values of four principal lunar periods are given below:

Sidereal period....................	27.32 *days.*
Synodical period....................	29.53 *days.*
Nodical period......................	27.21 *days.*
Anomalistic period..................	27.55 *days.*

Rotation of the Moon.

95. It is a matter of common observation that we always see very nearly the same face of the moon; that this may be the case, the moon must revolve around an axis in the same time that she makes a revolution in her orbit, and, furthermore, her axis of revolution must be nearly perpendicular to the plane of her orbit.

More accurate observations show that the plane of the moon's equator intersects the plane of her orbit in a line that is parallel to the line of nodes. A plane passing through this line and parallel to the ecliptic lies between her equator and her orbit, the former making an angle of about $1\frac{1}{2}°$ on one side, and the latter an angle of about 5° on the other side, as shown in Fig. 51; hence, the plane of the moon's equator makes an angle of 6½° with the plane of her orbit.

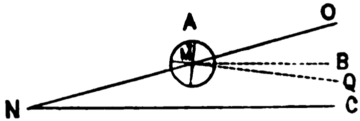

Fig. 51. Position of the Moon's Equator.

EXPLANATION. The plane of the paper is supposed to be perpendicular to the ecliptic and to the moon's orbit. N is the projection of the line of nodes; NC is the projection of the ecliptic; NO is the projection of the moon's orbit; MQ is the projection of the moon's equator; and MB is parallel to NC. The angle QMB is equal to 1½°; the angle OMB is equal to 5°; and the angle QMO is 6½°. MA, perpendicular to MQ, is the axis of the moon, making an angle of 1½° with the axis of the ecliptic.

The moon's axis of rotation makes an angle of 1½° with the axis of the ecliptic, and is always perpendicular to the line of nodes; hence the *axis* of the moon has a retrograde motion by virtue of which it describes a very acute conical surface in 18.6 years, which is the time required for the line of nodes to complete an entire revolution. This gyratory motion is similar to that of the earth's axis as explained in Art. 73.

The Moon's Librations.

96. In consequence of the moon's irregular motion her visible face is not always exactly the same; it is subject to slight periodical changes, such as would be produced if the moon were made to rock back and forth around certain lines as axes. These oscillatory motions, which are only *apparent*, are called **librations.**

The moon has two principal librations, one with respect to an axis perpendicular to the plane of the orbit, and the other with respect to an axis in that plane; the former is called **libration in longitude**, and the latter **libration in latitude.**

1°. **Libration in longitude.** This libration is due to the fact that the moon revolves *uniformly* around her axis whilst her angular velocity with respect to the earth is *variable.* Because the moon's radius-vector sweeps over equal areas in equal times, she will occupy the same time in passing from perigee to apogee as in passing from apogee to perigee; hence, so far as this libration is concerned, the visible face of the moon at apogee will be the same as at perigee. In setting out from perigee her orbital angular velocity is greater than her angular velocity of rotation; we therefore see more of her western and less of her eastern face than we do at perigee. The additional portion that thus becomes visible goes on increasing during the *first quarter* of the anomalistic period, and then it decreases during the *second quarter*, at the end of which time the visible portion, as we have said above, is the same as at perigee. But, in setting out from apogee the circumstances of motion are reversed, and we see more of her eastern and less of her western face than we do at apogee. This additional portion goes on increasing during the *third quarter* of the anomalistic revolution, and then it diminishes during the *fourth quarter*, at the end of which time the moon presents to us the same face as at apogee.

The entire cycle of this libration is equal to the *anomalistic* period of the moon, during which the appearances presented are the same as though the moon had been slightly rocked back and forth around an axis perpendicular to the plane of her orbit.

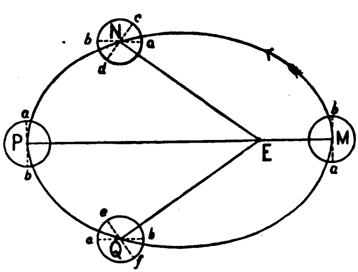

Fig. 52. The Moon's Libration in Longitude.

EXPLANATION. M and P are the positions of the moon at perigee and apogee; N and Q are her positions at the end of the first and third quarters of her anomalistic revolution; *ab* is the plane that determines the visible portion of her surface when at M and P; and *cd* and *ef* are the planes that limit her visible surface when at N and Q.

2°. **Libration in latitude.** This libration is due to the fact that the axis of the moon is inclined to the plane of her orbit. When the moon is at either node the plane that limits her visible surface passes through her axis, and consequently the visible surface extends from pole to pole. When her angular distance from either node is 90°, the plane that limits her visible surface makes an angle of 6½° with the axis; if at this time she is south of the ecliptic, the visible surface extends 6½° beyond the north pole, but if she is north of the ecliptic the visible surface extends 6½° beyond the south pole.

The entire cycle of this libration is equal to the *nodical* period of the moon, during which the appearances presented are the same as though the moon had been slightly rocked back and forth around the line of nodes of the moon's orbit.

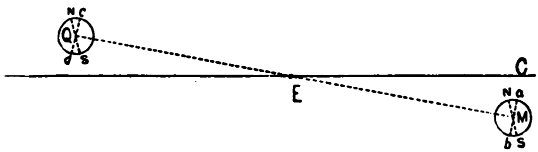

Fig. 53. The Moon's Libration in Latitude.

EXPLANATION. The plane of the paper is perpendicular to the line of nodes which is projected at E, the place of the earth; EC is the projection of the ecliptic; M and Q are the positions of the moon when 90° from either node; NS is the axis of the moon; and *ab* and *cd* are the planes that limit the visible part of the moon's surface when at M and Q.

In this connection we may mention a change that takes place in the visible face of the moon between the times of rising and setting. This change, which is sometimes called the **diurnal libration**, is simply parallactic. It is due to the fact that the centre of the moon's visible face as seen from the surface of the earth is not the same that it would be if seen from the centre. As a consequence, a little more of her *western* limb, or edge, is visible at the time of rising and a little more of her *eastern* limb, or edge, at the time of setting than can be seen when she is on the meridian.

The combined effect of the moon's librations enables us at one time or another to see nearly $\frac{4}{7}$ths of the moon's entire surface.

Variation of the Moon's Meridian Altitude.

97. It is a matter of common observation that the altitude of the moon at her upper culmination is widely variable. This variation is caused by the continual change in the moon's declination.

The moon's meridian altitude, as observed at any place, is equal to *the co-latitude of the place* increased by *the moon's declination,* due regard being paid to the sign of the latter element (Art. 16). Now, the moon's declination depends not only upon her place in her orbit, but also on the position of her orbit with respect to the ecliptic. The variation in the moon's declination is greatest when the ascending node of her orbit is at the vernal equinox, and least when the ascending node is at the autumnal equinox. In the former case the declination varies in a *nodical* period from $+28\frac{1}{2}°$ to $-28\frac{1}{2}°$; in the latter case it varies from $+18\frac{1}{2}°$ to $-18\frac{1}{2}°$ in the same time.

For a place whose latitude is 40° N. the greatest meridian altitude of the moon in any month is $78\frac{1}{2}°$, and the least meridian altitude is $22\frac{1}{2}°$.

On the day that the moon has the greatest meridian altitude in any month she is said to **run high**, and on the day that her meridian altitude is least she is said to **run low.**

The full moon, being nearly opposite to the sun in the heavens, will be north of the equinoctial when the sun is south of it, and south of the equinoctial when the sun is north of it. Hence, in winter the full moon tends to run high, and in summer to run low. We therefore have the greatest amount of moonlight in the long nights of winter, and the least amount in the short nights of summer.

The Harvest Moon.

98. On account of the eastward motion of the moon with respect to the sun, her time of rising is continually *retarded;*

her daily retardation, which is variable, amounts on an average to about 49 minutes. The retardation is least when she is in that part of her orbit which is least inclined to the horizon, for in that case her daily advance carries her but little below the horizon, and consequently the change in the time of her rising is correspondingly small. The retardation in the time of rising of the full moon that falls near the time of the autumnal equinox is generally less than half an hour for several days in succession. In England, on account of increased latitude, the phenomenon in question is more strongly marked than it is in the United States; and because it occurs about the time of their harvest, the September moon has been called the **harvest moon.**

Character of the Moon's Surface.

99. To the naked eye the surface of the moon presents a mottled appearance such as we might suppose it would offer if it were made up of land and water. When examined with a good telescope, it is found that the brighter portions are *mountains* and the darker portions slightly undulating *plains*, but no trace of water is anywhere to be seen.

The mottled appearance of the moon's surface, which is more strongly marked along the terminator, is shown in Fig. 54.

100. Taken as a whole, the visible surface of the moon is exceedingly irregular, more than half of it being made up of rugged mountain masses variously grouped and arranged. Occasionally we see an isolated peak casting its black shadow on the neighboring plain, and sometimes we meet with a continuous mountain range interrupted by deep and rocky gorges; but for the most part the grouping is so irregular as to defy all attempts at description. The arrangement of the mountain systems is shown in Fig. 55.

101. The roughness of a large portion of the lunar surface is much greater than that of our most mountainous regions. The ridges everywhere show an abruptness of declivity and a sharpness of outline which seem to preclude all idea of the existence of those atmospheric agencies which are ever at work smoothing down and rounding off irregularities on the surface of the earth. The rugged character of the moon's surface is shown in Fig. 56.

Fig. 54. Telescopic Appearance of the Moon. From a photograph by Prof. Henry Draper.

102. A striking feature in the lunar topography is the tendency of its mountain forms to a circular arrangement. The number of crater-like objects that are shown by a good telescope amounts to many thousands; in some parts of the moon they are crowded together like the cells of a honeycomb. The larger formations of this class consist of circular ridges enclosing large plains; the enclosed areas are called **bulwark plains**, and their surrounding ridges are named **ring mountains**. In almost every case of this kind the inner slope of the ring mountain is steeper than the

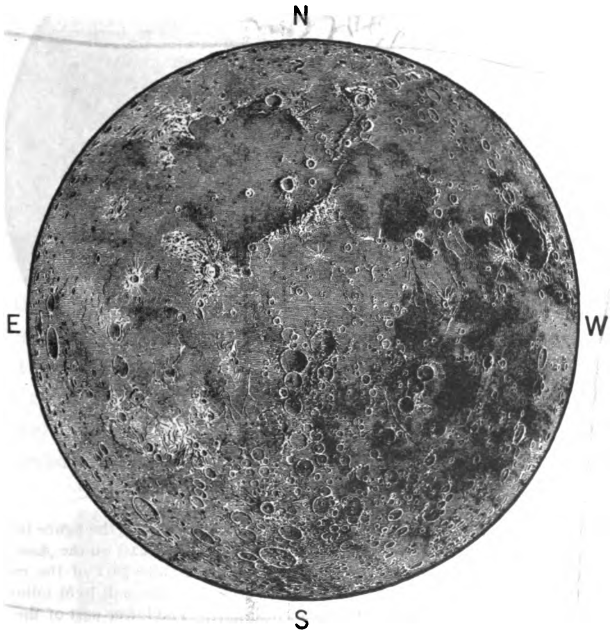

Fig. 55. Distribution of Mountains and Plains. From a photograph of a Model of the Moon by Nasmyth.

EXPLANATION. The top of Fig. 55 corresponds to the northern limb of the moon and the left-hand side to the eastern limb. The prominent mountain range, originating near a large crater-like formation in the north-eastern quadrant and running in a north-westerly direction, is called *the Apennines;* the crater itself is named *Copernicus*. The shorter chain, north of and nearly perpendicular to the Apennine range, but separated from it by a wide gap, is called *the Alps;* the Alpine chain terminates toward the north-east in a large crater named *Plato*. The southern part of the figure shows little else than a confused mass of compacted cliffs, ridges, and volcanic craters.

outer one. In some instances the ring mountain is made up of irregular concentric ranges; such a formation is shown in Fig. 57.

Fig. 56. Enlarged View of the Alpine Region.

EXPLANATION. The large crater toward the upper part of the figure is *Plato;* the character of its bounding rim is shown by the shadows cast on the *floor* of the enclosed area. The remarkable cleft, traversing the middle part of the range, is *the great valley of the Alps;* it is more than 80 miles long, from 3½ to 5¼ miles wide, and more than 2 miles in depth at its deepest part. The lower part of the figure represents a part of the great plain, called *Mare Imbrium.*

The smaller circular formations have every appearance of being true volcanic craters. In some of these the central depression consists of a deep cavity, apparently terminating in a point; in others the central depression terminates in a flat plain lying below the general level of the moon's surface; not infrequently there is a conical peak rising from the middle of this *floor* of the crater.

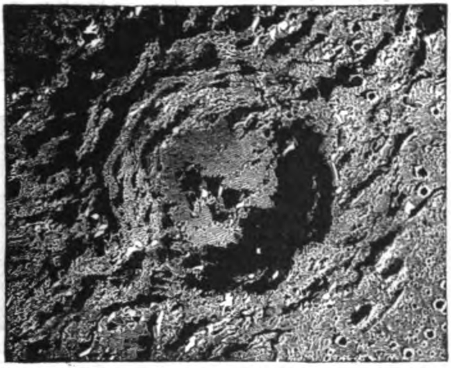

Fig. 57. Copernicus.

Explanation. Fig. 57 represents the ring mountain Copernicus. It is composed of terraces and ridges separated by deep ravines. The diameter of the enclosed area is more than 50 miles. Rising from the enclosed plain are 5 or 6 peaks, one of which is nearly half a mile in height.

103. In some parts of the lunar surface vast cracks or fissures exist, which may be traced to a considerable distance from their apparent origin. Such a system of cracks is shown in Fig. 58, the principal ones seeming to start from a small crater, near the large ring mountain, or crater, Triesnecker, situated not far from the centre of the lunar disk.

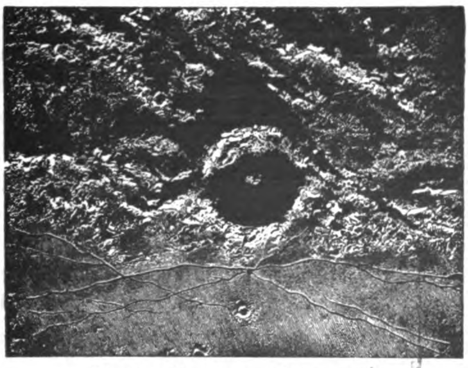

Fig. 58. Fissures near Triesnecker.

Another example of these cracks, or faults, is shown in Fig. 59, which represents an ideal view of the peak named *Pico*, situated nearly south of Plato in the *Mare Imbrium*.

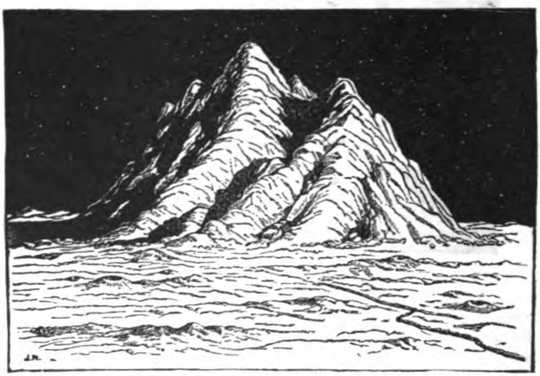

Fig. 59. Pico.

EXPLANATION. Fig. 59 is an ideal view of a lunar mountain peak. In the foreground we see not only the crack, or fissure, referred to, but also a number of minute craters.

104. At the time of full moon several systems of bright streaks are seen, each system diverging from a central crater. Of these the most remarkable set seems to originate in Tycho, the most prominent volcanic centre in the southern hemisphere of the moon. Some of these streaks extend to a distance of more than 1,700 miles. They appear to coincide with the general level of the moon's surface, and in many cases they pass over mountains and across ravines without any apparent interruption. Proctor says: "It seems clear that, as Nasmyth has illustrated by experiment, they belong to that stage of the moon's history when her still hot and plastic crust parted with its heat more rapidly than the nucleus of the planet, and so, contracting more quickly, was rent by the resistance of the internal matter, which, still hot and molten, flowed into the rents, and spreading, formed the long broad streaks of brighter surface."

VI. THE SUN AND PLANETS.

The Sun's Place in the System.

105. The sun is the principal body of the solar system, and as such it not only controls and regulates the motions of all the others, but it is to them their chief source of light, heat, and physical energy. His volume is more than 600 times the volume of all the planets taken together, and his mass is more than 700 times their aggregate mass. Among the fixed stars he is a peer, but in the solar system he is a ruler.

Orbit of the Earth. The Sun's Apparent Orbit.

106. It has already been stated (Art. 11) that the sun's *apparent* annual motion from west to east among the stars is due to the *actual* motion of the earth, which revolves around the sun in an orbit whose plane passes through the centres of the two bodies and retains a sensibly fixed position with respect to the stars.

If the line joining the centres of the earth and sun be indefinitely prolonged, it will meet the celestial sphere in two points diametrically opposite to each other. One of these is the **heliocentric place** of the earth, and the other is the **geocentric place** of the sun. Inasmuch as the line from the earth to the vernal equinox is parallel to the line from the sun to the same point, it follows that the difference between the *geocentric longitude* of the sun and the *heliocentric longitude* of the earth is equal to 180°.

The **orbit of the earth** is an ellipse having one of its foci at the centre of the sun. Its **excentricity** is about

$\frac{1}{60}$, that is, the distance of the sun from the centre of the orbit is about one-sixtieth of the semi-transverse axis. The heliocentric longitude of the *perihelion* point at the present time is not far from 100° 54′; hence, the geocentric longitude of the sun when in **apogee**, that is, when nearest the earth, is about 280° 54′.

The relation between the earth's actual orbit around the sun and the sun's apparent orbit around the earth is illustrated in Fig. 60.

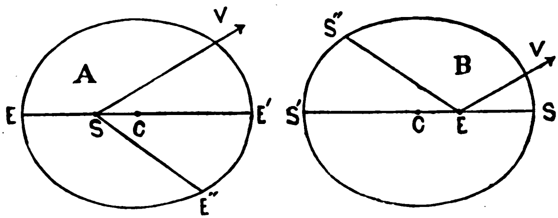

Fig. 60. Diagram showing the Earth's Actual Orbit and the Sun's Apparent Orbit.

EXPLANATION. Diagram (A) represents the real orbit of the earth: S is the sun at one focus; C is the centre; SC is the excentricity, CE being equal to 1, and SC to .01677; E is the perihelion point; V shows the direction of the vernal equinox; VSE is the heliocentric longitude of E; E′ is the aphelion point; and E″ is any point of the orbit, its radius-vector being SE″. Diagram (B) represents the apparent or *relative* orbit of the sun: E is the earth at one focus; S is the place of the sun when in perigee; S′, his place at apogee; V shows the direction of the vernal equinox; VES, reckoned around to the left, is the geocentric longitude of S; and S″ is the position of the sun corresponding to E″ in diagram A, the line ES″ being always equal to SE″, but lying in the opposite direction.

107. The angle between the plane of the earth's orbit and that of the equinoctial, which is the same as the **obliquity of the ecliptic**, may be found when we know the sun's right ascension and declination; it is equal to about 23° 27′.

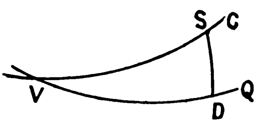

Fig. 61. Diagram.

Let V be the vernal equinox; VC, an arc of the ecliptic; VQ, an arc of the equinoctial; S, the position of the sun; VD, his right ascension; and DS, its

declination. In the right-angled spherical triangle VDS we know the right angle and the two adjacent sides; hence, the other parts may be computed. The angle V is the *obliquity*, and the hypothenuse VS is the sun's geocentric longitude. The earth's heliocentric longitude is found by adding 180° to VS, diminishing the sum by 360°, if necessary.

Variation of the Earth's Distance from the Sun.

108. The earth is in perihelion about the last of December, and at that time is nearest the sun; a half year later she is in aphelion, and at that time is farthest from the sun. Her distance from the sun increases continually from perihelion to aphelion, and then it diminishes continually to perihelion, and so on perpetually. To compute her distance at any time we must know her mean distance, which is equal to the semi-major axis of her orbit, and her angular distance from the perihelion point, which is called the **anomaly.**

If in Diagram (A), Fig. 60, we make the semi-major axis, CE, equal to 1, the excentricity equal to .01677, any radius-vector, SE″, equal to r, and the corresponding anomaly, ESE″, to ϕ, we have from the polar equation of the ellipse

$$r = .99972 \div (1 + .01677 \cos \phi),$$

from which the earth's distance can be computed when we know ϕ, which is equal to the heliocentric longitude of the earth (increased by 360°, if necessary), *diminished* by that of the perihelion point. If $\phi = 0$, we have $r = .98323$; if $\phi = 180°$, $r = 1.01677$; these are the perihelion and the aphelion values of r.

The values of r, as found from the preceding formula, correspond to the mean distance 1; if we multiply each by 92,500,000 *miles*, the products will be the corresponding values of r in miles.

Astronomical Units.

109. In measuring the distances and dimensions of the solar system (except in case of the moon) astronomers employ, in the first instance, **the earth's mean distance from the sun** as a unit. The mean distances of all the other planets in terms of this unit are deduced from their periodic times (which can be found by observations that are comparatively simple) by means of Kepler's third law. From these distances, combined with suitable observations on the bodies themselves, all the other distances and dimensions of the system are deduced.

To convert these *relative* distances and dimensions into miles, each must be multiplied by the number of miles in the earth's mean distance from the sun, and any error in this distance will give rise to a proportionate error in each of the others.

In determining the masses of the bodies of the solar system the **mass of the earth** may be taken as the unit, but for purposes of computation it is often more convenient to regard the sun's mass as the unit.

The Different Solar Periods.

110. A **sidereal year** is the time required for the earth to make a complete revolution around the sun. It is the same as the earth's *periodic time,* and is equal to the interval between two successive conjunctions of the sun and the same fixed star. Expressed in mean solar time, it is found to be equal to 365d. 6h. 9m. 9s., or to 365.25636 days.

A **tropical year** is the interval between two successive returns of the sun to the vernal equinox. This is the year to which our calendars are adjusted, and is equal to 365d. 5h. 48m. 46s., or to 365.2422 days. In consequence of the precession of the equinoxes the tropical year is *shorter* than the sidereal year by the time required for the sun to move over an arc of 50″.2, that is, by a little more than 20 minutes.

The **anomalistic year** is the interval between two successive returns of the earth to perihelion. In consequence of perturbation, the earth's perihelion has a slow motion from west to east amounting to about 11″.5 per year. In consequence of this advance of the perihelion point, the anomalistic year is longer than the sidereal year by the time it takes the earth to move over an arc of 11″.5. The length of the anomalistic year is equal to 365d. 6h. 13m. 49s., or to 365.2596 days.

The **nodical period** is the interval between two successive returns of the sun to the ascending node of the moon's orbit. This period is used in treating of eclipses; in consequence of the rapid retrogression of the moon's nodes, it falls considerably short of a year. Its value expressed decimally is 346.62 days.

Periodic Times of the Planets.

111. The periodic time of a planet may be deduced from the length of its synodic period in the following manner. If we divide 360° by the earth's periodic time the quotient will be the mean daily angular motion of the earth around the sun. Now, an *inferior* planet has a greater angular velocity than the earth, in consequence of which it gains a complete revolution of 360° in a synodic period; hence, if we divide 360° by the number of days in the synodic period, the quotient will be the average daily gain of the planet, and this added to the earth's daily motion will give the planet's mean daily angular motion about the sun; the number of times that this result is contained in 360° will be the number of days in the planet's periodic time.

In the case of a *superior* planet it is the earth that gains 360° in a synodic period; if therefore we divide 360° by the number of days in the synodic period and subtract the quotient from the earth's daily motion, the difference will be the planet's daily motion, from which the periodic time may be found as before.

From the preceding principles we may deduce a simple formula for the periodic time of a planet. Let e denote the earth's periodic time; p, the planet's synodic period; and t, the planet's periodic time, all expressed in days. From what has been said before, we have for the daily motion of the planet

$$\frac{360^\circ}{e} \pm \frac{360^\circ}{p}, \text{ which is equal to } 360^\circ\left(\frac{p \pm e}{pe}\right);$$

dividing 360° by this result, we have,

$$t = \frac{pe}{p \pm e},$$

in which the upper sign is to be used for an inferior, and the lower sign for a superior planet. The value of p is found by actual observation. It is to be noted that the value of p for the same planet is slightly variable, and to secure accuracy the mean of a great number of synodic periods should be taken.

Irregularities of Planetary Motion.

112. As seen from the sun, each of the planets has a continuous progressive motion from west to east; this motion, however, is not quite uniform, being greatest when the planet is in perihelion and least when it is in aphelion. When viewed from the earth, the planetary motions are exceedingly irregular; sometimes the motion of a planet is *direct*, then after a short period of apparent rest it becomes *retrograde*, and again, after another short period of apparent rest, it once more becomes direct, and so on, the cycle of change for each planet being equal to its synodic period. The arc of direct motion is always greater than that of retrogradation, so that the aggregate motion for long periods is from west to east.

The cause of these irregularities is the motion of the earth, the stand-point from which the planetary motions are viewed; in other words, the apparent motions of the planets are purely *relative*. According to the laws of relative motion, a planet should appear to advance about the time that it is farthest from the earth, and to retrograde about the time that it is nearest to the earth; this is what is actually observed.

The conditions under which the motions are either direct or retrograde are shown in Fig. 62.

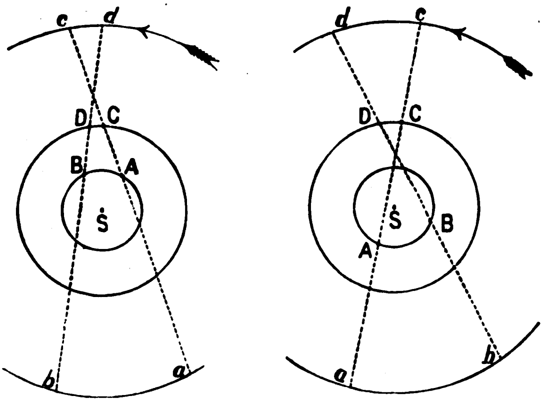

Fig. 62. Illustrating the direct and retrograde motions of the planets.

Of two planets, the one that is nearer the sun has the greater angular and also the greater linear velocity. This being premised, let AB, in the left-hand diagram, be an arc of the earth's orbit, and CD the corresponding arc of the orbit of a superior planet at about the time it is nearest the earth, that is, in opposition; also let *cd* and *ab* be arcs on the celestial sphere. When the earth is at A the planet appears to be at *c*, and when the earth is at B the planet appears to be at *d*; hence, whilst the earth moves over the arc AB the planet appears to move over the arc *cd*, that is, it retrogrades. Now let us suppose that CD is an arc of the earth's orbit and AB the corresponding arc of the orbit of an inferior planet at about the time it is nearest the earth, that is, in inferior conjunction. In the same manner as before it may be shown that whilst the earth is moving from C to D, the apparent motion of the planet will be from *a* to *b*, that is, retrograde. Hence, *when a planet is nearest the earth,* whether it is a superior or an inferior one, *its apparent motion is retrograde.*

Again in the right-hand diagram, let AB be an arc of the earth's orbit and CD the corresponding arc of the orbit of a superior planet at about the time it is farthest from the earth, that is, in conjunction. It may be shown as before that whilst the earth moves over the arc AB, the planet seems to move over the arc *cd*, that is, its motion is *direct.* Now let DC be an arc of the earth's orbit and AB the corresponding arc of the orbit of an inferior planet at about the time it is farthest from the earth, that is, in superior conjunction. It may be shown as

before that whilst the earth moves over the arc CD the planet appears to move from *a* to *b*, that is, its apparent motion is direct. Hence, *when a planet,* whether superior or inferior, *is farthest from the earth, its apparent motion is direct.*

Elements of a Planet's Orbit.

113. To trace out the path of a planet in the heavens by means of Kepler's laws, we must know the position and the form of its orbit, and also the time at which the planet is at some determinate point of its orbit.

The line of nodes (Art. 51) is the line in which the plane of the planet's orbit cuts the plane of the ecliptic. If therefore we know the **heliocentric longitude of the ascending node,** we know one line in the plane of the planet's orbit; if in addition we have the **inclination** of the orbit, the position of the plane of the orbit is completely fixed in space.

Again, if we know the **heliocentric longitude of the perihelion** we know the direction of the major axis of the planet's orbit, and if in addition we know the **mean distance** and the **excentricity** we know the shape and the dimensions of the orbit.

Further, if we have the time when the planet is in perihelion, called the **epoch,** and the **periodic time** of the planet, we have all the data required for predicting the place of the planet at any time whatever.

The quantities that must be known in order to predict the place of a planet are called **elements.** The method of finding some of these elements has already been explained; the others are found by methods of practical astronomy, descriptions of which do not fall within the scope of this work. For convenience of reference, we recapitulate the elements of a planet's orbit:

1°. The heliocentric longitude of the ascending node;

2°. The inclination of the plane of the orbit to that of the ecliptic;

3°. The heliocentric longitude of the perihelion point;
4°. The planet's mean distance from the sun ;
5°. The excentricity of the orbit;
6°. The epoch ; and
7°. The planet's periodic time.

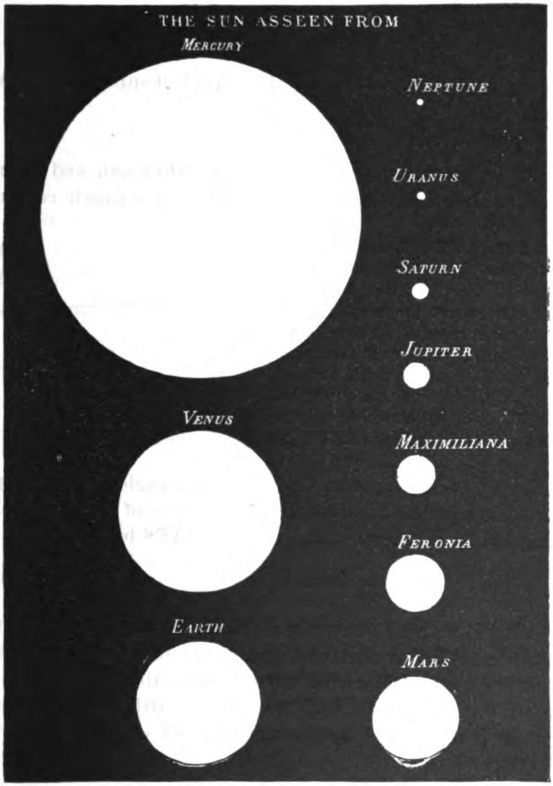

Fig. 63. Relative sizes of the sun's disk as seen from the different planets.

The Sun's Angular Diameter.

114. The angle subtended by the sun may be measured directly by means of a micrometer, or its value may be deduced from the observed time that it takes the sun's disk to cross the meridian of any place. When the sun is at his mean distance this diameter is a little more than 32′; at other distances his apparent diameter varies very nearly as the reciprocals of those distances. When nearest the earth his apparent diameter is about 32′ 34″; when farthest from the earth it is about 31′ 28″.

The sun's apparent diameter as seen from the various planets, including two of the planetoids, is shown in Fig. 63.

When we know the sun's distance from the earth and his angular diameter, we can find his diameter in miles by a simple computation.

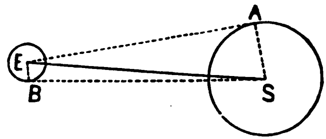

Fig. 64. Diagram.

EXPLANATION. The figure represents a plane section of the earth and sun, the plane passing through the earth's centre E and the centre of the sun S; EA is tangent to the section of the sun, and SB to the section of the earth; ES is the sun's distance from the earth, and AS, BE are radii of the sun and earth; the angle AES is the apparent or angular semi-diameter of the sun, and ESB is the corresponding solar parallax.

In the right-angled triangle EAS, right-angled at A, the perpendicular AS is equal to ES multiplied by the sine of the angle AES; or denoting ES by D, AS by R, and the angle AES by δ, we have

$$R = D \sin \delta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1).$$

Knowing R we find the sun's diameter by multiplying it by 2. If the distance ES is the mean distance, and if it is taken equal to 1, we have the sun's actual diameter equal to twice the sine of 16′.

From the triangle ESB, we have EB, the earth's radius, denoted by r, equal to D multiplied by the sine of ESB, or, denoting the latter angle by π,

$$r = D \sin \pi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

From (1) and (2) we have

$$R : r :: \sin \delta : \sin \pi \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

That is, the ratio of the sines of the sun's apparent semi-diameter to the corresponding parallax of the sun is constant.

The Sun's Distance and the Solar Parallax.

115. It has been shown that the relative positions of the sun and planets can be found at any time, and also that their distances from each other can be expressed in terms of the earth's mean distance from the sun as a unit. Now, if the latter distance can be found in miles, all the other distances can also be found in miles; in fact, the dimensions of the solar system are so connected that the determination of any one (except the moon's distance from the earth) is equivalent to the determination of all the others.

Many different methods of finding the sun's distance have been devised, all of which are more or less indirect. Among these, the most noted are the following: 1°, by observations on the transit of Venus; 2°, by observations on Mars when in opposition; and 3°, by means of the velocity of light.

By observations on a transit of Venus. When Venus comes directly between the earth and the sun, as she does at long intervals, she may be seen as a round black spot traversing the sun's disk in a line which, were it not for the motion of the observer, would be a chord, parallel to the direction of the planet's motion. This phenomenon, which is called **a transit of Venus**, presents slightly different aspects when seen from different points of the earth's surface, the *chord of transit* experiencing a parallactic displacement corresponding to the change of position of the observer.

In the method of determining the solar parallax suggested by Halley, and commonly known as **Halley's method**, two stations are selected as far apart as possible, one in the northern and the other in the southern hemisphere, from each of which the whole transit can be seen. The times of beginning and end of the transit are observed at each station, and from these times, combined with the known rates of angular motion of the earth and Venus, the lengths of the chords of transit and also the distance between them are computed in *seconds of arc.* The distance between the chords in *miles* can be found from the known positions of the points of observation and the relative distances of the earth and Venus from the sun. We then have the data for computing the angle that would be subtended by the earth's equatorial radius at the sun's mean distance, which is the **solar parallax.**

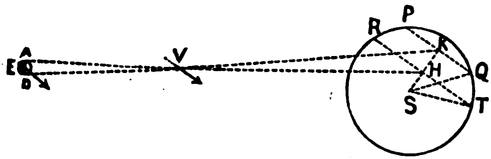

Fig. 65. Solar Parallax by Halley's Method.

EXPLANATION. S is the sun; V is Venus; E is the earth; A and D are two stations, which, for the purpose of illustration, are taken on a line perpendicular to the plane of the orbit of Venus; PQ is the chord of transit seen from D; and RT is the chord of transit seen from A.

From observations at D the chord PQ is determined in seconds of arc, and from observations at A the chord RT is determined in seconds of arc. Let SK be perpendicular to both chords; then in the triangle SQK we know QK and SQ, and consequently can compute SK; in like manner we can find SH; hence, we can find SK−SH, or HK in seconds of arc. Again, knowing AD in miles, we can find HK also in miles; for from the similar triangles ADV and HKV we have HK=AD×(HV÷VA) or since HV÷VA equals about 72÷28, or 2$\frac{4}{7}$, we have HK=AD×2$\frac{4}{7}$. If we divide HV in miles by the number of seconds of arc in HV, the quotient will be the number of miles required to subtend one second of arc at the sun's actual distance, and from this we can easily deduce the value of the *solar parallax.*

The method of determining the solar distance suggested by Delisle, and commonly known as **Delisle's method,** depends on the principle that any phase of a transit (as its beginning, for example) is not seen simultaneously at all points of the earth's illuminated hemisphere.

To understand this method, suppose the sun and Venus to be enveloped by a common tangent cone whose vertex, H, is between the two bodies, and let this cone be indefinitely prolonged beyond Venus; then will this prolongation embrace all the points from which any part of Venus will be projected on the face of the sun. As Venus moves past the earth, at the time of a transit, the advancing surface

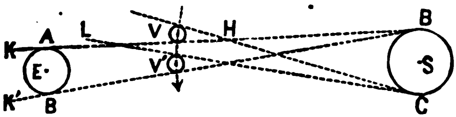

Fig. 66. Solar Parallax by Delisle's Method.

of the cone will touch the surface of the earth (externally) at some point, A, at which the transit will begin *earliest*; then, after sweeping over the earth, it will after a time become internally tangent at some point, B, at which the transit will begin *latest*. During the interval between these times of beginning, both planets being in motion, Venus will pass over a portion, VV′, of its synodic orbit, the length of which in miles can be found from the length of AB, combined with the known positions and motions of the earth and Venus.

In applying this method, two stations are selected, at one of which the phase to be observed begins *early*, and at the other *late*, and their latitudes and longitudes are carefully determined. The Greenwich time of the phase in question is noted at each station, and the corresponding interval is found. The length of the corresponding arc of the synodic orbit of Venus is then computed. From these data and the known synodic period of Venus the entire length of the orbit of Venus can be found, and consequently the distance of Venus from the sun can be determined in miles. From this we can readily deduce the solar distance of our earth and also the solar parallax.

By observations on Mars when in opposition. The orbits of the earth and Mars are both excentric and their major axes are inclined to each other; hence, the distances from the earth to Mars at different oppositions are widely different. The most favorable oppositions for determining the parallax are those that happen when Mars is nearest the earth, and these occur when Mars is near its perihelion. Such an opposition occurred in 1877, and another will happen in 1892.

When a favorable opposition takes place, two stations are selected as far apart as possible, one in the northern and the other in the southern hemisphere. From the former the planet is displaced towards the south, and from the latter towards the north. Observations are made at both stations for some time preceding and following the period of opposition, the displacements being determined by measuring the angular distance of Mars from certain fixed stars by means of a filar micrometer. The computations are made in the manner already explained for determining the lunar parallax, and from them we deduce the distance of Mars from the earth. This distance being known, the *solar distance* and *parallax* are readily determined.

Observations may be made from a single station near the equator. Just after the rising of Mars he is thrown toward the east by the effect of parallax, and just before setting he is thrown toward the west. Between these times the observer is carried by the motion of the earth along an arc whose chord serves as a base line; the principle is the same as before.

By observations on the velocity of light. One of the most available, and perhaps one of the most reliable methods of determining the solar distance is by comparing the velocity of light with that of the earth, by means of the *constant of aberration.* The constant of aberration (Art. 71), which is equal to $20''.49$, is the angle at the vertex of a right-angled triangle whose base is the velocity of the earth and whose altitude is the velocity of light; hence, the velocity of the earth may be found when we know that of light, and from this the *solar distance* and *parallax* can be deduced. One of the most recent and probably one of the most accurate determinations of the velocity of light was made a short time since by Lieut. MICHELSON of the U. S. Navy; he employed a modification of FOUCAULT'S apparatus, and obtained as a result the velocity 186,360 *miles* per second; this velocity corresponds to a solar parallax of about 8″.8.

Summary. The observations on the transits of Venus in 1761 and 1769 were carefully compared and discussed by ENCKE, who deduced for the *solar parallax* the value 8″.587, a value that was used in computations for more than 30 years. This corresponds to a solar distance of more than 95,000,000 of miles.

Since 1854 much doubt has existed as to the real value of the parallax, and many different opinions have been held by astronomers. All the recent observations, however, go to show that ENCKE'S value is too small.

Prof. NEWCOMB, in his *Popular Astronomy*, says: "It would appear that the solar parallax must lie between pretty narrow limits, probably between 8″.82 and 8″.86, and that the distance of the sun in miles probably lies between 92,200,000 and 92,700,000." Prof. YOUNG, in his recent valuable work on the sun, says: "It would seem that the solar parallax cannot differ much from 8″.80, though it may be as much as 0″.02 greater or smaller; this would correspond, as has already been said, to a distance of 92,885,000 miles."

A mere statement of the solar distance in miles conveys but a feeble idea to the mind of one who is not trained to contemplate the gigantic distances of astronomy. To compare it with familiar things, let us consider the rate of motion of an express train on one of our best railways. The speed of such a train hardly exceeds 38 miles an hour, at which rate it would have to run day and night for 3 entire years to accomplish a single million of miles, or more than 277 years to pass over a distance equal to that which separates us from the sun. And yet we shall find that the solar distance, enormous as it is, sinks into insignificance in comparison with that which intervenes between the sun and the nearest fixed star.

Diameter, Surface, and Volume of the Sun.

116. The **diameter of the sun** in miles is equal to the solar distance *multiplied* by the natural sine of its angular semi-diameter. Assuming the solar distance given by Newcomb, this diameter is about 860,000 miles, or in round numbers it is about 109 times the equatorial diameter of the earth.

The surfaces of spheres are to each other as the squares of their radii, and their volumes are to each other as the cubes of their radii. Hence, the **surface of the sun** is nearly 12,000 times as great as that of the earth, and **his volume** is about 1,280,000 times the volume of the earth.

If we represent the earth by a ball 1 inch in diameter, the sun, on the same scale, would be represented by a globe 9 feet in diameter, and the distance between the two globes would be more than ¼ of a mile.

Mass of the Sun.

117. We may find an *approximate* value for the mass of the sun in terms of that of the earth by comparing the **sun's attraction on the earth** with the **earth's attraction on the moon**, in accordance with the laws of motion and gravitation.

Let us suppose the orbits of the sun and the moon to be circles, the radius of the former being denoted by R, and that of the latter by r; denote the mass of the sun by M and that of the earth by m; also denote the sun's attraction on a unit of mass at the earth's distance by F, and the earth's attraction on a unit of mass at the moon's distance by f. Then, from the law of universal gravitation (Art. 52), we have

$$F : f :: \frac{M}{R^2} : \frac{m}{r^2} \quad \text{. . . . . (1).}$$

Because action and reaction are equal (Mech., Art. 12), the attraction of the sun on a unit of the earth's mass is equal to the centrifugal force of that unit, and this, by a law of mechanics, is equal to the square of its velocity divided by the radius of curvature of its path. If we now denote the earth's periodic time by T, the length of her orbit will be $2\pi R$, and her velocity will be equal to $2\pi R + T$. Squaring this, dividing by R, and making the result equal to F, we have

$$F = \frac{4\pi^2 R}{T^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

In like manner if we denote the moon's sidereal period by t, we have

$$f = \frac{4\pi^2 r}{t^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Substituting these values of F and f in (1), and suppressing the common factor, $4\pi^2$, we have

$$\frac{R}{T^2} : \frac{r}{t^2} :: \frac{M}{R^2} : \frac{m}{r^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4),$$

from which we find

$$\frac{M}{m} = \frac{R^3 t^2}{r^3 T^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5).$$

Making $R = 92{,}500{,}000$, $r = 239{,}000$, $T = 365.256$, and $t = 27.32$, which are only approximate values, and reducing, we find $\frac{M}{m} = 324{,}840$, which differs by less than 1% from that given in Table II., Art. 47, a value that was computed from more accurate data.

Masses of the Planets.

118. Formula (5) of the last article can be used for finding the mass of any planet having a satellite; for we may make T equal to the planet's periodic time; R, its distance from the sun; t, the time of revolution of the satellite: and r, its distance from the planet. Then, because M is known, we can deduce the value of m, which in this case will be the mass of the planet. Mercury and Venus having no satellite, their masses must be determined from the perturbations produced by their attractions on other bodies of the system. The results of these computations are given in Table II., Art. 47.

The Sun's Light and Heat.

119. Many experiments have been made to determine the light given out by the sun in terms of what physicists call a **candle power**, and though successful to a certain degree, the results expressed in figures are so enormous as to be almost unintelligible.

More satisfactory results have been reached in comparing the relative brightness of different parts of the solar disk. These comparisons show that the disk is brightest at its centre, and that the brightness diminishes, at first slowly and then more and more rapidly as we approach its edge, where, according to Pickering, it is no more than $\frac{3}{8}$ths of what it is at the centre.

It has been shown by experiment that the amount of heat received from different parts of the solar disk varies according to a similar law, though its diminution in approaching the edge is not so rapid as in the case of light. Prof. LANGLEY found that the heat received from a small area near the border of the disk was about $\frac{1}{2}$ of that received from an equal area at its centre.

These results seem to show that the sun is surrounded by an absorbing medium whose action on light and heat is similar to that of the terrestrial atmosphere. At the centre of the disk the rays of light and heat pass directly through the medium, and consequently experience a *minimum* amount of absorption. In approaching the border of the disk the rays pass through a continually increasing thickness of the medium, and consequently experience a continually increasing amount of absorption.

In 1838 Sir John Herschel undertook a series of observations to determine the sun's annual expenditure of heat. By means of a suitable apparatus he allowed a beam of solar rays, 3 inches in diameter, to fall perpendicularly on a vessel containing a known quantity of water, and after a certain time he observed the increase in the temperature of the water. From the data thus obtained he computed the amount of heat that falls upon a square yard perpendicularly exposed, and found that it was sufficient to melt a layer of ice having the same area and a thickness of 1 inch in about 2 hours and 13 minutes. Now, because the sun radiates heat equally in all directions, the entire amount of heat given out by the sun in 2 hours and 13 minutes is sufficient to melt a spherical shell of ice whose thickness is 1 inch and whose radius is the distance from the sun to the earth. It has been shown that this enormous amount of heat is equal to that which would be produced by the combustion of a layer of anthracite coal extending over the entire surface of the sun and 35 feet in thickness. A simple computation will show that the heat given out by the sun in 6000 years would be more than that which would be produced by the combustion of a volume of coal equal to that of the entire sun.

The Sun's Probable Constitution.

120. Recent researches lead to the belief that the sun consists of the following parts: 1°. A great central mass called the **nucleus**; 2°. A shining, cloud-like envelope, 8 or 10 thousand miles in thickness, surrounding the nucleus, and called the **photosphere**; 3°. An envelope of gases and vapors, 3 or 4 thousand miles in thickness, lying immediately outside the photosphere, and called the **chromosphere**; and 4°. An extremely tenuous atmospheric envelope, lying outside the chromosphere, and of unknown extent, called the **corona**.

In this description it is not to be supposed that these parts are separated by definite surfaces, or that the envelopes themselves are of uniform thickness throughout; all that is intended is to convey an idea of the order in which the parts are situated with respect to each other.

The Nucleus.

121. The nucleus of the sun forms at least nine-tenths of its entire volume, but being hidden from view by the intervening photosphere, we know little or nothing of its actual constitution. Some astronomers suppose that it is composed of substances similar to those that make up our earth, but so intensely heated that they cannot combine either chemically or physically, that is, they exist in a state that has been called **dissociation.** According to this view we may regard the solar nucleus as a mixture of metallic and other gases, so compressed that their average density is nearly 1¼ times that of water. Inasmuch as we have nothing of an analogous description on our earth, it is almost impossible to reason either on the properties of such a body or on the conflicting forces that must be in constant activity among its ultimate atoms. It is not unreasonable to suppose that it is subject to great internal disturbance, and this supposition is rendered more than probable by the gigantic commotions that are continually manifested, both in the photosphere and in the chromosphere. This supposition with regard to the nature of the nucleus involves as a necessary consequence a continually increasing temperature as we approach its centre.

Before proceeding to a study of what may be called the *solar envelopes*, it will be necessary to explain the construction and use of the spectroscope.

The Spectroscope.

122. A **spectroscope** is an instrument used in analyzing light. It consists *essentially* of three parts: 1°, a **collimator** whose function it is to form a flat beam of parallel rays ; 2°, either a **prism** or a **finely-ruled surface** which disperses this beam so as to form a spectrum; and, 3°, a **view-telescope**, by means of which the different parts of the spectrum may be examined.

In some of the best modern spectroscopes the spectra are formed by reflection from a ruled surface ; when, however, they are formed by refraction the requisite amount of dispersion is obtained by using a train of prisms.

The essential parts of a *simple refracting spectroscope* are shown in Fig. 67. The collimator, which resembles in appearance a small telescope, is shown at A. Instead of an eye-piece, there is a slit at K, through which the light to be analyzed is allowed to pass ; this slit is formed by means of two parallel jaws of metal which can be moved by screws so as to make the opening as narrow or as wide as desirable; at L is a lens which can be so adjusted as to make the rays coming from the slit parallel to each other ; we then have a flat beam of light whose plane, like the direction of the slit, is perpendicular to the plane of the paper. The refracting prism is shown at B, its edges being perpendicular to the plane of the paper. The prism is made of dense glass with a refracting angle N, equal to about 60°; it can be turned around an axis (not shown in the drawing) parallel to its refracting edge so as to make the angle of incidence equal to the angle of emergence, a position which is found to give the best results. The flat beam, in passing through the prism, is dispersed so as to form a spectrum, which can be seen by interposing a screen PO ; if the beam is composed of white light the red end of the spectrum will be at P and the violet end at O.

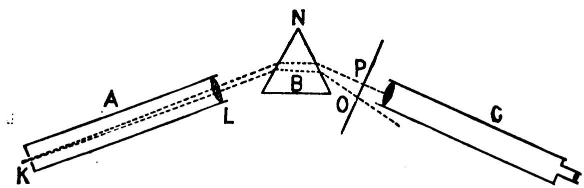

Fig. 67. The principle of the Spectroscope.

Instead, however, of receiving the spectrum on a screen the deviated rays are allowed to fall upon the objective of the view-telescope, C, which differs in no material respect from an ordinary refracting telescope of low power. The telescope is attached to the frame of the instrument, and can be turned around an axis parallel to the edges of the prism ; if the dispersion is small the entire spectrum may be brought within the field of view, or if the observer desires it, the line of collimation may be made to coincide with any one of the refracted rays.

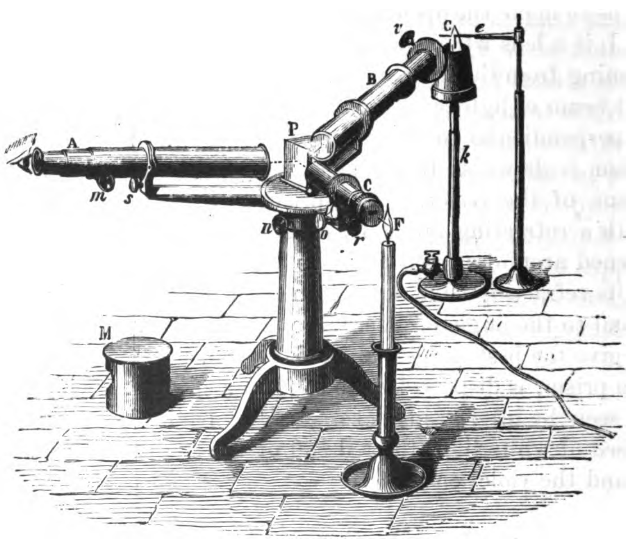

Fig. 68. **Perspective view of a simple Spectroscope.**

EXPLANATION. B is the collimator; P is the refracting prism : and A is the view-telescope. C is a tube which carries at the end nearest the light F a fine scale of equal parts photographed on glass ; the divisions of the scale, illuminated by the light F, are thrown on the face of the prism P, whence they are reflected into the telescope A; the observer sees the divisions of the scale superposed on the spectrum formed by refraction, and is thus enabled to locate the lines observed in the spectrum.

If the telescope is pointed at P (Fig. 67), the observer sees a red image of the slit ; that is, a red line perpendicular to the plane of the paper ; if pointed at O, he sees a violet image of the slit; if pointed at any intermediate point, he sees an image of an intermediate color. In a word, the spectrum is composed of a succession of images of the slit, each corresponding to rays of different degrees of refrangibility. If a ray of any particular degree of refrangibility is wanting in the bundle of deviated rays, the observer will see at the corresponding point of the spectrum a *black line.*

The positions of the different images, and also of the black lines, are determined by micrometrical measurements; these positions may be given in terms of the equal parts of an arbitrary scale, or more satisfactorily in terms of the corresponding wave-lengths of light.

The relations of the different parts of the spectroscope are more fully shown in Fig. 68, which represents the form used in the laboratory.

In more complex refracting spectroscopes the flat beam is transmitted through a succession of prisms, each of which aids in its dispersion. The manner of increasing the power of a spectroscope is shown in Fig. 69.

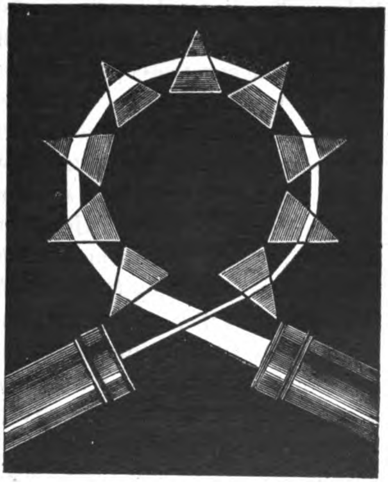

Fig. 69. Method of increasing the dispersion of light.

Principles of Spectrum Analysis.

123. The principles of spectrum analysis are embraced in the following summary:

1°. The spectrum of an incandescent solid, liquid, or gas under high pressure, is continuous.

2°. The spectrum of an incandescent body in a *gaseous state and under low pressure is discontinuous, being made up of bright lines; the order and the number of bright lines is characteristic, that is, it is always the same for the same substance.*

3°. A substance in a gaseous state absorbs from white light, when transmitted through it, the rays of which its own spectrum consists.

As an illustration of the foregoing principles, let us consider the action of the vapor of sodium on the calcium light. If a piece of lime is rendered incandescent by heating it in the oxy-hydrogen flame, its light, when transmitted through the spectroscope, gives a perfectly continuous spectrum. Again, if sodium is made incandescent by burning one of its salts in a Bunsen burner, its light, when transmitted through the spectroscope, gives the bright-lined spectrum characteristic of sodium, the principal feature of which is a double line in the orange part of the spectrum. If now the light of incandescent lime is superposed upon that of the sodium by transmitting the former through the latter, there will result a continuous spectrum interrupted by a double black line occupying the exact place of the principal sodium lines; the vapor of the sodium has absorbed the corresponding rays of the calcium light.

Chemical Constituents of the Sun.

124. The solar spectrum when formed by a highly dispersive spectroscope is found to be crossed by hundreds, even thousands, of dark lines and bands. Many of these have been found, by the principles explained in the last article, to correspond with the bright lines of the spectra of terrestrial substances, indicating that the solar light on its way to us has passed through and been acted upon by the vapors of those substances. Thus, of the 600 bright lines which constitute the complex spectrum of the vapor of iron, more than 450 have been recognized as corresponding with the dark or *reversed* lines of the solar spectrum. More than one-third of the elements that we are acquainted with on our earth are known to exist in the sun. A few of the more common ones are iron, sodium, calcium, hydrogen, manganese, nickel, cobalt, barium, strontium, lead, and titanium.

Telescopic Appearance of the Photosphere.

125. The **photosphere**, as its name implies, is the light-giving part of the sun. It surrounds the nucleus, and appears to be made up of enormous cloud-like masses, suspended as it were, in a medium which is nearly or quite transparent. These shining masses, for want of a better name, may be called *clouds;* they differ, however, very materially from terrestrial clouds, inasmuch as the latter consist of watery vapor, whereas the former are made up of metals and other substances maintained in a vaporous condition by intense heat. It is thought by some that the photospheric cloud-forms are columnar in shape, and that the intervals between them are filled with matter thrown up from the interior regions of the sun.

When viewed with a telescope of sufficient power the surface of the photosphere presents a mottled appearance, which Newcomb compares to that of a fluid in which ill-defined rice-grains are suspended; Herschel says that nothing represents this appearance so faithfully as "the slow subsidence of some flocculent chemical precipitate in a transparent fluid when viewed perpendicularly from above;" Nasmyth likens the shape of the shining masses to willow leaves. It is not unlikely that the different appearances described by observers are somewhat dependent on accidental circumstances, such as variations in the power of the telescope or in the clearness of the atmosphere, and the like.

The cloud masses that give to the photosphere its general mottled appearance are subject to considerable changes, both in form and in magnitude, in consequence of which the actual appearance of the sun is not always the same at all points of its surface. These changes in the apparent character of the photosphere are particularly noticeable in the neighborhood of those dark patches yet to be described, and which are known as *solar* spots.

The mottled character of the sun's surface is shown in Fig. 70, which also illustrates some of the curious appearances presented by the sun-spots yet to be described.

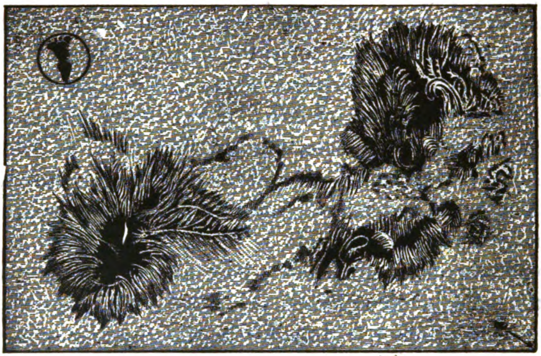

Fig. 70. Sun Spot. Drawn by Prof. Langley.

Explanation. This figure shows the mottled character of the sun's surface, and also shows a curious group of sun-spots. The circle in the upper left-hand corner represents our earth on the same scale.

Faculæ.

126. Besides the shining cloud-tops that produce the ordinary mottling, larger and brighter spots, called **faculæ**, are frequently seen on different parts of the sun's surface. Sometimes they take the form of irregular luminous spots, and sometimes they are long and narrow, appearing like immense masses of photospheric matter heaped up in billowy ridges. The faculæ, which are particularly numerous in the neighborhood of solar spots, are seen to best advantage when they are near the border of the solar disk, an effect which is probably due to perspective, in the same way that we have a more striking view of a mountain range when we look at it horizontally than when we look down upon it from above.

The general appearance of the faculæ is shown in Fig. 71, which is from a photographic view of a portion of the sun near its border.

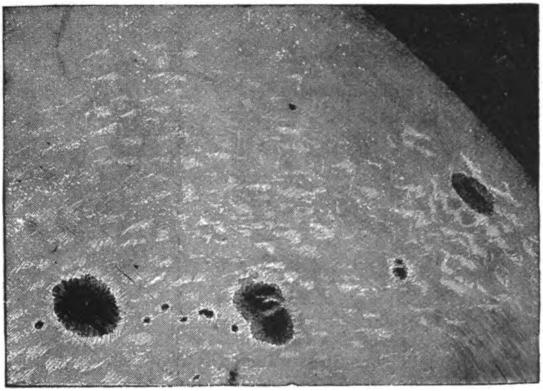

Fig. 71. Photographic view of Spots and Faculæ.

EXPLANATION. Fig. 71 shows a line of solar spots with their surrounding faculæ. The spot on the right-hand is foreshortened by perspective, and the faculæ in its neighborhood are very conspicuous.

Sun Spots.

127. The dark patches on the solar disk, to which reference was made in a preceding article, are called **sun-spots**; they vary so much in many respects that a general description of them is almost impossible. Sometimes they are nearly circular, but as a rule their outlines are exceedingly irregular; sometimes they occur singly, but more frequently they are grouped in clusters like islands in the ocean; sometimes they are seen in vast numbers, and then again not a spot is to be seen; an occasional spot may last for many weeks, but such persistency is exceptional; as a rule, the spots only continue for a few days, and not infrequently they close up and disappear in the course of a few hours; some are so small that they are only visible under high magnifying powers, some are many thousands of miles in extent, and occasionally one occurs that is large enough to be visible to the naked eye.

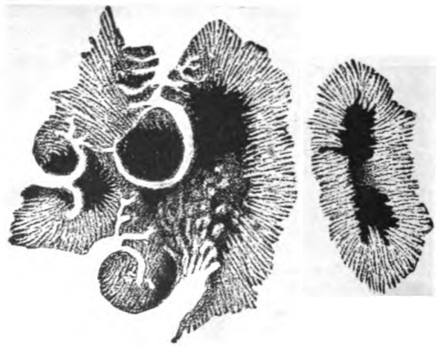

Fig. 72 Sun Spots. Drawn by Trouvelot.

A fully developed sun-spot, like the right-hand one in Fig. 72, consists of a dark central portion called the **nucleus**, surrounded by a lighter border called the **penumbra**. The nucleus is separated from the penumbra, and the penumbra from the photosphere, by irregular but well defined lines. Under a high magnifying power the penumbra is seen to be striated, the filamentary masses which constitute the striæ being directed towards the nucleus. Very often these filaments, which appear to consist of photospheric matter, extend far into the nucleus, and not infrequently they reach entirely across, forming as it were luminous bridges. It is a fact worthy of note, that the penumbra is brightest near the nucleus, growing darker as it approaches the outer edge of the spot.

The entire spot appears to be a cavity or rent in the photosphere, the central part, corresponding to the nucleus, being filled with comparatively non-luminous gases; the penumbra seems to be made up of columnar masses that have been detached from the photosphere and drawn inward amongst the gases that form the nucleus. According to this view, the crowding together of the photospheric filaments as they are drawn inward would account for the greater brightness of the penumbra in the neighborhood of the nucleus. Sometimes the filaments appear to melt away as they reach the nucleus, and at other times they assume curiously distorted forms as though they were acted upon by powerful conflicting forces. (See Fig. 70.)

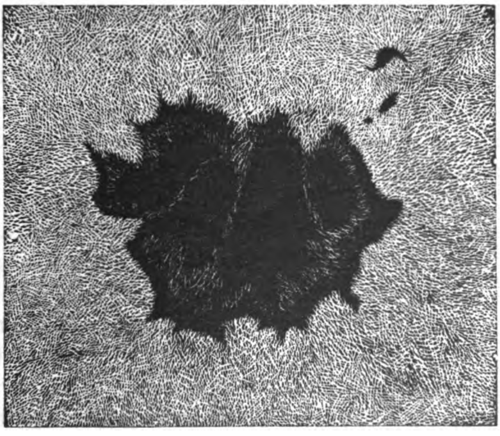

Fig. 73. Sun Spot. Drawn by Nasmyth.

Fig. 73 represents a sun-spot drawn by Nasmyth. It shows the mottling produced by the intersections of forms shaped like willow leaves. It also shows the manner in which spots are often cut up and divided by bridges and prolongations of the penumbral filaments.

That solar spots are depressions in the photosphere is shown by their appearances when near the sun's limb; when near the eastern border of the disk we see only the eastern portion, and when near the western border we see only the western portion of the penumbra; in each case the opposite portions of the penumbra are apparently hidden by the intervening and more elevated part of the photosphere. In some cases a notch in the disk has been observed at the point where a spot is passing from the visible to the invisible hemisphere of the sun.

Rotation of the Sun.

128. Solar spots, when observed from day to day, are found to move across the sun's disk in such a manner as to indicate that the sun revolves on an axis, turning from west to east and performing a complete revolution in about 25 days. This axis prolonged northward meets the celestial sphere in the constellation Draco at a point which is about 7° from the pole of the ecliptic and about 26° from the pole of the heavens; that is, the inclination of the sun's equator to the ecliptic is about 7° and its inclination to the equinoctial is about 26°.

The earth passes through the plane of the solar equator twice a year, once in the early part of June and again in the early part of December; at these times the paths of the solar spots, which are circles parallel to the sun's equator, are seen edgewise, and consequently appear to be straight lines; at all other times they are seen obliquely and consequently appear to be elliptical. The curvilinear character of their apparent paths is most noticeable in the months of September and March.

Recent observations show that the different parts of the sun's surface do not all revolve in the same time, the angular velocity being greatest near the equator and diminishing toward the poles. At the equator the time of revolution, as already stated, is about 25 days, and at a point 45° distant from the equator the time is more than 27 days. The cause of this continued lagging motion as we recede from the solar equator has not been satisfactorily explained.

Distribution and Periodicity of Spots.

129. Spots do not occur with equal frequency at all points of the sun's surface, but are generally found within the limits of two zones, oue north and the other south of the equator and extending from 8° to 40° of solar latitude; they are most numerous in both zones between the parallels of 10° and 25° of solar latitude. In the immediate neighborhood of the equator they are seen but rarely, and the appearance of a spot beyond the parallel of 45° is exceptional.

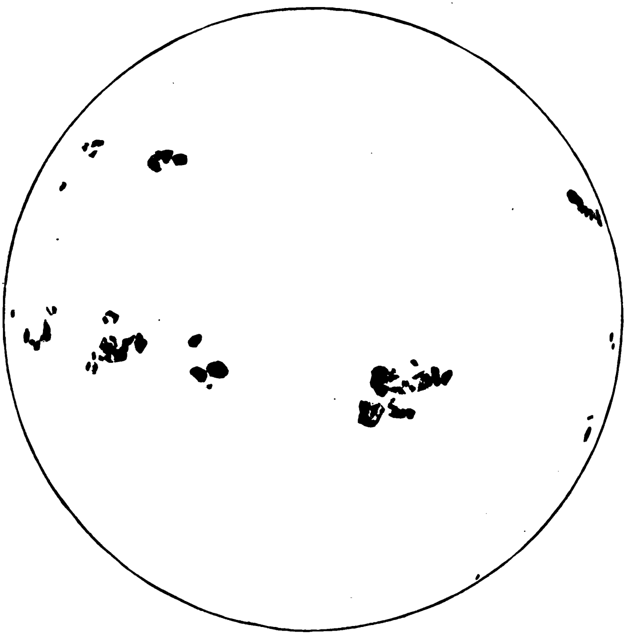

Fig. 74. The Spotted Zones.

EXPLANATION. The outer circle represents the sun's disk. The solar equator is parallel to the lower line of spots.

The tendency of spots to occur in zones or belts is shown in Fig. 73, taken from a drawing by Trouvelot.

Furthermore, spots are not equally nnmerous in different years, their occurrence being subject to a pretty definite law of periodicity. The attention of astronomers was called to this law by Schwabe of Dessau, who published in 1851 the results of 25 years observation on solar spots. He concluded as the result of his labors that the spots increase and diminish periodically, both in respect to frequency and size. He assigned a period of about 10 years as the length of the cycle of change.

The conclusions of Schwabe with respect to the periodicity of sun-spots has been confirmed by subsequent investigations, particularly by those of Wolfe, who made an exhaustive examination of the subject. Wolfe assigns as the average length of a spot cycle 11.1 years; that is, about 9 cycles in a century. It is now conceded that the cycles are of variable length, sometimes being only 8 or 9 years, and sometimes amounting to 15 or 16 years. It is a curious fact that the fluctuations of terrestrial magnetism are also periodic, the cycles corresponding closely with the sun-spot cycles. The periods of greatest magnetic disturbance appear to correspond with the maximum of sun-spots, and those of least magnetic disturbance with the minimum of sun-spots. The auroral phenomena also seem to conform to a similar law of periodicity.

The Chromosphere.

130. Immediately above the photosphere, and resting upon it, is an envelope three or four thousand miles in thickness, which, on account of its brilliant scarlet color, has been named the **chromosphere**. It consists of a mixture of incandescent gases and vapors, the most marked constituent and the one to which its color is due being hydrogen. Prof. Young says that it appears "as if countless jets of heated gas were issuing through vents and spiracles over the whole surface, thus clothing it with flame which heaves and tosses like the blaze of a conflagration."

The dense vapors of iron, barium, sodium, manganese, magnesium, nickel, titanium, calcium, strontium, and the like, are found at the bottom of the envelope, whilst the upper regions in their normal condition consist almost entirely of hydrogen. The denser vapors are, as a rule, found in a stratum which is not more than five or six hundred miles in thickness, the remaining part consisting of incandescent hydrogen. For this reason, some solar physicists have been inclined, perhaps without sufficient reason, to regard what we have called the chromosphere as two separate envelopes, calling the lower one the **reversing layer**, and the upper one the **chromosphere**.

The lower surface of the chromosphere conforms to the upper surface of the photosphere, but its upper surface is very rough and irregular, presenting an appearance that may be likened to a gigantic ocean of billowy flame. At the time of a total solar eclipse the chromosphere, and particularly its upper regions, may be seen with an ordinary telescope ; but by the aid of the spectroscope it may be seen and studied at other times.

The *reversing layer*, when viewed along the sun's border by means of the spectroscope, gives a bright-line spectrum, corresponding to the materials of which it is composed ; but the white light from the photosphere shining through it is, in accordance with principle 3°, Art. 123, partially absorbed, and the corresponding spectrum is interrupted by black lines; hence, the name *reversing layer*. The upper layer seems to be the principal origin of the solar protuberances described in the next article, though it is believed that the occasional evidences of other matter than hydrogen are due to matter thrown up from the lower or reversing layer.

Solar Protuberances.

131. Observation shows that the chromosphere is a region of intense commotion; under the action of enormous forces it is kept in a state of continual agitation, and frequently huge masses of chromospheric matter are projected into the overlying solar atmosphere, constituting what are called **solar protuberances**. These brilliant, cloud-like prominences, which consist principally of incandescent hydrogen, though sometimes containing other substances, are undoubtedly scattered over the entire surface of the sun, but owing to the dazzling brightness of the photosphere we can see only those which are situated near the border of the solar disk. Some of these rise to great heights, and are often seen during the time of a total solar eclipse projecting from behind the black disk of the moon like vast tongues of flame.

Prior to 1868 no protuberances had been seen except at the time of a solar eclipse, but in that year it was discovered, almost simultaneously by Lockyer and Jansen, that they may be seen and studied at any time when the sun is visible.

The instrument employed for this purpose consists of a spectroscope attached to an equatorial telescope, the combination constituting what is sometimes called a telespectroscope. In order to see a protuberance the telescope is directed so that the slit of the spectroscope shall be tangential to the sun's disk, and then the slit is slightly opened. The light that comes from the protuberance is not dispersed, whilst that from the surrounding region is so much scattered as to render the protuberance visible.

Solar protuberances differ widely in magnitude and in general appearance. Of 2,767 measured protuberances referred to by Young in his book on the sun, fully two-thirds of the whole were more than 18,000 miles in height, nearly one-quarter of the whole were over 28,000 miles high, and several reached an altitude of more than 84,000 miles. He says that he has seen three or four whose heights were more than 150,000 miles, and that Secchi saw one whose altitude was over 300,000 miles. He also says that he himself observed one which attained the unprecedented height of 350,000 miles. When first seen this protuberance had an altitude of only 40,000 miles, and therefore attracted no special attention. He then goes on to say: "When next seen, half an hour later, it had become very brilliant, and had doubled its height; during the next hour it stretched upward until it reached the enormous altitude mentioned, breaking up into filaments which gradually faded away, until by 12.30 P. M. there was nothing left. A telescopic examination of the sun's disk showed nothing to account for such an extraordinary outburst, except some small and not very brilliant faculæ."

The protuberances vary as much in appearance as they do in magnitude. Some resemble masses of clouds stretching along the solar disk like sierras, or perhaps floating in the solar atmosphere, either entirely detached from the disk, or connected with it by slender filaments. Others take the form of jets as if shot forth from the sun with enormous energy, sometimes combing over and descending like ocean breakers, and at other times apparently rent asunder and shattered by contending forces, as shown in Fig. 75.

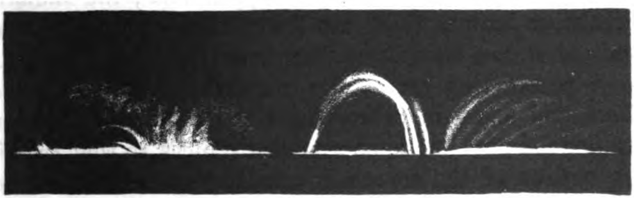

Fig. 75. Solar Protuberances. Drawn by Trouvelot.

Sometimes the protuberances assume arborescent forms, as shown in Fig. 76.

Fig. 76.

In all cases their shapes are indicative of gigantic forces, sometimes acting, normally from below, and sometimes sweeping along the surface of the sun, either progressively, or in a revolving direction like a vast cyclone.

The Corona.

132. The **corona**, which has never been seen except during a total solar eclipse, is an envelope of complex constitution, lying above the chromosphere, and extending outward to a distance that has not yet been determined. At the time of totality it is seen surrounding the dark body of the moon as a ring of silvery light, often crossed by radiating streaks, which give it an appearance that has been likened to the *halo of glory* that we sometimes see depicted around the heads of saints. The part next the sun, and extending outward to the distance of a tenth of its radius, is very bright and tolerably uniform in appearance; the radiating streaks or beams, which are frequently inclined and curiously bent, are irregularly distributed around the sun; in some places they are few in number and comparatively short, and again in other places they are very numerous, and extend outward to enormous distances, so that the visible outline of the corona is usually jagged and extremely irregular.

The jagged outline of the corona is shown in Fig. 77, which represents its appearance as drawn by Fœnander during the total eclipse of 1871.

Fig. 77. Corona seen in 1871.

The general appearance of the corona is never the same at two different eclipses, and even at the same eclipse observers differ in their account of its outline, especially if their observations are made at different stations. Sometimes the radial wings are seen to extend to great distances in the direction of the solar equator. An example of this kind is shown in Fig. 78, which represents the corona as seen by Bullock during the eclipse of 1868.

Prof. Young, in speaking of the corona, says "that of the eclipse of 1878 is remarkable on account of the enormous extension of the faint brushes of nebulosity, which were traced to a distance of 6° or 7° from the sun by Professors Langley, Abbe, and Newcomb." It is to be noted that an angle of 6° at the sun's distance corresponds to a distance of more than 9,000,000 of miles.

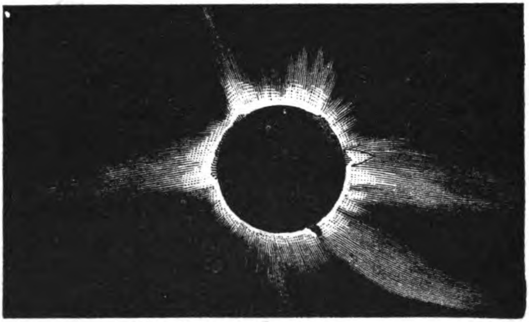

Fig. 78. Corona as seen in 1868.

The peculiar form of the corona as seen during the eclipse of 1878 by a party of astronomers in Texas is shown in Fig. 79.

Fig. 79. Corona as seen in 1878 in Texas.

But little is known about the physical constitution of the corona; it has even been suggested that it is an optical phenomenon, and some weight has been given to this suggestion by the observations recently made at the Caroline Islands on the eclipse of May 6, 1883. Previous observations, however, leave but little room to doubt that it consists, in part at least, of gases far more tenuous than any with which we are acquainted on our earth. The corona was carefully observed with the spectroscope during the eclipse of 1869 by Professors Young and Harkness; they found in its spectrum a greenish *bright* line, corresponding to the number 1474 of Kirchoff's scale. Subsequent observations have shown numerous *dark* lines, corresponding to the dark lines of the solar spectrum. These observations would seem to indicate that the corona contains a glowing gas in which is suspended a certain amount of matter which is capable of reflecting solar rays.

The Zodiacal Light.

133. The **zodiacal light** is a lenticular-shaped blush of light that is visible in the western sky after sunset in early spring, and in the eastern sky before sunrise in early autumn.

Its base, which is 10° or 15° in breadth, rests on the horizon, its axis coincides sensibly with the ecliptic, and its apex is 30° or 40° from its base. It is generally less luminous than the milky way, and its edges are not so well defined; for these reasons it is very difficult to determine its exact limits.

It is seen to best advantage in the evenings about the time of the vernal equinox, and in the mornings about the time of the autumnal equinox, because at those times its axis makes the greatest possible angle with the horizon.

Within the tropics it is a conspicuous object, and is visible at all seasons, both in the evening and in the morning.

Under favorable conditions the light is visible both in the east and in the west at midnight; it has even been seen extending across the entire heavens from horizon to horizon.

Humboldt, speaking of its brilliancy in the tropical regions, says: "Those who have lived for many years in the zone of palms must retain a pleasing impression of the mild radiance with which the zodiacal light, shooting pyramidally upwards, illuminates a part of the uniform lengths of tropical nights. I have seen it shine with an intensity equal to that of the Milky Way in Sagittarius."

The intensity of the zodiacal light is somewhat variable, but whether its variations are periodic or not is unknown. The fact of its variability is testified to by Humboldt, who had ample opportunity for observation during his long stay in South America. It is also noticed, even in our unfavorable situation for observation, that the intensity of its light varies from night to night and from season to season more than would seem to be due to varying atmospheric conditions.

Various theories have been proposed to account for this phenomenon, the most plausible one being that it is due to a ring of meteorites revolving around the sun, each meteorite being too small to be separately visible, but aggregated in such numbers as to reflect a considerable amount of solar light.

VII. ECLIPSES.

Definitions.

134. A **solar eclipse** is an obscuration of the sun caused by the passage of the moon between it and the observer.

A **lunar eclipse** is an obscuration of the moon caused by her entrance into the earth's shadow.

A **solar eclipse** can occur only at the time of *new moon*, and a lunar one only at the time of *full moon ;* and even at those times no eclipse can take place unless the moon happens to be very near the plane of the ecliptic.

Shadow Systems of the Earth and Moon.

135. In Fig. 80, let S represent the sun, E the earth, and suppose two cones of rays to be drawn tangent to both

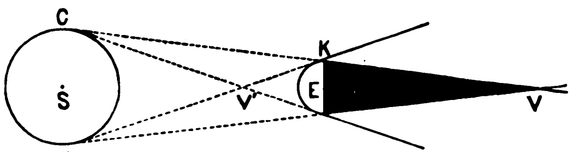

Fig. 80. Section of Shadow System by a Plane through its Axis.

bodies, the vertex of the first being beyond the earth, and that of the second being between the earth and the sun. The part of the first cone, which lies between E and the vertex V, is the **umbra**, or shadow proper of the earth; the prolongation of this cone beyond V is called the **second nappe** of the shadow cone; and that part of the second cone lying beyond E and outside of the first cone, is called **the penumbra**, or partial shadow; all these taken together constitute the earth's **shadow system.** The moon in like manner has a similar *shadow* system, consisting of *umbra*, *second nappe*, and *penumbra*.

The length of the earth's umbra can easily be found in terms of the solar distance:

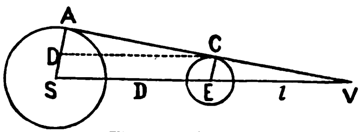

Fig. 81. Diagram.

Let S and E represent sections of the sun and earth by a plane through their centres, SV their line of centres, and AV an external tangent. Draw SA and EC perpendicular to AV, and CD parallel to VS. Denote SA, the radius of the sun, by R; EC, the radius of the earth, by r; SE, the earth's distance from the sun, or its equal DC, by D; and EV, the length of the umbra, by l. From the similar triangles DAC and ECV, we have

$$DA : DC :: EC : EV, \text{ or } R - r : D :: r : l,$$

$$\therefore \; l = \frac{rD}{R - r} \quad . \; . \; . \; . \; . \; . \; . \quad (1).$$

If we assume that the sun's radius is 109 times that of the earth, which is very nearly true, we have $R - r = 108r$, whence $l = \frac{D}{108}$; that is, *the length of the earth's umbra is equal to the earth's distance from the sun divided by* 108.

In like manner, by assuming the sun's radius to be 400 times that of the moon, which is sufficiently accurate for our purpose, we find that *the length of the moon's umbra is equal to the moon's distance from the sun divided by* 399.

When we know the length of the shadow, and the diameter of the body which casts it, we can find the diameter of the cross-section of the shadow at any distance, x, from its apex. For if we denote the diameter of the body by d, the diameter of the shadow's cross-section by d', the length of the shadow by l, and the distance of the section from the apex by x, we shall have

$$d : d' :: l : x, \; \therefore \; d' = \frac{xd}{l} \quad . \; . \; . \; . \; . \; . \quad (2).$$

Formula (2) is equally applicable when x is measured on the prolongation of l, that is, when the section is made in the second nappe.

If we change $-r$ into $+r$, formula (1) will be applicable to finding the vertex of the penumbral cone of either the earth or the moon.

Thus, *the vertex of the moon's penumbral cone lies between the sun and moon, and at a distance from the latter equal to her distance from the sun divided by* 401.

Kinds of Solar Eclipses.

136. Whenever any part of the moon's shadow system sweeps over the earth there is a *solar eclipse* which is visible from every point on which the shadow falls. To an observer within the penumbra, the eclipse is **partial**, and the visible part of the sun's disk is crescent-shaped; to an observer within the umbra, the eclipse is **total**, no part of the sun's disk being visible; to an observer in the second nappe of the umbra, the eclipse is **annular**, that is, a portion of the sun's disk is seen completely surrounding the moon like a ring. To an observer in the axis of the shadow system, the eclipse is **central**, and may be either *total* or *annular;* in the latter case the visible ring of the solar disk is of uniform width throughout.

An eclipse when considered with respect to a given point is said to be **local**; when considered with respect to the whole earth, it is **general**.

Solar Ecliptic Limits.

137. In order that a solar eclipse may be *possible* at the time of any new moon, it is necessary that the moon should be near enough to the plane of the ecliptic to bring some part of her disk between the observer and the sun. This can only happen when the sun is near the moon's node at the time of conjunction.

It has been found by computation that a solar eclipse is *impossible* when the sun, at the time of new moon, is more than 18°.5 from the moon's node, and that an eclipse is *certain* when this distance is less than 15°. These distances are called the **solar ecliptic limits.** If at the time of conjunction the sun's distance from the node lies between these limits, the occurrence or non-occurrence of an eclipse must be determined by calculation.

In order that a solar eclipse may be *central*, the line passing through the centres of the sun and moon must strike the earth. This *cannot happen* if the sun at the time of new moon is more than 11°.9 from the lunar node, and it is *certain to happen* if this distance is less than 9°.5. If the sun's distance from the node, at the time of conjunction, lies between these limits, the occurrence or non-occurrence of a central eclipse must be determined by computation.

Of the Central Eclipse.

138. The central eclipse will be *total* whenever the moon's umbra is long enough to reach the earth; in all other cases it will be *annular*.

The length of the moon's umbra, in any given case, is easily found; for, we have only to divide the moon's distance from the sun by 399 (Art. 135). Knowing this length and the moon's distance from the earth, we can at once decide whether the eclipse will be total or annular.

Let it be required to find the greatest and the least lengths of the moon's umbra at the time of conjunction. For this purpose let us assume that the greatest distance from the sun to the earth is 94,000,000 miles, and that his least distance is 91,000,000 miles; also that the greatest and the least distances of the moon from the earth are 252,000 miles and 226,000 miles.

Now it is obvious that the moon's umbra will be *longest* at the time of conjunction when the sun is farthest from, and the moon is nearest to, the earth. In this case the moon's distance from the sun is 93,774,000 miles, and by the rule above given, the corresponding length of the umbra is 235,000 miles. Hence, the umbra extends 9,000 miles beyond the earth's centre, or about 13,000 miles beyond the nearest point of the earth's surface. (Fig. 82.)

The moon's umbra will be *shortest* at the time of conjunction when the sun is nearest to, and the moon farthest from, the earth. In this case the moon's distance from the sun is 90,748,000 miles and the corresponding length of the umbra is about 227,400 miles. Hence, the umbra falls short of the earth's centre by 24,600 miles, and of the nearest point on the earth's surface by about 20,600 miles. (Fig. 83.)

Limits of Visibility.

139. From what was stated in Art. 136, it is plain that a *partial* eclipse will be visible from every part of the earth's surface which is swept over by the moon's penumbra, that a *total* eclipse will be visible from every part of the belt or zone swept over by the umbra, and that an *annular* eclipse will be visible from every part swept over by the second nappe of the umbra.

Let us first consider the case in which the moon's umbra is longest, its axis being perpendicular to the earth's surface, as shown in Fig. 82.

EXPLANATION. M is the moon, E is the earth, and MV the moon's umbra when its axis is perpendicular to the earth's surface, the umbra being at its longest. The space between the umbra and the broken lines in the figure is the penumbra.

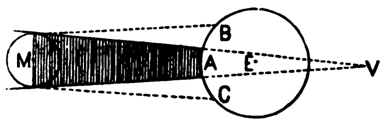

Fig. 82. Maximum Visibility of Total Eclipse.

The distance AV being 13,000 miles, we can easily compute the cross-section of the umbra at A, by means of the principles explained in Art. 135; in the case under consideration this cross-section is found to be a little less than 120 miles. This would be the greatest breadth of the moon's shadow, and consequently of the *zone of totality*, if the axis of the shadow were always perpendicular to the earth's surface, but as the shadow sweeps over the earth its axis falls more or less obliquely upon the earth; hence, it may happen that the breadth of the shadow will be considerably greater than 120 miles. If the sun is nearer the earth than we have supposed, or if the moon is more distant, the breadth of the zone of totality will be correspondingly narrower; it may even reduce to a mere line.

In the case considered the breadth of the penumbra, BC, is more than 4,200 miles; this indicates the breadth of space from which the eclipse is partially visible.

Let us next consider the case in which the moon's umbra is shortest, its axis being perpendicular to the earth's surface as shown in Fig. 83.

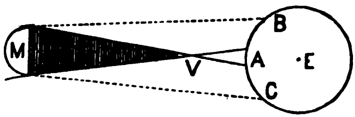

Fig. 83. Maximum Visibility of Annular Eclipse.

EXPLANATION. In this figure the explanation is the same as before, except that VA is a part of the umbra's second nappe.

The distance VA being 20,600 miles, we find the diameter of the cross-section of the second nappe at A to be something greater than 190 miles, and the diameter of the penumbral section at BC to be more than 4,500 miles.

In consequence of the obliquity of the shadow-cone's axis to the surface of the earth, we see that the breadth of the zone from which an annular eclipse is visible may be something greater than 190 miles. In a majority of cases it is much narrower; it may even be reduced to a mere line.

The Moon's Relative Orbit.

140. In discussing the circumstances of an eclipse, whether local or general, it is found convenient to suppose the sun to remain at rest and the moon to move with the relative motion of the two bodies. The path that the moon appears to follow is then called **the moon's relative orbit.**

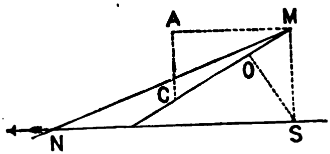

Fig. 84. The Moon's Relative Orbit.

To explain what is meant by *the moon's relative orbit*, let SN (Fig. 84) be the ecliptic and MN the moon's actual orbit, both projected on a plane perpendicular to the line of nodes of the moon's orbit. Let S and M be the places of the sun and moon at the time of conjunction in longitude. Draw MA parallel to SN, and make it equal to the moon's hourly motion in longitude diminished by the sun's hourly motion in longitude; draw AC perpendicular to MA and make it equal to the moon's hourly motion in latitude, then will a line through M and C be the moon's relative orbit, and the distance from M to C will be the moon's hourly motion *with respect to the sun.*

If we draw SO perpendicular to MC, the point O will be the relative place of the moon at the time of nearest approach of the centres of the sun and moon, and MO expressed in terms of MC will represent the fractional part of an hour that constitutes the interval between the time of conjunction and the time of *nearest approach,* which last is obviously the same as the time of the middle of the eclipse.

Of the Local Solar Eclipse.

141. The circumstances of a local eclipse that are usually predicted by astronomers, and laid down in the almanacs are the *times of beginning, middle,* and *ending;* also in case of a total eclipse, the *times of beginning and ending of totality;* and in case of an annular eclipse the times of *formation* and *rupture* of the ring.

In the case of a partial eclipse the **magnitude** is generally given, that is, the fractional part of the sun's disk that is covered at the time of greatest obscuration.

The *time of beginning* is the instant at which the eastern limb of the moon appears to touch the western limb of the sun. From this time the form of the sun's visible disk may be described as *crescent,* the line joining its *horns* or *cusps* being always perpendicular to the line of centres of the solar and the lunar disks.

The *middle of the eclipse* is the instant the centres of the two disks are nearest to each other. At this time the line of cusps is parallel to the moon's relative orbit.

The *time of ending* is the instant at which the western limb of the moon appears to separate from the eastern limb of the sun.

The times of these different phases of a solar eclipse depend not only upon the relative motion of the moon with respect to the sun, but also upon the actual motion of the observer in consequence of the earth's axial rotation.

The *magnitude* of the eclipse is measured by the *greatest* breadth of the obscured portion of the sun's disk. This is expressed in terms of the sun's diameter, sometimes *decimally*, and sometimes in **digits**, a digit being the twelfth part of a diameter. Thus, if three-fourths of that diameter of the sun which is directed toward the moon's centre is covered by the moon's disk, the eclipse is said to have a magnitude of .75, or of 9 digits.

For the method of computing the times of the above phenomena the student is referred to Loomis' Practical Astronomy.

Of the General Solar Eclipse.

142. In considering the general eclipse it is to be borne in mind that the moon's *shadow system* is sweeping eastward across the earth by virtue of the moon's motion along her relative orbit, and also that every place on the earth is at the same time moving from west to east, but less rapidly, by reason of the earth's rotation on her axis. The circumstances resulting from a combination of these motions are predicted by astronomers, and graphically recorded by means of maps like that shown in Fig. 85, which was constructed to illustrate the annular eclipse of October 19, 1865. The figure and its explanation, copied from an almanac of that year, show the usual method of recording certain specific details of a general eclipse.

In order to explain the lines laid down on the map, let us suppose a plane to be passed through the centres of the sun and moon and perpendicular to the plane of the moon's orbit. This plane, which may be called the central plane, is supposed to follow the moon in its motion, always dividing its umbra and penumbra into two symmetrical parts, an eastern or preceding part, and a western or following part. It is obvious that the eclipse is just *beginning* to an observer who is anywhere on the surface of the *preceding part*, and just *ending* to an observer who is anywhere on the surface of the *following part*

When the preceding surface of the moon's penumbra strikes the earth the general eclipse *begins*, and the point at which the contact takes place is marked first contact on the map. Because the element of the penumbral cone that determines the *place* of contact is a solar ray tangent to the earth's surface, the sun must be in the eastern hori-

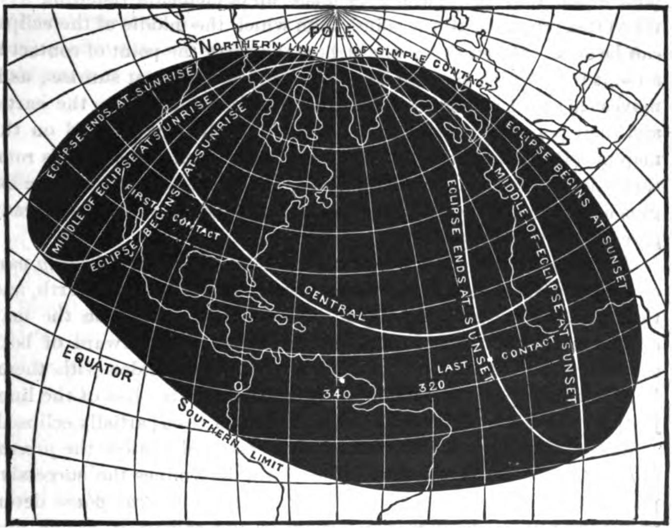

Fig. 85. General Eclipse of October, 1865.

EXPLANATION. The eclipse first touches the earth in long. 30° 51′ 12″ W. of Washington, in lat. 35° 0′ 30″ N., at the instant of sunrise there, it being then at Washington 8h. 17m. A.M. The eclipse ends on the earth in mid-ocean, in long. 53° 18′ 18″ E. of Washington, in lat. 4° 24′ 54″ N., at sunset there, it being then 2h. 3m. 36 sec. P.M. at Washington. The *central* eclipse begins in lat. 47° 11′ 12″ N., long. 45° 47′ 24″ W. of Washington, at sunrise there, and passes southeasterly through Kansas, Missouri, Tennessee, Alabama, and Georgia, entering the ocean near Savannah, and ends finally in Africa in lat. 16° 45′ 54″ N., long. 290° 7′ west of Washington. The eclipse will be visible wherever the dark ground in the engraving is seen, but as an *annular eclipse* only along the central line—each side of which it will be partial, the magnitude of the *partial* eclipse being smaller the farther we go from that line.

zon at the instant of contact; hence, the eclipse begins at local *sunrise.* As the shadow system sweeps eastward, other elements of the penumbral cone become tangent to the earth's surface in succession, and the points of contact thus determined make up the curve along which the eclipse begins at sunrise. This curve, whose concavity is turned toward the west, in consequence of the earth's rotation, terminates at the points which are determined by the two elements of the penumbral cone that lie in the central plane.

That part of the central plane which lies within the penumbral cone (and which may be regarded as made up of elements radiating from the vertex) contains all the points from which the middle of the eclipse can be seen. When this plane strikes the earth the point of contact is a point from which the *middle* of the eclipse is seen at sunrise; as it moves eastward its successive elements become tangent to the earth, and their points of contact make up the line which is marked on the map **middle of eclipse at sunrise.** In consequence of the earth's rotation this line lies to the westward of that along which the eclipse begins at sunrise, except at its extremities, which, for reasons already given, are identical with it.

As the shadow system moves on, the elements of the *following* part of the penumbral cone become successively tangent to the earth, and their points of contact make up the line which is marked on the map **eclipse ends at sunrise.** This curve lies to the westward of both the others, except at its extremities, where it coincides with them. Within the looped space included by the first and the last of the lines just described is a region within which the sun rises partially eclipsed.

As the moon's penumbra continues its eastward motion, the *preceding part*, by its intersection with the earth, determines the successive places at which the eclipse is just beginning, the *central plane* determines the places at which the middle of the eclipse is visible, and the *following part* determines the places where the eclipse is just ending.

In passing off from the earth the *preceding part* determines a succession of points which make up the line marked **eclipse begins at sunset**; the *central plane* determines the points that constitute the line marked **middle of eclipse at sunset**; and the *following part* determines the line marked **eclipse ends at sunset.** The point at which the shadow finally leaves the earth is the point which is marked **last contact.** The looped space bounded by the first and third of these curves contains all the places at which the sun sets partially eclipsed.

When the line of centres of the sun and moon strikes the earth the central eclipse begins; the intersection of this line with the earth's surface is the path of the central eclipse; and when this line again becomes tangent to the earth the central eclipse ends. The intersection of the second nappe of the moon's umbra with the earth determines a zone along which the annular eclipse is visible. This zone is represented by the broad white line on the chart marked **central.** Had the eclipse been total a similar zone corresponding to the intersection of the moon's umbra with the earth would have marked the zone from which the total phase would have been visible.

Observers to the northward of this zone see a partial eclipse *on the sun's southern limb*, and observers to south of it see a partial eclipse *on the sun's northern limb*, the magnitude in each case diminishing as the observer is situated nearer to the lines marked northern line of simple contact and southern limit.

Greatest Duration of a Total Eclipse.

143. The period of total obscuration at a given place is the time that it takes the moon's umbra to pass over that place. In order that this time may be as great as possible, the observer should be on the central line, the breadth of the moon's shadow should be as great as possible, and its relative motion with respect to the observer should be as small as possible.

We have already seen that the breadth of the shadow will be as great as possible when the sun is at his greatest and the moon at her least distance from the earth. Furthermore, the relative velocity of the shadow will be as small as possible when it travels through the equatorial region, and nearly parallel to the equator, for in that case the observer is carried eastward by the earth's rotation nearly half as fast as the shadow travels in the same direction. Hence, the duration of totality is greatest when the eclipse happens in summer, the moon being at that time near perigee and the central line being near the equator. Under favorable circumstances the length of totality at a given place may amount to nearly 7 minutes.

Phenomena Observed.

144. A total solar eclipse at any particular locality is so rare an event that comparatively few people ever see one. Halley, in speaking of one that was visible in London in 1715, says it was the first one that had happened at that place since 1140, an interval of 575 years.

The phenomena presented during the short period of totality are regarded as of so much importance, that astronomers often take long journeys, at great expense of time and money, for the purpose of observing them. Indeed, almost every total eclipse that occurs in any part of the world is now carefully observed by well-equipped parties of scientific men scattered all along its path.

Some of the phenomena observed are of special interest to the solar physicist, while others, if less important in this respect, are equally interesting to the student of general science. The appearances presented at different eclipses, and sometimes during the same eclipse at different places, are so various as to render it difficult to give a description of them all. Appearances that are clearly marked at one time are either not presented at all, or else pass unnoticed, at another. Some of these differences may undoubtedly be accounted for by varying atmospheric conditions, possibly some may be due to a variation in the character of the phenomena themselves, and not unlikely some arise from the peculiar temperaments of the observers. The most important phenomena generally observed are embraced in the following summary.

Some time before the sun disappears, the atmosphere begins to grow gloomy and the shadows of trees are strangely mingled with crescent-shaped images of the waning sun formed by rays penetrating the intervals between their leaves. As the time of complete obscuration approaches, the aspect of the heavens undergoes a change; the sky assumes a lurid leaden hue which seems to be diffused over all terrestrial objects ; the faces of the observers take on a cadaverous ashy tint; birds seek their perches and animals their usual places of rest; and a general feeling of uneasiness, like that which precedes impending calamity, seizes upon the minds of men. Then, the moon's umbra is seen approaching like a "wall of darkness;" the last trace of the sun's thin crescent breaks up into shining bead-like points and disappears; and the observer, plunged suddenly into an unnatural but not intense darkness, sees instead of the sun a black globe surrounded by a silvery coronal halo, broken here and there by the projecting flame-like protuberances of the sun's chromosphere. For a few fleeting minutes the brighter stars and planets appear, and then the glittering points of the chromosphere show themselves on the other side of the moon; the thin sickle of the solar disk begins to form; the moon's umbra is seen sweeping away along its path; and the observer is returned to daylight more suddenly even than he was plunged into darkness.

Mr. Lockyer, in speaking of the beginning of totality, says: "One seems in a new world—a world filled with awful sights and strange forebodings, and in which stillness and sadness reign supreme; the voice of man and the cries of animals are hushed; the clouds are full of threatenings and put on unearthly hues; dusky, livid, or purple, or yellowish crimson tones chase each other over the sky irrespective of the clouds. The very sea is responsive and turns lurid red. All at once the moon's shadow comes sweeping over air, and earth, and sky, with frightful speed. Men look at each other and behold, as it were, corpses, and the sun's light is lost."

The brilliant points seen at the instants of disappearance and reappearance of the sun's disk are called **Baily's beads,** being so named from the astronomer who first described their appearance; in his description he speaks of them as "a row of lucid points, like a string of bright beads." The beads disappear suddenly at the commencement of totality, and reappear on the other side with equal suddenness at the end of totality. They have been accounted for by supposing that the solar crescent, when it consists of a mere thread of the chromosphere, is cut into segments by projections of the serrated edge of the moon; these brilliant segments, continually changing in form, are seen for an instant shining through the lunar valleys. The different appearances of the beads at different times would seem to be dependent upon the degree of roughness of that part of the moon's surface which happens to form the edge of the lunar disk, and perhaps also upon slight variations in the apparent semi-diameters of the sun and moon at different eclipses.

The corona, which has already been described, is by far the most important of all the phenomena manifested during a total eclipse, and for this reason we subjoin the following additional description of it as given by Lockyer. After speaking of other appearances observed during the eclipse of 1871 in India, he says: "* * * there in the leaden colored, utterly cloudless sky shone out the eclipsed sun! a worthy sight for gods and men. There, rigid in the heavens, was what struck everybody as a decoration, one that emperors might fight for, a thousand times more brilliant even than the the Star of India, where we then were! a picture of surpassing loveliness, and giving one an idea of serenity among all the activity that was going on below; shining with the sheen of silver essence; built up of rays almost symmetrically arranged round a bright ring above and below, with a marked absence of them to the right and left, the rays being composed of radial lines, separated by furrows of markedly less brilliance."

Lunar Eclipses. Lunar Ecliptic Limits.

145. Whenever, at the time of opposition, any part of the moon enters the earth's umbra there is a *lunar eclipse*, which may be either *partial* or *total*; it is *partial* when only a part of the moon enters the umbra, and it is *total* when the entire moon enters the umbra.

In passing through the earth's penumbra, the light of the moon is but slightly dimmed, no more, perhaps, than it would be by an intervening haze. This dimming or partial obscuration is not usually regarded as an eclipse.

The occurrence or non-occurrence of a lunar eclipse at the time of any full moon will depend upon the relative distances of the sun and moon and upon the position of the latter in her orbit.

It has been shown by calculation that a lunar eclipse is *impossible* when, at the time of opposition, the sun is more than 12° from the moon's node, and that an eclipse is *certain* when this distance is less than 9°. These angular distances are called the **lunar ecliptic limits.** When the sun's distance from the node lies between these limits the occurrence or non-occurrence of an eclipse must be determined by computation.

The ecliptic limits corresponding to a *total* lunar eclipse are 5°.6 and 4°.

The circumstances of a lunar eclipse which are predicted by astronomers and laid down in the almanacs are the times of *beginning*, of the *middle*, and of *ending*, and in case of a total eclipse the times of *beginning* and *ending of the total phase*; in case of a partial eclipse the *magnitude* also is given.

The circumstances of a partial lunar eclipse are illustrated by Fig. 85a.

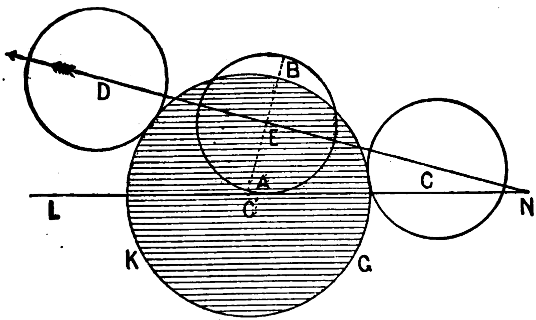

Fig. 85a. Partial Eclipse of the Moon.

EXPLANATION. NL is an arc of the ecliptic; ND is the relative orbit of the moon; KGB is the cross-section of the earth's umbra at the moon's distance from the earth; C, E, D, are the positions of the moon at the times of beginning, middle, and end of the eclipse; and AB, expressed in terms of the diameter of the moon, is the magnitude of the eclipse. In this case the moon is eclipsed on its southern limb.

Extent of Visibility of Eclipses.

146. A solar eclipse, being simply an occultation, or hiding, of the whole or a part of the sun by the intervening moon, is visible only at those places which are swept over by the moon's shadow system, and under the most favorable circumstances the area from which it can be seen is only a portion of a hemisphere.

In a lunar eclipse, however, the whole or a part of the moon actually ceases to shine because its light is cut off by the intervening earth ; hence, the eclipse is visible over the entire hemisphere which is turned toward the moon.

In consequence of the earth's rotation on her axis, the hemisphere which is turned toward the moon is continually changing, the eastern part passing out of the field of visibility and a new part from the west coming in. Hence, in an eclipse of long duration (and a total eclipse is sometimes visible for nearly two hours), some part of the eclipse may be seen over a region much greater than a hemisphere.

As we shall see hereafter, solar eclipses are more numerous than lunar ones, but on account of the greater area over which the latter can be seen the number of lunar eclipses visible at any given place is much greater than the number of solar ones.

Color of the Moon in Eclipse.

147. During the time of a lunar eclipse the moon with all its markings remains visible, shining with a dull red or copper color, even during the time of totality. This phenomenon is due to the action of the earth's atmosphere on the solar rays that pass through its lower strata. In entering our atmosphere these rays are bent toward the earth by more than half a degree, and at the same time they take on a reddish hue in consequence of the absorption of their more refrangible elements ; in passing out of the atmosphere, on their way to the moon, they are still further refracted and also undergo a still further absorption. The total bending, which may amount to more than a degree, is sufficient to throw them within the earth's umbra, and the total absorption is sufficient to produce the reddish color that we observe on the moon's disk.

The depth of the color depends on the state of the atmosphere along the circle in which the umbral cone is tangent to the earth, and the distinctness with which it is seen depends on the state of the atmosphere at the place of observation. It is only in rare instances that the moon is completely invisible during the time of totality. When such cases occur the eclipsed moon is usually very near the horizon of the observer.

Eclipse Seasons.

148. If we suppose the sun to set out from one of the moon's nodes, traveling eastward at the rate of 360° a year, while the node itself is traveling westward at the rate of nearly 20° a year, the two will meet after an interval of 346.62 days (Art. 110); hence, the sun's average daily motion with respect to the node is nearly 1°.04, at which rate he would traverse the greatest solar ecliptic limit in about 17.9 days, and the greatest lunar ecliptic limit in about 11.5 days. We see, therefore, that no eclipse, either solar or lunar, can take place more than 18 days from the time of the sun's passing one of the moon's nodes, either before or after. For this reason we call the period made up of 18 days before the sun reaches either node and of 18 days after he passes that node an **eclipse season.** Inasmuch as it takes the sun 173.31 days to pass from either node to the one opposite, the interval between the end of one eclipse season and the beginning of the next is a little more than 137 days.

Number of Eclipses in an Eclipse Season.

149. The number of eclipses that may occur in a single eclipse season depends upon the ecliptic limits and also upon the position of the sun at the times of full and new moon.

The average value of the solar ecliptic limits is 16¾°, and that of the lunar ecliptic limits is 10½°; if we regard 1°.04 as the average daily motion of the sun with respect to the node, the former distance will correspond to 16.1 days, and the latter distance to 10.1 days; hence, we say that there will *probably* be a solar eclipse when new moon happens within 16 days of the node on either side, and a lunar eclipse when full moon occurs within 10 days of the node on either side.

There may be *three* eclipses in one eclipse season; for, if we suppose full moon to happen within 1 day of the node, there will be a lunar eclipse at that time, and furthermore, the new moon that occurs 14.8 days before, and also the new moon that takes place 14.8 days after, will both be within less than 16 days of the node, and consequently at each of these times there will *probably* be a solar eclipse. It is impossible to have two lunar eclipses in one season; for, the interval between two full moons is 29.5 days; hence, if one falls within 11.5 days of the node, the other must happen at a greater interval than 11.5 days from the node. We see therefore that when there are three eclipses, one must be lunar and two solar. In this case it is to be noted that the lunar eclipse will be total, both of the solar eclipses being partial.

It may happen that there will be but one eclipse in a season; for if we suppose new moon to happen within 1 day of the node, there will be a central solar eclipse at that time, and inasmuch as the full moon that occurs 14.8 days before, and the full moon that takes place 14.8 days after, are each more than 11.5 days from the node, there will probably be no lunar eclipse at either of these times.

It is easily seen that in most cases there will be two eclipses in a season, one of which will be lunar and the other solar.

Flammarion, in his Popular Astronomy, gives the details of all the eclipses that have happened and that will happen from the beginning of 1880 to the end of 1900. If we take a cycle of 38 eclipse seasons, beginning with December 1, 1880, we find that 4 of these seasons embrace 3 eclipses each, 12 contain but 1 each, and 22 contain 2 each, the whole number in the cycle being 68.

The average number of eclipses in a calendar year is nearly $3\frac{3}{4}$, that is, there will be at the rate of 15 eclipses in 4 years. It is theoretically *possible* that 7 eclipses may occur in a single year, and it is absolutely impossible that there should be less than 2; of the 21 years above referred to, 1 year has 6 eclipses, 5 years have 5 each, 8 years have 4 each, 1 year has 3, and 6 years have 2 each.

The Eclipse Cycle, or the Saros.

150. The time that it takes for the sun to revolve from one of the moon's nodes around to the same node again is 346.62 days, and the time of 19 such revolutions is 6585.78 days; the average length of the moon's synodical revolution is 29.53058 days, and the length of 223 such revolutions is 6585.32 days; hence, a period of 223 lunar months falls short of 19 nodical revolutions of the sun by .46 of a day, in which time the sun's motion with respect to the node is less than half of a degree.

Furthermore, 223 lunations correspond almost exactly to two revolutions of the line of apsides with respect to the node. Hence, at the end of a period of 223 lunar months the sun and the moon will have returned very nearly to the same positions with respect to the moon's orbit that they had at the beginning of it, and consequently the eclipses of that period will be repeated in the same order and with but little variation in magnitude. This period of 6585.32 days is an **eclipse cycle**; it is equal to 18 years and $10\frac{1}{3}$ or $11\frac{1}{3}$ days, according to the number of times that the cycle contains the 29th day of February; it was known to the ancients, by whom it was called the Saros.

If we have the date of the middle of any eclipse we can find the date of its return to a very close degree of approximation, by adding 6585.32 days. The following illustration showing the times of recurrence of a total eclipse, and the regions in which the central eclipse is visible in each case, is copied from Newcomb's Popular Astronomy:

1850, August 7th, 4h. 4m. P. M., in the Pacific Ocean;
1868, August 17th, 12h. P. M., in India;
1886, August 29, 8h. A. M., in Central Atlantic and S. Africa;
1904, September 9th, at noon, in South America.

It will be seen that the region in which the central phase is visible at each return shifts toward the west by a distance nearly equal to one-third of the earth's circumference: this change is due to the fact that the interval between two successive returns exceeds an integral number of days by nearly 8 hours.

It is to be noted that there is a slight difference in phase of an eclipse at its successive recurrences; for the place of the sun with respect to the node is .46 of a day further to the west at each return. In consequence of this slight change, new eclipses gradually come into the cycle from the east and old ones leave it on the west. The average time that a lunar eclipse remains in the cycle is something more than 800 years, and the time that a solar eclipse remains is more than 1200 years.

The following account of the changes that may occur in an eclipse at successive returns is taken from Chambers' Descriptive Astronomy. In speaking of a solar eclipse which appeared at the north pole in June, 1295, and which moved southward at each return, he says: "On August 27, 1367, it made its first appearance in the north of Europe; in 1439 it was visible all over Europe; at its 19th appearance, in 1601, it was central in London; on May 5, 1818, it was visible at London; and was again nearly central at that place on May 15, 1836. At its 39th appearance, August 10, 1980, the moon's shadow will have passed the equator, and, as the eclipse will take place near midnight, it will be invisible in Europe, Africa, and Asia. At every subsequent period the eclipse will go more and more toward the south, until finally, at its 78th appearance in September 30, 2665, it will go off at the south pole of the earth, and disappear altogether."

In the cycle of eclipses which includes the 1st of December, 1880, and extends to the 12th of December, 1898, there are 68 eclipses, of which 42 are solar and 26 lunar; that is, the numbers of solar and lunar eclipses are very nearly proportional to the average values of the solar and lunar ecliptic limits.

Of the solar eclipses in this cycle, 15 are partial, 12 are total, and 15 are annular; of the lunar eclipses 15 are partial and 11 are total.

Occultations.

151. When one celestial body is hidden from view by the interposition of another, the phenomenon is called an **occultation**. According to this definition a total eclipse of the sun would be called an occultation, but astronomical usage has made the term *technical,* and it is now restricted almost entirely to the phenomenon of the moon's passage over a star or planet.

As the moon advances from west to east it sweeps over a belt of the heavens whose breadth is about half a degree, and every star in that belt must be occulted as the moon passes over it. When a star is occulted it disappears at the eastern or *advancing* limb of the moon, and reappears at the western or *following* limb; the instant of its disappearance is the **time of immersion**, and the instant of its reappearance is the **time of emersion**.

It is difficult to observe either phase, even in the case of a bright star, except at the moon's dark limb. During the first half of a lunar month the dark limb is turned toward the east, and during the last half it is turned toward the west; hence, *times of immersion* are usually observed between new moon and full, and *times of emersion* between full moon and new, the most favorable times in both cases being near new moon.

Occultations are usually observed for the purpose of determining the longitude of the place of the observer. To aid him, a list of stars liable to occultation is given in the Astronomical Ephemeris, together with certain data intended to facilitate computation. When the observed time, either of immersion or emersion, is known, the *local time* of conjunction of the moon and star as seen from the centre of the earth can be calculated; the *Greenwich time* of this conjunction can be found from the ephemeris; then, the difference of these times is the observer's longitude from Greenwich.

VIII. OF TIDES.

Definitions.

152. Tides are periodical elevations aud depressions of the surface of the ocean; as a general rule the waters rise for about six hours, and fall for an equal time, remaining stationary for a short interval at each turn of the tide. The rising of the waters is called **flood tide**, their falling is called **ebb tide**, and during the intermediate intervals it is said to be **slack water.** The average time required for a tide to pass through all its phases is 12h. 25m., or half a *lunar day*.

Causes of Tides.

153. The tides are caused by the *inequality of attraction* exerted by the moon, and also of the sun, upon opposite sides of the earth.

To explain the manner in which these causes operate to produce tides, let us first consider the action of the moon alone.

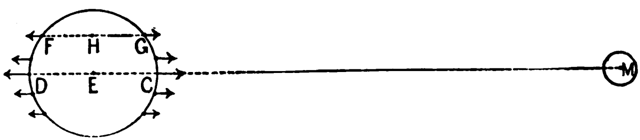

Fig. 86. Popular Illustration of the Cause of the Tides.

EXPLANATION. In Fig. 86 let M be the centre of the moon, E the centre of the earth, FDCG a section of the earth by any plane through M and E, DC the diameter whose direction passes through M, FG any chord whose direction passes through M, and which is therefore nearly parallel to DC, and H a point of FG whose distance from M is equal to ME.

Suppose C, E, and D to be three equal particles; then, from the Newtonian law, the moon's attraction on C will be greater than it is on E, and her attraction on E will be greater than it is on D; hence, C will be drawn away from E, and E away from D, or what is the same thing *relatively*, the action of the moon is to draw both C and D away from the centre E. Again, let G, H, and F be three equal particles; then it may be shown as before that the action of the moon is to draw both G and F away from H. The total effect of the moon's attraction is therefore to draw all the particles on the side CG toward M, and all the particles on the opposite side FD, away from M, this effect being greatest near C and D, as shown by the arrow-heads in the figure.

If the earth were at rest, these forces would produce two broad protuberances, one having its apex at C, directly under the moon, and the other having its apex at D, diametrically opposite; but before these protuberances have time to form, the earth turns on its axis so as to bring new points under the moon, at which the tendency to form the protuberances is renewed, and so on continually. The result of this continued action is the formation of two broad flat waves, called **tidal waves**, which follow the moon in its diurnal motion, moving from west to east around the globe.

In what precedes we have supposed the entire earth to be covered by water, whereas in reality the ocean is interrupted by continents, islands, and shoals, which break up and greatly modify the continuity of the tidal waves, without destroying them.

The action of the sun upon the waters of the globe is similar *in kind* to that of the moon, but inasmuch as its *inequality of attraction* on opposite sides of the earth is much smaller, its tide-producing power is less than that of the moon in the ratio of 4 to 9. It might be expected that the sun would form two independent tidal waves, but instead of this the sun and moon conspire to produce two *resultant* waves lying on opposite sides of the earth, of which the heights and, in some degree, the positions are dependent upon the relative positions of these two bodies.

The resultant wave, whose crest is on the side of the earth turned toward the moon, is called **the upper tide wave,** and the one that is on the opposite side of the earth is **the lower tide wave.** When either wave is approaching a place it is *flood tide,* when the crest of the wave reaches the place it is *high water,* and whilst the wave is receding it is *ebb tide.* In explaining the law of distribution of tides it will generally be sufficient to consider the upper wave only, for what is said of it will be equally true of the lower one.

Distribution of Tides.

154. If the entire earth were surrounded by a deep ocean, the crest of the tide-wave would lie nearly north and south; following the westward motion of the moon in her diurnal path, it would move regularly around the earth in a *lunar day,* its velocity in the equatorial regions being about 1000 miles an hour; the tides would be highest near the equator, and would gradually diminish in altitude toward the poles, where they would be insignificant.

In consequence, however, of the peculiar arrangement of the land and water of the globe, this simple law is greatly changed, so that the *actual law of distribution* of the tides is exceedingly complex. And yet, in spite of this complexity, there is at each place on the earth so great a regularity in the times and heights of the tides that both may be predicted with sufficient precision for all practical purposes.

It is found by observation that all the principal tides of the world depend on a great *primal* wave, which is developed by the direct action of the sun and moon on the vast expanse of water in the southern Pacific Ocean. The general course of this wave is westward, but as it advances it sends off branches, first into the northern Pacific, then into the Indian Ocean, and finally into the Atlantic, being everywhere reinforced and sustained by the minor tide-waves that are generated in those oceans.

The branch sent into the northern Pacific moves rapidly along the deep waters, and more slowly in the shallower waters of that ocean, and at the end of 10 or 12 hours reaches the eastern shores of northern Asia and the western shores of North America.

The main wave, after being delayed by shoals and islands, reaches the waters of southwestern Australia about half a lunar day after its generation, that is to say, when it is about half a day old. Sending a branch northward, which goes to produce the tides of the Indian Ocean, the main wave reaches the South Atlantic at the Cape of Good Hope after another half of a lunar day. Here it is deflected northward by the opposing continent of America, reaching the middle of the North Atlantic when it is about 37 hours old.

When the wave first enters the Atlantic Ocean, its crest has a curved form, whose convexity is turned toward the northwest; as it moves on, the curve that marks the advancing crest becomes more convex, the vertex of the curve following the general line of the deepest water; when it reaches the middle of the North Atlantic the crest has taken a parabolic form, whose axis is directed northward, whose western side is nearly parallel to the general trend of the eastern coast of the United States, and whose eastern side is nearly parallel to the coast line of the Eastern Continent. The western portion of the wave falling upon the coast of the United States, gives us our tides, the eastern portions produce the tides of southwestern Europe, and the still advancing front, after sending off branches to the east and west, finally loses itself in the Arctic Ocean.

It will be seen that the wave which produces the tides of the eastern coast of the United States is something more than 1½ lunar days old when it reaches us; hence, the tides that we get are not due to the last transit of the moon, except so far as they are reinforced by the local tide-wave generated in the Northern Atlantic, but to the action of the sun and moon nearly 40 hours before. The tides at London, which reach that place by a wave that passes around to north of Scotland, and then down the North Sea, take place nearly 2½ days later than the genesis of the primal wave in the Pacific Ocean.

Spring and Neap Tides.

155. The heights of the tides at any place depend upon the relative positions of the sun and moon. When these bodies are in conjunction or in opposition, that is, at the times of *new moon* and of *full moon*, they both tend to produce high water at the same time. This gives rise to the highest tides, which are called **spring tides.** When the sun and moon are 90° apart, that is, at the times of *the first* and of the *third quarter* of the moon, the sun acts to produce high water at the same time that the moon acts to produce low water, and the reverse; this gives rise to the lowest tides, which are called **neap tides.**

In consequence of the retardation of the primal wave, as explained in the preceding article, the spring tides on our coast do not occur till the third or fourth tide after new or full moon, nor do the neap tides happen till an equal interval after the first and third quarters of the moon.

Variations due to the Distances of the Sun and Moon.

156. It has been found by computation that the tide-producing powers of the sun and of the moon, when both are at their mean distances from the earth, are to each other very nearly as 4 to 9. If we represent the corresponding height of the solar tide by 1, that of the lunar tide will be represented by 2.25; on the same scale, the height of neap tide will be represented by 1.25 and that of spring tide by 3.25, that is, the average height of neap tide is to that of spring tide as 5 is to 13.

The relations between the heights of the tides, both solar and lunar, undergo considerable variations on account of the varying distances of the sun and moon from the earth. It has been shown by the higher analysis that *the tide-producing power of either of these bodies varies inversely as the cube of its distance from the earth.*

By means of this principle, we can show that the heights of the lunar tides corresponding to the moon's *greatest, mean,* and *least distances,* are to each other as the numbers 85, 100, and 117. On the scale adopted, the heights of the corresponding lunar tides are represented by the numbers 1.91, 2.25, and 2.63. It may also be shown that the heights of the solar tides corresponding to the sun's *greatest, mean,* and *least distances,* are proportional to the numbers 95, 100, and 105. On the scale adopted, the heights of the corresponding solar tides are represented by the numbers .95, 1, and 1.05.

The highest possible spring tide will occur when the moon is in perigee and the earth in perihelion ; on the scale adopted it will therefore be denoted by the number 3.68. The lowest possible neap tide will happen when the moon is in apogee and the earth in perihelion ; it will be represented by the number .86. These results indicate the greatest possible range of the tides measured at open sea.

The tides that occur when the moon is in perigee are called **perigean** tides, and those that occur when the moon is in apogee are called **apogean** tides. If we consider the sun at his mean distance, the greatest *apogean* will be to the greatest *perigean* tide as 291 is to 363.

The Diurnal Inequality.

157. We have seen that the combined action of the sun and moon gives rise to a single upper and to a single lower tide; we have also seen that the vertices of these tides tend to conform to the position of the moon rather than to that of the sun; consequently the vertex of the upper tide is generally on the same side of the equator as the moon and that of the lower one is on the opposite side, or what is the same thing, the vertices of the two tides cross the meridian of any place at unequal distances from that place. But the height of the tide at any place depends upon the distance of the place from the apex of the corresponding tide-wave; hence, there is a difference between the heights of the upper and lower tides at any place, which difference is called the **diurnal inequality.**

The diurnal inequality is dependent principally on the declination of the moon, but somewhat also on the sun's declination; it is greatest when both the sun and the moon are farthest north or farthest south, and it totally disappears when both are in the plane of the equator.

On the eastern coast of the United States, where the tides arrive by a circuitous route, the diurnal inequality is so modified as to be quite inconspicuous; but on the western coast, where the tides are received more directly, it is a marked feature of the alternating tides. Thus, in the port of San Francisco, when the moon has its greatest declination, the range of the higher tide is nearly 7 feet, and the range of the lower one varies from 1½ to 3 feet; on the Atlantic Coast the greatest value of the diurnal inequality is less than 1 foot.

Priming and Lagging of the Tides.

158. The combined action of the sun and moon tends at each instant to produce a tide-wave whose vertex, as seen from the centre of the earth, lies between the two bodies and nearer the latter. The interval between two successive passages of this wave over the meridian of any place, which is the same as the interval between two successive upper tides at that place, is called a **tidal day.** In the course of each synodic revolution the *average* length of a *tidal day* is the same as that of a *lunar day;* but on account of the varying angular distance of the moon from the sun, the position of the tidal wave with respect to these bodies is continually changing, and consequently the actual lengths of different tidal days are unequal.

At the time of the moon's conjunction with the sun the vertex of the tide-wave is supposed to be directly under the moon. Setting out from this time, the tide-wave continually falls behind, that is, to the westward of the moon, until the end of the first quarter, when the total retardation becomes a maximum ; during this interval the average length of the tidal day is less than that of a lunar day. At the beginning of the second quarter the tidal-wave begins to gain on the moon, and continues to gain until the end of the second quarter, at which time the upper tide of the moon will coincide with the lower tide of the sun : during this period the average length of the tidal day is somewhat greater than a lunar day.

Setting out again from the time of full moon, and remembering that we are now comparing the position of the upper lunar with the lower solar tide, we find as before that the average tidal day during the third quarter is *shorter,* and during the fourth quarter *longer* than a lunar day. Hence, during the first and third quarters the time of high water is *accelerated,* and during the second and fourth quarters it is retarded: the acceleration is called **priming,** and the retardation is called **lagging.**

As an illustration we may state that the average time of high water at Montauk Point, L. I., is 8h. 20m. after the transit of the moon; but in consequence of *priming* it may happen as early as 7h. 50m. after the time of transit, or in consequence of *lagging* it may not occur till 8h. 50m. after the time of transit, or the time of *southing of the moon,* as it is called in the almanacs.

Establishment of a Port.

159. The mean interval between the moon's transit across the meridian and the time of the following high water at any port, taken on the days of new and full moon, is called the **establishment of the port.** This is the *common establishment,* and is given in books on navigation and laid down on charts. The average of all the intervals between the times of transit of the moon and the following times of high water, during a month, is known as the **mean** or **corrected establishment.** It is this *establishment* which is given in the Coast Survey reports, and laid down on the Coast Survey charts.

When we know the establishment of a port and the range of priming and lagging, we can form a pretty close estimate of the time of high water at that port. The time of the moon's transit can be found with sufficient accuracy from a common almanac.

We subjoin a short table compiled from a Coast Survey report. In the *first* column is the name of the port; in the second column is *the establishment;* in the third, is the *extreme range* of the variation from the establishment; in the fourth, the *mean height* of high above low water; in the fifth, is the *height of spring tides;* and in the sixth, is the *height of neap tides.*

TABLE.

1.	2.	3.	4.	5.	6.
Eastport, Me.........	11h. 8m.	51m.	18.1ft.	20.6ft.	15.4ft.
Portsmouth, N. H.....	11h. 23m.	53m.	8.6ft.	9.9ft.	7.2ft.
Boston, Mass.........	11h. 27m.	43m.	10.0ft.	11.3ft.	8.5ft.
Sandy Hook, N. Y....	7h. 29m.	47m.	4.8ft.	5.6ft.	4.0ft.
New York City.......	8h. 13m.	43m.	4.3ft.	5.4ft.	3.4ft.
Philadelphia, Pa......	1h. 18m.	44m.	6.0ft.	6.8ft.	5.1ft.
Charleston, S. C......	7h. 26m.	48m.	5.1ft.	6.0ft.	4.1ft.
Savannah, Ga.........	8h. 13m.	51m.	6.5ft.	7 6ft.	5.5ft.
San Diego, Cal.......	9h. 38m.	1h. 35m.	3.7ft.	5.0ft.	2.3ft.
San Francisco, Cal.....	1h. 14m.	1h. 15m.	4.8ft.	5.2ft.	4.1ft.

Modifications Due to the Form of a Coast.

160. The tides at different places along an extended coast are greatly modified by the conformation of the shore line and by the manner in which the wave strikes it.

When the crest of the advancing wave falls centrally upon a projecting cape, the two parts into which it is divided move along the sides of the cape, giving a comparatively small tide at the cape, and larger ones further on; thus, the Atlantic wave when it falls upon Cape Hatteras gives a tide of only 2 feet at the cape, whilst those which are produced both to the north and south of the cape are from 4 to 6 feet in height.

If the wave falls obliquely upon the cape, it is partially deflected so as to produce a smaller tide behind the cape; thus, the wave that moves up St. George's Channel in Great Britain is deflected by Carnsore Point in Ireland toward the opposite shore of Wales, where it produces large tides, while the tides on the eastern shore of Ireland are comparatively small.

When a bay or indentation of the coast presents a favorable opening to the tidal wave, the tide becomes higher and higher from the mouth to the head of the bay. Prof. Hilgard, in the Smithsonian report for 1874, says that this is due to the concentration of the wave by the approach of the shores and the gradual shoaling of the bottom. He illustrates the law by referring to the tides of the Atlantic coast of the United States which, in general outline, is made up of three large bays: the great *southern*, from Cape Florida to Cape Hatteras; the great *middle*, from Cape Hatteras to Nantucket; and the great *eastern*, from Nantucket to Cape Sable.

The Atlantic tide-wave arrives at about the same time at Cape Florida, Cape Hatteras, Nantucket, and Cape Sable, and at those points its height is inconsiderable compared with the rise at the heads of the several bays. At Cape

Florida the mean rise and fall is only 1¼ ft., and at Cape Hatteras only 2 ft., while at Savannah it reaches 7 ft. Again, at the head of the middle bay in New York harbor it reaches 5 ft., while at Nantucket it is but little greater than 1 ft.

The configuration of the eastern bay is less regular, and the correspondence of heights is not so obvious. The recess of Massachusetts Bay is well marked, and the tides reach the height of 10 ft. at Boston and Plymouth. Rolling eastward along the coast of Maine, the tide continually increases; but the most striking effect of converging shores is exhibited in the bay of Fundy. At Eastport and St. John's the mean height of the tide is 19 ft., but at Sackville, in Cumberland basin, it is 36 ft., attaining to 50 ft. or more at spring tides.

In a similar manner we can explain the high tides at the head of Panama Bay in Central America, and in Bristol Channel in England.

Effect of Depth on the Velocity and Height of Tide-Wave.

161. We have seen that the great tide-wave moves over more than 70° of latitude in about 12 hours in its advance along the deep channel of the Atlantic Ocean. As it approaches the coast its velocity is rapidly diminished, and when it enters our harbors and rivers, where the water is shoal, it is reduced to 20 or 30 miles an hour, and sometimes to even less.

The average velocity of the tide-wave flowing through Long Island Sound is but little more than 35 miles an hour; in advancing from Sandy Hook to New York City it is only about 20 miles an hour; and in moving from New York, up the Hudson River to Albany, it is not far from 16 miles an hour. In all of these cases the height of the tide tends to increase as the depth of water diminishes and the sides of the channel converge; this tendency, however, is subject to the counteracting effect of friction and obstructions of various kinds.

The effects of these changes of height and velocity are strikingly manifested in the tidal system of New York and its vicinity. The great Atlantic wave enters New York harbor at Sandy Hook about the same time that it enters the east end of Long Island Sound, and the two partial waves advance to meet each other in the neighborhood of Fort Schuyler. The wave that enters by Sandy Hook advances at first with a velocity of 20 miles an hour and with comparatively little variation in height; on entering the East River its velocity is rapidly reduced to about 7 miles an hour, and in consequence of the tortuosity of the channel its height is diminished rather than increased.

The wave that enters the east end of the sound is at first less than 2 feet in height, but as it travels westward this height increases, being 6 feet at New Haven, and rising to over 7 feet when it reaches Throg's Neck. In consequence of the greater height of tide thus produced by the wave coming through the sound, a portion of the *flood* passes through the narrow channel below the place of meeting, giving rise to numerous irregular currents, and finally leaves New York harbor with the ebb, thus contributing to the *scouring* effect of the outgoing tide, and aiding to keep up the depth of channel necessary for the purposes of navigation.

The tides of the North, or Hudson, River average about 3½ feet in height at Tarrytown, are less than 3 feet at West Point, and rise to 4 feet at Tivoli, from which place they diminish in altitude to Albany, where they are a little over 2½ feet. The rate at which the tide-wave ascends the river is not far from the speed of the North River steamboats; hence, if a boat leaves New York at high water it has the benefit of the tidal current all the way to Albany.

In many cases where the mouth of a river is at the head of a bay, and the waters are shoal in its vicinity, the in-coming wave is thrown into the form of a *head* or *wall of water* that has been named a **bore**, which ascends the river with great impetuosity. The tidal bore at Tsien-tang is said to extend across the river, and to be 30 feet high; the tidal bore of the Hooghly, one of the mouths of the Ganges, is from 20 to 25 feet high; and at the mouth of the Amazon it is 12 or 13 feet high.

Tides of Inland Seas.

162. In consequence of the narrowness of the entrance channels to the Mediterranean and the Baltic seas, their tides are very small. In the Mediterranean the average height of the tides is no more than 1½ feet, although in some places they reach an altitude of 3 feet.

In inland lakes the tides are so insignificant that they are almost entirely masked by other and greater irregularities. A few years ago Gen. Graham made a long series of observations on Lake Michigan, from which he inferred that the height of the tides on that body of water was less than 2 inches. Hence, we may conclude that inland seas like the Caspian and the large lakes like those on our northern border are practically tideless.

IX. OF CALENDARS.

Definitions.

163. A **calendar** is a register of *epochs* and *periods of time* arranged to meet the wants of civilized life.

When arranged with reference to the needs of civil life it is a **civil calendar**; when arranged to meet the demands of the church it is an **ecclesiastical calendar.**

Natural and Artificial Units of Time.

164. The natural units of time are the **solar day,** the **lunar month,** and the **tropical year.**

The *mean solar day* is the average length of all the solar days in a year; the *mean lunar month* is equal to 29.53058 mean solar days; and the *mean tropical year* is equal to 365.2422 mean solar days.

It will be seen that the lengths of natural months and the natural year are incommensurable with the day, which is the fundamental unit of time; for this reason, the calendars now in use are constructed by combining *artificial months and years* as explained below.

In the civil calendar each year is made up of 12 artificial months, called **calendar months**; a calendar month may contain 28, 29, 30, or 31 days.

The calendar years are of two kinds: **common years,** containing 365 days, and **bissextile** or **leap years,** containing 366 days; these are so distributed that after a long period of time the average length of the calendar year shall be very nearly equal to that of the mean tropical year.

In the ecclesiastical calendar the months employed are of two kinds: **solid months,** which contain 30 days each, and **hollow months**, which contain 29 days each; these are so distributed that after a long period of time their average length shall be very nearly equal to a mean lunar month.

The **week**, though not an astronomical period, corresponds roughly to a quarter of a lunar month; it is used both in the civil and in the ecclesiastical calendar.

The *order* of arrangement of the Latin names of days is suggested by the following geometrical construction.

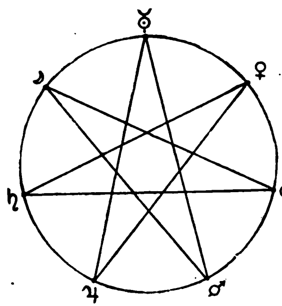

Fig. 87. Order of the Days of the Week.

EXPLANATION. The circumference of a circle is divided into 7 equal parts, and at each point the sign of a planet is placed, the order of succession being the same as the order of their assumed distances from the earth regarded as the central body. The points are then joined by lines as shown in the diagram, thus forming a regular 7-pointed star polygon. Starting now from any planet, say the Sun, and following the directions indicated by the arrows, we come in succession to the Moon, Mars, Mercury, Jupiter, Venus, Saturn, and thence back to the sun. This order is the same as the order of the days of the Roman week.

The week, as a cycle of time, appears to have been introduced among the Romans during the reign of the emperors. The names which the Romans gave to the days of the week were derived from those of the seven bodies, which at that time were called *planets*, viz.: the Sun, the Moon, Mercury, Venus, Mars, Jupiter, and Saturn. These names, in being transmitted to us, were modified by our Saxon ancestors, who substituted Woden for Mercury, Friga for Venus, Tuisco for Mars, and Thor for Jupiter. The original names and their modifications are shown in the following

TABLE.

Latin names.	*Modified names.*	*Present names.*
Dies Solis	Sun's Daeg	Sunday
Dies Lunæ	Moon's Daeg	Monday
Dies Martis	Tuisco's Daeg	Tuesday
Dies Mercurii	Woden's Daeg	Wednesday
Dies Jovis	Thor's Daeg	Thursday
Dies Veneris	Friga's Daeg	Friday
Dies Saturni	Saturn's Daeg	Saturday.

Origin of the Civil Calendar.

165. Our civil calendar is based on that of the ancient Romans. It is said that Romulus instituted a cycle of 304 days, divided into 10 months, which were called *Martius, Aprilis, Maius, Junius, Quintilis, Sextilis, September, October, November,* and *December.*

His successor, Numa Pompilius, added two months, called *Januarius* and *Februarius,* the former of which he placed at the beginning and the latter at the end of the Romulian cycle. He arranged the lengths of the months so that the twelve should contain 355 days, which differs but 1 day from 12 lunar months. To adjust this to the tropical year, which is the cycle of the seasons, he directed that every second year should be increased by an additional month, called *Mercedonius.* This added month contained alternately 22 and 23 days, and was intercalated between the 23d and 24th of February, the former being the day set apart for the feast of *Terminalia.* The *luni-solar* year thus established was, on the average, about 1 day longer than the tropical year, a fact which soon led to a modification of the rule for intercalation, and ultimately to much irregularity in the calendar.

Under the Decemviri the month of January was taken from the beginning of the year and placed between the months of December and February. The order of the months and the number of days in each then stood as follows: Martius, 31; Aprilis, 29; Maius, 31; Junius, 29; Quintilis, 31; Sextilis, 29; September, 29; October, 31; November, 29; December, 29; Januarius, 29; and Februarius, 28. The rule for intercalation at this time is somewhat uncertain, though Scaliger, in speaking of the old Roman luni-solar calendar, says that "the principle was to intercalate a month alternately of 22 and 23 days every other year during periods of 22 years, *passing over the last biennium*, so that in each period 10 such intercalary months were inserted." According to this rule the average year would approximate pretty closely to the year of the seasons; but the rule was misapplied, and the calendar soon fell into great confusion.

The Julian Reform.

166. Acting on the advice of Sosigenes, an Alexandrian astronomer, Julius Cæsar, made a radical reform in the calendar. He abolished the old lunar calendar, with its *intercalary* months, and substituted therefor a purely solar calendar. He changed the order of the months so as to make the year begin when the earth was in perihelion; this was done by causing the year 45 B. C., which at that time began a little before the middle of October, to end on the last day of the second following December. This year, which was thus made to contain 445 days, is known by chronologists as the *year of confusion*. He assumed the length of the solar year to be 365¼ days, and in order to take account of the fractional part of a day, he directed that the first three years of each quadrennium should contain 365 days, but that the fourth year should contain 366 days. The additional day in every fourth year was intercalated in the place occupied by the old month Mercedonius, that is, between the 23d and the 24th of February.

He readjusted the lengths of the months, the name of the old month Quintilis being changed to Julius in honor of the reformation. The names of the months and the number of days in each then stood as follows: Januarius, 31 ; Februarius, 29 ; Martius, 31 ; Aprilis, 30 ; Maius, 31 ; Junius, 30 ; Julius, 31 ; Sextilis, 30 ; September, 31 ; October, 30 ; November, 31 ; and December, 30.

The Augustan Correction.

167. In carrying out the orders of Julius Cæsar, the rule for intercalating the additional day was misunderstood, so that a day was actually added every third instead of every fourth year, until the year 9 B.C. inclusive. To correct this error, the Emperor Augustus directed that no further intercalation should be made till the sixteenth year following, which was the year 8 A.D. In honor of this correction an obsequious senate changed the name of the month Sextilis to Augustus, and in order that this month should be of the same length as the month Julius it was increased by one day taken from Februarius ; then, to prevent 3 long months from coming in succession, one day was transferred from September to October and one day from November to December. These changes having been made, the order of the months and their lengths was the same as we find them now, and the calendar, thus perfected, remained without further alteration for nearly 16 centuries.

According to the Roman method of counting the days of the month *backward* from the first day of the succeeding month, it happened that the 23d of February in every common year was called *sexto calendas Martias ;* the intercalated day in the fourth year of each quadrennium was called *bis sexto calendas Martias ;* hence, the fourth year of the quadrennium came to be called a **bissextile year.**

A common year contains one day more than 52 weeks ; consequently the years that follow common years begin one day later in the week. The years that follow bissextile years begin two days later in the week, that is, they skip or leap over one day; hence, bissextile years are frequently called **leap years.**

The Gregorian Reformation.

168. The average Julian year being .0078 *of a day* longer than the tropical year, the Julian date of the vernal equinox must fall back by that amount annually, in the same way that a clock which runs too slow falls behind one that keeps accurate time. At the time of the Julian Reformation, the date of the vernal equinox was March 24th, but at the time of the Council of Nice, 325 A. D., it had fallen back to March 21st. Now it was this council that fixed the time of Easter by declaring that it should be celebrated on the first Sunday following the full moon that happened on, or next after, the vernal equinox.

At the time of Pope Gregory XIII., the date of the vernal equinox had fallen back to March 11th, and a corresponding change had taken place in the date of Easter. To remedy this defect in the calendar, Gregory proposed a change which was adopted by the ecclesiastical council that assembled in 1582. To restore the date of the equinox to what it was in the year 325, *ten* days were added to the Julian count, and to prevent a recurrence of the difficulty, it was agreed to omit the intercalary day in each subsequent centesimal year, whose number is not divisible by 400. According to this scheme the rule for determining the length of a year may be written as follows: ***every year whose number is not divisible by 4 and every centesimal year whose number is not divisible by 400 is a common year of 365 days; all other years are leap years of 366 days.***

The calendar thus revised was adopted at once in the principal Catholic countries, but more slowly in other countries. It was not adopted in Great Britain till 1752, at which time, because of the omission of the intercalary day in 1700, the difference between the Julian and the

Gregorian count had become 11 days. At the same time the beginning of the year was changed from the 25th of March to the 1st of January. Parliament enacted that the year 1752, which began on the 25th of March, should end on the 31st of December, and also that the day following September 2, 1752, should be called the 14th of September.

These changes gave rise to two methods of writing dates: the **old style** (O. S.) and the **new style** (N. S.), the former being the Julian and the latter the Gregorian date.

As an illustration of the effect of the change of *style*, we may instance the case of Washington. He was born February 11, 1732, before the change of style. Inasmuch as 1752 began on the 25th of March and ended on the 31st of December, he had no birth-day in that year; hence, he was 20 years old on the 22d of February, 1753, new style. Because anniversaries are always determined according to the civil calendar, the birth-day of Washington is properly celebrated on the 22d of February, and not on the 23d, as some have contended, on account of the day dropped in the year 1800.

Notes on the Civil Calendar.

169. The years as named in the civil calendar are years *current*. There is no such thing as a 0 year. In order, therefore, that the years *before* and *after* the beginning of the Christian era may be reckoned in a continuous series, the numbers denoting years B. C. must be diminished by 1: thus, the year 45 B. C. is the same as —44 A. D.

From this principle it follows also that a century does not end till the end of the centesimal year. Thus, the 18th century did not end till December 31, 1800.

The difference between the old and new style is now equal to 12 days, in consequence of the omission of an intercalary day in the year 1800. This is the difference between our own dates and those of Russia, which still adheres to the Julian calendar.

With the corrections already noted, the civil calendar will not depart from the astronomical reckoning by so much as one day before the year 5,000 A. D.

The Ecclesiastical Calendar.

170. The ecclesiastical calendar as it now exists was formed by bringing a system of artificial periods, called **calendar lunar months**, into harmony with the Gregorian Calendar. Its most important use is the determination of the dates of the movable fasts and festivals of the church. This determination depends, so far as we are concerned, upon the English law, which says, ". . . . Easter Day, on which the rest depend, is always the first Sunday after the full moon that happens upon or next after the 21st day of March. . . . ." The full moon referred to has always been understood to mean the 14th day of the calendar lunar month.

The Lunar Cycle, Golden Number, and Epact.

171. The **lunar cycle** is a period of 19 Gregorian years, which coincides very closely with 235 mean lunar months. It begins with the year in which the new moon of the calendar lunar month falls on the 1st of January, and the number of any year of the cycle is called the **golden number** of that year. The present cycle commenced with 1881, so that the golden number of 1883 is 3, that of 1884 is 4, and so on.

A lunar cycle is divided into calendar lunar months as follows: the *first* month of any year is a **solid month** of 30 days; the *second* is a **hollow month** of 29 days, unless it includes the 29th of February, in which case it is a solid month; the *third* is solid; the *fourth* is hollow, and so on alternately to the end of the year. The residual days at the end of each calendar year are carried forward to form a part of the first month of the following year, until by accumulation they amount to 30 or more, in which case an **embolismic month** of 30 days is formed, and the remaining days are carried forward as before, and so on to the end of the cycle, which closes with a hollow month of 29 days.

The number of days carried forward to any year is the **epact** of that year. Hence, the epact of a year is the age of the calendar moon at the end of the preceding year. The epact for 1881, the first year of the present cycle, is 0; for 1882 it is 11; for 1883 it is 22; for 1884 it is 33 — 30, or 3, and so on to the last year of the cycle, for which it is 18. From what precedes, it is evident that the epact for any year may be found by the following

RULE.

Diminish its golden number by 1; multiply the remainder by 11; and divide the product by 30; the remainder will be the epact required.

Because the epact is also the age of the calendar moon at the end of February, we can easily deduce the time of the full moon that precedes Easter. Thus, for 1883 the epact is 22; subtracting this from 30, we have the day that the March moon ends; increasing the remainder, which is 8, by 14, we have the time of the following full moon, which is March 22d.

Correction of the Epact.

172. When long periods of time are taken into account it is found that the average length of the calendar lunar month is a little less than that of a mean lunar month. This difference amounts by accumulation to 1 day in about 300 years. To take account of this error and to bring the calendar moon into harmony with the actual moon of the heavens, it has been agreed to augment the length of one of the calendar lunar months by 1 day in every period of 300 years. This is done by diminishing the epact by 1 at every 300th year. This correction was made in 1800, and will be repeated in the years 2100, 2400, etc.

The Dominical Letter and the Solar Cycle.

173. The days of the year were formerly designated by letters, A being written opposite the first, B opposite the second, and so on to G, which stood opposite the seventh day, after which the same letters and in the same order were continually repeated to the end of the year, always skipping over the 29th of February. The letter opposite Sunday in any year was called the **Dominical or Sunday letter** of that year. In common years there is but *one* Sunday letter, but in leap years there are *two*, one before the 29th of February and the other after; as the latter is most used in practice, it is taken for the Dominical letter of the year, the former being neglected.

It is easily seen that the Sunday letter falls back *one* place every common year and two places every leap year; thus, the Dominical letter for 1881 is B; for 1882 it is A ; for 1883 it is G ; and for 1884 it is E.

In a regular quadriennium of 4 Julian years the Sunday letter falls back 5 places, and in 7 such periods it falls back 35 places, or 5 entire cycles, after which the days of the week recur on the same days of the year as in the preceding cycle. This period of 28 years is called the **solar cycle.**

The preceding principles enable us to compute the number of the Dominical letter for any year, but for practical purposes it is found more convenient to use Table I., from which we can take out the Sunday letter for any year from 1600 A.D. up to 2400 A.D.

A simple inspection of the table is sufficient to suggest the method of its formation.

TABLE I.

Years in Excess of Centuries.					Centuries.				Years in Excess of Centuries.			
					2000 1600	2100 1700	2200 1800	2300 1900				
0	..	23	34	45	A	C	E	G	56	..	79	90
1	12	..	35	46	G	B	D	F	57	68	..	91
2	13	24	..	47	F	A	C	E	58	69	80	..
3	14	25	36	..	E	G	B	D	59	70	81	92
..	15	26	37	48	D	F	A	C	..	71	82	93
4	..	27	38	49	C	E	G	B	60	..	83	94
5	16	..	39	50	B	D	F	A	61	72	..	95
6	17	28	..	51	A	C	E	G	62	73	84	..
7	18	29	40	..	G	B	D	F	63	74	85	96
..	19	30	41	52	F	A	C	E	..	75	86	97
8	..	31	42	53	E	G	B	D	64	..	87	98
9	20	..	43	54	D	F	A	C	65	76	..	99
10	21	32	..	55	C	E	G	B	66	77	88	..
11	22	33	44	..	B	D	F	A	67	78	89	..

Explanation. The table indicates the Dominical letter for every Gregorian year from 1600 A.D. up to 2400. To use it, we find the exact century of the year at the top of one of the four middle columns, and the excess over exact centuries in one of the columns on the right or left; the required Dominical letter will be found in the same column as the former and in the same line as the latter.

Examples. Let it be required to find the Dominical letters for the years 1799, 1800, and 1804. In the column headed 1700, and on the same line as 99, we find F; hence, F is the Dominical letter for 1799; in like manner we find that the Dominical letter for 1800 is E, and that for 1804 is G. The year 1804 being a leap year, the Dominical letter given in the table is the one that follows February 29th; for the time preceding that date the Dominical letter is A.

When we know the Sunday letter for any year, we can easily find the day of the week corresponding to the 1st of January, from which we can, by a simple computation, find the day of the week corresponding to any day of the year. This operation is more conveniently performed by means of Table II., from which we can at once take out the day of the week corresponding to the 1st, 8th, 15th, 22d, and 29th days of any month.

TABLE II.

Common Years.	Dominical Letters.							Leap Years.
	A	B	C	D	E	F	G	
Jan., Oct........	S	Sat.	Fr.	Th.	Wed.	Tu.	Mon.	October.
May.............	Mon.	S.	Sat.	Fr.	Th.	Wed.	Tu.	May.
August..........	Tu.	Mon.	S.	Sat.	Fr.	Th.	Wed	Feb, Aug.
Feb., Mar., Nov.	Wed.	Tu.	Mon.	S.	Sat.	Fr.	Th.	Mar., Nov.
June............	Th.	Wed.	Tu.	Mon.	S.	Sat.	Fr.	June.
Sept., Dec......	Fr.	Th.	Wed.	Tu.	Mon.	S.	Sat.	Sept., Dec.
April, July......	Sat.	Fr.	Th.	Wed.	Tu.	Mon.	S.	Jan., Apr., July.

EXPLANATION. To use Table II., find the month in the left-hand column for common years, and in the right-hand column for leap years; then in the same line and under the Dominical letter for the year will be found the day of the week corresponding to the 1st, 8th, 15th, 22d, and 29th days of that month.

EXAMPLES. 1°. The battle of Bunker Hill was fought June 17th, 1775: on what day of the week did it occur?

SOLUTION. From Table I. we see that the Dominical letter for 1775 was A; from Table II., under the letter A and opposite June, we find Th.; hence, the 15th of June was Thursday, and consequently the 17th was *Saturday*.

2°. On what day of the month was Easter in the year 1883?

SOLUTION. We have already seen that the calendar full moon of March fell on the 22d. By means of Tables I. and II. we find that the 22d of March fell on Thursday; hence, the following Sunday, which was Easter, came on the 25th.

Chronological Cycles.

174. Besides the solar cycle of 28 years and the lunar cycle of 19 years, both of which are astronomical, the Romans made use of a civil cycle of 15 years called the **Cycle of Indiction.** This cycle was used in the courts of law, and in the fiscal administration of the empire, and its use was thus introduced into legal dates.

Different nations have reckoned time from different epochs, and sometimes in different units; but for the convenience of astronomers and chronologists it has been found desirable to have a common epoch from which time is to be reckoned in terms of the same unit. For this reason it has been agreed to form a grand cycle of 7,980 Julian years based upon the three cycles already mentioned.

This cycle, which is called the **Julian Period**, commences with the beginning of the year 4713 B. C., which epoch is also the beginning of a solar cycle, of a lunar cycle, and of a Cycle of Indiction. Because 7980 is the least common multiple of 28, 19, and 15, it is obvious that the first years of all three of these cycles cannot again concur till the beginning of the year 3268 A. D., which will be the first year of the next Julian Period. To find the year of the Julian Period corresponding to any calendar year, we have only to add the number of the calendar year to 4713: thus, the calendar year 1884 A. D. is the 6597th year of the Julian Period. When this style of reckoning is used for determining specific dates, these dates must first be reduced to the Julian, or old style.

If we know the year of the Julian Period, it is obvious that we can find the corresponding years of the subordinate cycles by the following simple rules:

1°. To find the year of the solar cycle: divide the year of the Julian Period by 28; if the remainder is not 0 it will denote the year of the solar cycle, or if it is 0 the given year will be the 28th year of the solar cycle.

2°. To find the year of the lunar cycle: divide the year of the Julian Period by 19; if the remainder *is not 0 it will denote the year of the lunar cycle, or if it is 0, the given year will be the 19th year of the lunar cycle.*

3°. To find the year of the cycle of indiction: divide the year of the Julian Period by 15; if the remainder is not 0 it will denote the year of the indiction cycle, or if it is 0, the given year will be the 15th of the cycle of indiction.

The year 1884 A.D. is the 6597th year of the Julian Period. Dividing 6597 in succession by 28, 19, and 15, we find the respective remainders 17, 4, and 12; hence, 1884 is the 17th year of the solar cycle, the 4th year of the lunar cycle, and the 12th year of the cycle of indiction; these numbers are generally given in the almanacs.

It is to be observed that the lunar cycle above referred to, is supposed to be exactly equal to 19 Julian years; it is therefore an artificial cycle. Hence, the above rule for finding the year of the lunar cycle will require a correction for ecclesiastical purposes as explained in Art. 172.

The **Dionysian Period** is a period formed by a combination of the lunar and the solar cycles; its length is equal to 28 × 19, or 532 years. This period marks the recurrence of new moon on the same day of the week and the same day of the month throughout the year. It is used by chronologists in verifying dates.

To find the year of the Dionysian Period corresponding to any calendar year, we first find the year of the Julian Period, and then divide its number by 532; the remainder, if not 0, will denote the year of the Dionysian Period, or if the remainder is 0 the year is the 532d of the Dionysian Period.

Thus, 1884 is the 6597th year of the Julian Period: dividing 6597 by 532 we find a remainder equal to 213.

Hence, the year 1884 is the 213th year of the current Dionysian Period. In the example just given the quotient found was 12; hence, 12 entire periods have elapsed, and we are now in the 13th Dionysian Cycle of the current Julian Period.

By applying the preceding rules we find that the first year of the Christian era was the 10th year of the 169th solar cycle, the 2d year of the 249th lunar cycle, the 4th year of the 315th indiction cycle, and the 458th year of the 9th Dionysian cycle of the current Julian Period.

X. PLANETS AND SATELLITES.

Preliminary.

175. The general relations of the planets with respect to each other and with respect to the sun have been explained in preceding parts of this work. It is now proposed to point out some of their individual peculiarities and also to give an account of their satellites and other appendages. This branch of the subject will treat more particularly of the forms and magnitudes of the planets, of their times of rotation, of their telescopic appearances, and of their physical conditions; it will also contain an explanation of their satellite systems, and of the ring system of Saturn. The data employed will be those laid down in Tables I., II., III., Arts. 46, 47, and 51, which are only approximate; it is therefore to be borne in mind that they are subject to correction for reasons similar to that given in the note to Table I.

MERCURY. ☿.

Magnitude, Distance, and Periodic Time.

176. Mercury is the smallest of the *eight* principal planets, and is also the nearest to the sun. Its diameter is 2,990 miles, which is but little more than $\frac{3}{8}$ of the earth's mean diameter; his surface is therefore about $\frac{1}{7}$ of the earth's surface, and his volume about $\frac{1}{19}$ of the earth's volume.

Mercury revolves around the sun in a little less than 88 days, its mean distance from that body being about $35\frac{3}{4}$ millions of miles. In consequence of the great excentricity of his orbit, he alternately approaches the sun to within 28¼ millions of miles, and recedes from it to a distance of 43 millions of miles.

Synodic Period, Elongation, and Visibility.

177. His synodic period, counted from inferior conjunction to inferior conjunction, is a trifle less than 116 days. At the beginning of this period he is at the middle of his arc of retrogradation, which on an average amounts to about 12½°. The time occupied in passing over this arc is about 22 days; during the remainder of the period his motion is direct; hence, the planet advances for about 94 days, and then retrogrades for about 22 days, and so on alternately. Once during each synodic period he is at his greatest *eastern* and once at his greatest *western* elongation.

In consequence of the planet's proximity to the sun, he is only visible to the naked eye for a few days at the time of his greatest elongation; it is seen after sunset at the time of *eastern* and before sunrise at the time of *western* elongation; these times will be more or less favorable for observation, according to the amount of the elongation and the obliquity of the planet's orbit to the horizon.

Inasmuch as the inclination of the planet's orbit to the ecliptic is only about 7°, its inclination to the western horizon at sunset will be greatest in the spring of the year, and its inclination to the eastern horizon at sunrise will be greatest in the fall of the year. The greatest elongation will have different values at different times, being dependent on the distances both of the earth and of Mercury from the sun, as may be seen from Fig. 88; it may have any value from 17¾° to 28°. The former value corresponds to the least distance of Mercury and the greatest distance of the earth from the sun, and the latter to the greatest distance of Mercury and the least distance of the earth from the sun.

EXPLANATION. ACM represents the orbit of Mercury, S the sun, E the earth, and M the place of Mercury when the line EM is tangent to the orbit. SEM is then the greatest elongation, and if we suppose SM to be perpendicular to EM, we shall have

$$\sin SEM = \frac{SM}{SE}.$$

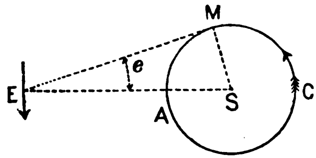

Fig. 88. Elongation of Mercury.

Making SM equal to 28½ millions of miles and SE equal to 94 millions of miles, we find the least value of SEM equal to 17° 40′; making SM equal to 43 millions of miles and SE equal to 91 millions of miles, we find SEM equal to 28° 12′.

When Mercury is visible to the naked eye it shines with a clear white light, appearing like a bright star of the first magnitude. Under favorable circumstances it is often visible in the latitude of New York for 6 or 8 days both before and after its greatest elongation.

Phases and Telescopic Appearance.

178. When viewed with a suitable telescope, Mercury is found to have phases like the moon, and which are accounted for in the same manner. The cycle of his phases is a synodic period; at the time of inferior conjunction his illuminated face is turned from the earth, and the planet is invisible unless it happens to pass exactly between the earth and the sun; when he emerges from the glare of the sun's rays so as to be seen with a telescope his phase is crescent; as he advances toward elongation the thickness of the crescent increases, and at his greatest elongation he has the same phase as the moon at *first quarter;* from this time to superior conjunction his phase is *gibbous;* at superior conjunction his illuminated hemisphere is turned directly toward us, but the planet is invisible, being enveloped and overpowered by the sun's rays. From superior conjunction back to inferior conjunction these phases are repeated, but in reverse order.

The telescope reveals no markings from which his time of rotation on an axis can be inferred with certainty, though

Schröter assigned a rotation period of 24h. 5m. The appearances on which this astronomer based his conclusion are now regarded as fallacious. The fact that the planet shows no markings has led some to suppose that he is surrounded by a dense mass of clouds or vapors. Observations at the times of transit indicate a pretty dense atmosphere.

Transits of Mercury.

179. The earth in his annual path crosses the line of nodes of the orbit of Mercury about the 7th of May and the 9th of November; if the planet happens to be at inferior conjunction within 2 or 3 days of either of these dates, he will probably be so near the ecliptic that he will pass *directly* between the earth and the sun, in which case he will be seen like a round black spot, moving from east to west across the solar disk; this phenomenon is called a **transit of Mercury**.

A cycle of 46 sidereal years differs from 191 sidereal periods of Mercury by less than one-third of a day; hence, if there is a transit very near either node at any time, corresponding transits will recur at that node every 46 years, for a pretty long period. During the 46-year cycle there are usually 6 transits, 4 of which *at present* occur at the ascending node in November, and 2 at the descending node in May. This cycle of transits is, like the eclipse cycle, only approximate; as in case of the Saros, new transits enter the cycle from time to time and old ones pass out.

The last transit of Mercury took place November 7, 1881; it was a recurrence of the transit of November 7, 1835. The next transit will be on May 9, 1891; this will be a recurrence of the transits of May 6, 1799 and May 8, 1845; after 1891 it will probably pass out of the cycle. The transit of November 10, 1894, will be a recurrence of the transits of November 9, 1802 and November 10, 1848.

The transits of Mercury are valued by astronomers principally on account of the opportunity they afford for verifying and correcting the tables of that planet. It was from a comparison of observations made on these transits that Leverrier reached the conclusion that the perihelion of Mercury's orbit is moving more rapidly than can be accounted for by the perturbations of known planets, and which led him to suggest the existence of a group of small planets lying between Mercury and the sun. The actual existence of these *intra-Mercurial* bodies has not, as yet, been established.

VENUS. ♀.

Magnitude, Periodic Time, and Distance.

180. Venus is the third of the principal planets in order of magnitude, counting from the smallest, and the second in order of distance from the sun. Her diameter is 7,660 miles, which is only 4 *per cent.* less than that of the earth ; we may say therefore that her volume is very nearly equal to that of the earth. She completes a sidereal revolution around the sun in a little less than 225 days, her mean distance from that body being 66¾ millions of miles. Her orbit is less excentric than that of any other principal planet, her least distance from the sun being about 66¼ millions of miles, and her greatest distance 67¼ millions of miles.

Synodic Period, Elongation, and Visibility.

181. The synodic period of Venus, counting from inferior conjunction to inferior conjunction, is nearly 584 days. At the beginning of this period she is at the middle of her arc of retrogradation, which is equal to nearly 16° ; the time occupied in traversing this arc is about 41 days ; during the remainder of the period her motion is direct ; hence, the planet advances 543 days and retrogrades 41 days in a complete synodic revolution. Once during each synodic period she is at her greatest eastern and once at her greatest western elongation.

Except for a few days at the times of her inferior and superior conjunction she is visible to the naked eye, half of the time on the east of the sun in the evening and half of the time on the west of the sun in the morning. In the former case it is called the **evening star**, and in the latter case the **morning star**; the ancients, thinking these to be different bodies, called the evening star **Hesperus** and the morning star **Lucifer.**

When Venus is far enough from the sun to be seen after twilight in the evening, or before twilight in the morning, she shines with a brilliant white light. At her maximum brilliancy she is the brightest of all the planets; at these times she can often be seen with the naked eye at midday, and at night her light is intense enough to form shadows of dark objects on a light ground. Her greatest elongations are more nearly equal than those of Mercury; the maximum value of her greatest elongation, found in the manner already described, is 47° 40′, and its minimum value is 44° 50′, the average being a little over 46°. She has the greatest brilliancy when her elongation is about 40°, just before reaching her greatest western, or just after passing her greatest eastern elongation; she reaches the former point about 2 months after, and the latter point about 2 months before she is at inferior conjunction.

Phases, and Distances from the Earth.

182. Venus passes through the same succession of phases as Mercury. In moving from inferior conjunction to the greatest western elongation her phase is *crescent;* at the greatest elongation it becomes *dichotomous;* after this it becomes *gibbous,* and it is only at superior conjunction that her illuminated face is turned fully toward the earth. In traveling back to inferior conjunction the same phases recur, but in reverse order. The cycle of her phases is a synodic period, but the duration of the crescent is much shorter than that of the gibbous phase; the time occupied in passing from inferior conjunction to the greatest western elongation is no more than 71 days, while she occupies a period of 221 days in moving from this place to superior conjunction.

The brilliancy of the planet depends upon her phase and also upon her distance from the earth, which varies very considerably. When at inferior conjunction her distance from the earth is only 25 or 26 millions of miles; at her greatest elongation this distance is about 66 millions of miles; and at superior conjunction it is nearly 160 millions of miles. As her apparent diameter varies inversely as her distance from the earth, it is more than 6 times as great when nearest the earth as it is when she is farthest removed. The relative sizes of her disk at different distances is shown in Fig. 89.

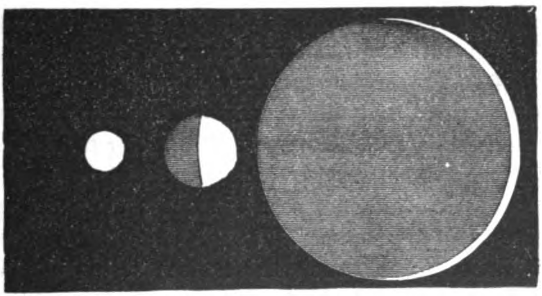

Fig. 89. Phases of Venus.

EXPLANATION. Fig. 89 represents three different phases of Venus. The figure on the right represents her apparent size and her phase just before or just after inferior conjunction; the figure on the left shows her apparent size and her phase at the time of her superior conjunction; the middle figure shows her apparent size and her phase when she is between her greatest elongation and her superior conjunction.

The combined effect of phase and distance gives the most brilliant surface, as was before stated, about 10 days before the planet reaches her greatest western and about the same time after she has passed her greatest eastern elongation.

Atmosphere. Telescopic Appearance.

183. Venus is undoubtedly surrounded by a dense atmosphere. Schröter noticed that the narrow crescent which the planet presented near the time of inferior conjunction extended considerably beyond its natural limit of 180°, a phenomenon which has since been witnessed by many other observers. At the time of inferior conjunction in 1866, Prof. Lyman, of Yale College, watched the planet from day to day until its nearest limb was only 1° 8′ from the sun. The slender crescent became more and more extended beyond 180°, until at favorable moments it was seen as a complete ring of light surrounding the dark body of the planet. This prolongation of the cusps can only be explained by supposing the solar rays to be refracted in passing through the atmosphere of Venus; the observations of Prof. Lyman indicate that the refraction of a horizontal ray is about 45′. From observations made at Dorpat in 1849, Mädler concluded that the refraction of a horizontal ray was nearly 44′, which is about one-third greater than that produced by the earth's atmosphere. Observations made upon Venus while in transit across the sun's disk are equally indicative of an atmosphere.

Prof. Newcomb, in giving an account of his observation on the last transit, before the Royal Astronomical Society, says: "There was but one physical phenomenon that was worthy of note, and that was so well marked that it could not escape any one; it was a line of light that surrounded the dark hemisphere of Venus which was off the sun. I looked very carefully before first contact to see whether it was possible to see Venus projected upon the corona, but was unable to see any sign of the planet until it had actually entered upon the sun's disk. When it was half way on, it appeared as if a piece of the sun had been sharply cut out with a knife; and the line of light which has been described by so many observers, and which I had looked for in vain before, began to show itself; but it was not continuous all around the planet; on the contrary, it was only seen at certain points. As the internal contact approached, I found that the line of light slowly became brighter, and for some seconds before internal contact it was quite continuous, and was seen as a fine arc of light joining the cusps of the sun."

Similar appearances were observed by many other astronomers who watched the transit. It has been suggested that the atmosphere is at places loaded with clouds. Mr. Huggins several years ago found certain lines in the spectrum of Venus, which are attributable to watery vapor in her atmosphere; Prof. Young says that the same thing was very clearly indicated during the recent transit.

When viewed with a telescope its light is so dazzling as to suggest the idea that the body of the planet is surrounded by white clouds, which reflect light far better than ordinary land and water. It is possible that this layer of clouds covers up and obscures the surface markings which some observers are said to have seen. It is probable, though not certain, that the planet revolves on an axis; Schröter assigned a period of 23¼ hours, but this determination is not universally accepted.

Transits of Venus.

184. The earth, in her annual revolution, crosses the line of nodes of the orbit of Venus about the 5th of June and the 7th of December; and when it happens, as it does at long intervals, that Venus is in inferior conjunction at either of these times, the planet will pass directly between the earth and the sun; this phenomenon is called a **transit of Venus.**

Because 243 sidereal years correspond to 395 sidereal periods of Venus within less than one-third of a day, it follows that a transit of Venus, which takes place very near either node, will recur at intervals of 243 years, and this for a long period. During this cycle of 243 years there are usually four transits, of which two happen at the ascending node in June, and two at the descending node in December. The two that occur at either node are separated by an interval of 8 years; from the last transit at one node to the first at the other is alternately 121½ and 105½ years.

The transit which took place on the 8th of December, 1874, was a recurrence of the transit of December 7, 1631; and that of December 6, 1882, was a recurrence of the transit of December 4, 1639. The transit of June 5, 1761, will recur on the 8th of June, 2004, and that of June 3, 1769, will recur on the 6th of June, 2012. These two transits will be the next that will happen till the year 2117. As already explained, the transits of Venus are utilized by astronomers to determine the solar parallax. The transit of 1874 was extensively observed, as was also that of 1882. The results of the numerous observations made in those years have not yet been fully discussed.

Comparison of Mercury and Venus.

185. The planets Mercury and Venus resemble each other in many respects. The apparent motions of both are very similar; both move back and forth with a shuttle-like motion in regard to the sun, which body they seem to follow in its general motion around the celestial sphere. Neither of them presents any decided marking, but the periods of rotation assigned to them by Schröter are very nearly equal. Both are supposed to be surrounded by layers of clouds floating in dense atmospheres. They resemble each other in their phases, in their arcs of retrogradation, and in their transits. Finally, they are the only planets that have no satellites.

MARS. ♂.

Magnitude, Periodic Time, and Distance.

186. Mars, the fourth of the principal planets in order of distance from the sun, is next to the smallest in order of magnitude, Mercury alone being smaller. Like the earth, its form is that of an oblate spheroid; its equatorial diameter is 4,220 miles, its polar diameter is 4,196 miles, and its mean diameter is 4,212 miles, the term *mean diameter* being used to denote the diameter of an equivalent sphere. Hence, its surface is considerably less than $\frac{1}{3}$ of the earth's surface, and its volume is not far from $\frac{1}{7}$ of the earth's volume.

He revolves around the sun in about 687 days, his mean distance from that body being 141 millions of miles. In consequence of the great excentricity of his orbit, he may approach to within 128 millions of miles of that body, and he may recede from it to a distance of 154 millions of miles.

When in opposition his average distance from the earth is about 48 millions of miles; but if opposition happens when the planet is near perihelion, this distance may become as small as 35 millions of miles; or if it occurs when the planet is near aphelion, this distance may become as great as 62 millions of miles.

The mean distance of the planet from the earth at the time of conjunction is about 233 millions of miles, but this distance may be as small as 220 and as great as 246 millions of miles. Hence, the extreme range of the planet's distance from the earth is from 35 to 246 millions of miles. This change of distance makes the variation of his apparent diameter very great, and consequently produces a corresponding variation in the brightness of the planet. When nearest the earth, the apparent diameter of the planet is more than 7 times as great as when it is farthest from the earth.

Synodic Period—Varying Brilliancy.

187. The average value of the synodic period of Mars, counting from opposition to opposition, is a trifle less than 780 days or nearly 26 months. Being a superior planet, it is at the middle of its arc of retrogradation at the time of opposition. The average value of this arc is about 15°, and the time required for the planet to move over it is about 70 days; hence, during each synodic period the planet retrogrades for 70 days, and its motion is direct for 710 days. The values above given are average values, and in consequence of the relative positions and shapes of the orbits of Mars and the earth, they will experience considerable variation at different periods.

The brilliancy of the planet is greatest when nearest to the earth, and least when farthest from the earth. When in opposition he is always more brilliant than any star of the first magnitude, and under favorable circumstances he is nearly as bright as Jupiter. When near conjunction his brilliancy diminishes to that of a star of the second magnitude. In all cases his light is of a decided red color, but his ruddy hue is most conspicuous when he is brightest.

The earth crosses the line from the sun to the perihelion point of the orbit of Mars on the 27th of August in each year; if the planet is in opposition at this time he will be at his least possible distance from the earth, and consequently in the most favorable position for observation. Of course this state of affairs can only occur at immensely long intervals; but it frequently happens that opposition takes place within a few days of the 27th of August, and oppositions of this kind are utilized by astronomers for determining the solar parallax, and for studying the physical character of the planet. The opposition of 1877 took place about 9 days after Mars had passed his perihelion, and was regarded as a remarkably favorable one by astronomers; a similar opposition took place in 1862, and another will occur in 1892.

Telescopic Appearances, Rotation, and Physical Condition.

188. Under the telescope, Mars is seen to be covered with large and irregular patches of a dusky red color which are supposed to be islands and continents; the remaining portions of his surface, which are of a faint greenish tint, are supposed to be seas and oceans. The outlines of these divisions are of a permanent character, but they are sometimes obscured for a time and then reappear, as if the planet were surrounded by an atmosphere more or less loaded with clouds. The existence of such an atmosphere is well established, and we learn from the spectroscope that it contains watery vapor, and probably clouds like our own.

From observations made on the spots it has been shown that Mars revolves on an axis in a period of 24h. 37m. 22.73s. The planet has then his *poles* and an *equator*; his equator is inclined to the plane of its orbit in an angle of about 27°; hence, the planet has seasons somewhat similar to our own, except in length. The **martial day** is, as we have seen, a little longer than the terrestrial day, but the inequalities of day and night are similar to those experienced at different places on our earth.

The **martial year** contains 668⅔ *martial days*, equal to nearly 687 terrestrial days; in consequence of the great excentricity of the planet's orbit, the lengths of his seasons are more unequal than on our earth, summer in the northern hemisphere being 372 martial days and winter only 297 days in length; this division of time refers to the periods that the sun is on the northern and on the southern side of the martial equator.

The telescope reveals the existence of two white spots, one at each pole; the northern spot is nearly concentric with the corresponding pole, but the southern one is excentrically situated with respect to its corresponding pole. It has been supposed that these spots are due to masses of ice and snow, a supposition which seems to be confirmed by their alternate decrease and increase according as the corresponding pole is turned toward or away from the sun.

It has been suggested by some observers that the objects described above as snow-spots are, at least in part, made up of clouds. Trouvelot, who has given a great deal of study to the subject, says "during the winter seasons of the southern hemisphere of Mars the polar spots are most of the time invisible, being covered over by white, opaque, cloud-like forms strongly reflecting light." In 1877 he "mistook for the polar spots a canopy of clouds which covered at least one-fifth of the surface of the whole disk." He says, "I only became aware of my error when the opaque cloud, beginning to dissolve at the approach of the martial summer, allowed the real polar spot to be seen through its vapors, as through a mist at first, and afterward with great distinctness."

The telescope shows that Mars has phases, but not like those of Mercury and Venus. At opposition and at conjunction his illuminated face is turned toward the earth; at intermediate periods he exhibits a gibbous phase corresponding to that of the moon two or three days before or after full moon.

The surface of Mars has been charted, but the charts are of little value except to the professional astronomer; the ordinary observer sees the outlines of oceans and continents only in perspective, and in consequence of the distortions produced in their apparent forms by the motions of the planet, he finds it almost impossible to recognize them at different times.

Comparison of the Earth and Mars.

189. We have already pointed out some analogies between Mercury and Venus, but the Earth and Mars are more strikingly alike. Both of these planets are surrounded by atmospheres containing clouds and watery vapor; their surfaces are alike diversified with continents and oceans; both have seasons which are only dissimilar in regard to length; both have days and nights of nearly equal lengths, and which have their corresponding inequalities; both have regions of snow and ice around their poles, which alternately increase and decrease with the cycle of the seasons; in a word, these two planets resemble each other more strongly than any other two in the system.

Satellites of Mars.

190. Mars has two satellites, both of which were discovered by Prof. Asaph Hall in August, 1877; the outer one was first seen on the 11th, and the inner one on the 17th of that month. Both are extremely minute bodies, probably not more than 6 or 8 miles in diameter, and both are very close to the surface of the planet. The planes of their orbits are very nearly coincident with the plane of the planet's equator.

The outer satellite, the one first discovered, and which has been named **Deimos**, revolves around Mars in about 30h. 17m.; the inner one, called Phobos, performs its revolution in 7h. 39m. The distance of the former from the centre of the planet is 14,350 miles, and that of the latter is no more than 5,830 miles.

The motions of the satellites as seen from Mars must present some curious phenomena; in explaining them it will be found convenient to use *martial time,* that is, to count time in *martial days,* each of which is equal to 1.025 times a terrestrial day. We readily find the periodic time of Deimos to be 1.231 days, or 29.55 *martial hours,* and that of Phobos to be .311 days, or 7.46 *martial hours.*

An observer on the equator of Mars is carried from west to east by the rotation of the planet at the rate of 360° in a day, but the outer satellite is carried eastward by its orbital revolution at the rate of only about 292½° in a day; hence, to the supposed observer on the planet this satellite appears to move westward at the rate of 67½° a day, at which rate it would appear to make the circuit of the heavens in about 5⅓ days. Deimos therefore appears to an observer on Mars to rise in the east and to set in the west, the interval between two consecutive culminations over the meridian being 5⅓ days.

Phobos moves eastward in its orbit at the rate of more than 1154° per day, thus gaining on the supposed observer at the rate of more than 794° per day; as a consequence, this satellite rises in the west and sets in the east, the interval between two successive transits over the same meridian being only .45 of a day, or 10.8 martial hours.

In consequence of the enormous horizontal parallaxes of the satellites, their diurnal circles are very unequally divided by the horizon; the upper arc in case of Deimos being 160°, and in case of Phobos less than 138°.

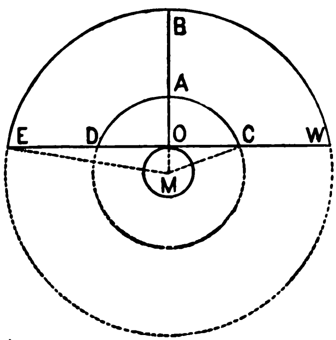

Fig. 90. Showing the Apparent Motions of the Satellites of Mars.

Explanation. The figure shows the equatorial section of Mars seen from the north side, and the orbits of the satellites supposed to be in the same plane. EW is the horizon of the observer, E being the east point and W the west point. The angle OEM is nearly 8½°, and OCM is nearly 21¼°; hence, the upper arc EBW is equal to 163°, and the arc CAD to 137½°. Deimos rises at E and sets at W, remaining above the horizon 2.418d., or 57h. 52m.; Phobos rises at C and sets at D, being above the horizon about 4h. 10m. Deimos remains below the horizon for 69 *hours*, and Phobos for 6h. 40m.

As the synodic periods of the satellites differ but little from their sidereal periods, Deimos will go through its entire cycle of phases in about 30 hours, and Phobos in less than 8 hours.

The fact that Phobos revolves from west to east at a more rapid rate than the planet itself, would seem to be an argument against the nebular hypothesis as it is usually enunciated. That hypothesis requires that a body shall move more slowly as its distance from the centre of motion becomes greater.

THE PLANETOIDS. ①.

General Description.

191. Proceeding outward from the sun, we next meet with a group of small planets called **Planetoids**, or sometimes **Asteroids**. The first of the group was discovered on the first day of the present century, namely on January 1, 1801, by Piazzi, a noted Italian astronomer; a second one was discovered in 1802, a third in 1804, and a fourth in 1807, after which no additional ones were found till 1845. Since that time new members have been rapidly added to the group, sometimes as many as 8 or 10 in a single year, until now (1883) their number amounts to more than 230.

The first four were named in the order of their discovery Ceres, Pallas, Juno, and Vesta; the remaining ones have also received proper names, but the difficulty of remembering them has led to the practice of numbering them, the numbers denoting the order of discovery; thus, the 226th planetoid discovered is denoted by the symbol (226).

Nearly all of the planetoids are *telescopic*, although Ceres and Vesta can be seen with the naked eye under favorable circumstances; in point of brilliancy they run from the 7th down to the 10th and 11th magnitudes, and some are even fainter; their actual magnitudes have not been determined, though we know that they are very small; some of the larger ones are thought to be from 300 to 400 miles in diameter, while some of the smaller ones are supposed to be no more than 30 or 40 miles in diameter.

Their orbits, which are elliptical, have a wide range, both in regard to excentricity and in their inclinations to the plane of the ecliptic; thus, the excentricity of (132), discovered by Watson, is .38, while that of (14) is no more than .03; the inclination of the orbit of (2), or Pallas, is 35°, while that of (24), as well as that of several others, is less than 1°. Their mean distances from the sun vary from 212 to 312 millions of miles, and their corresponding periods of revolution vary from 1195 to 2267 days.

Some of the planetoids approach so near the earth at favorable oppositions that they are observed, like Mars, for the purpose of determining the solar parallax. Though at a greater distance from the earth, they present the advantage of appearing as shining points of moderate brilliancy, instead of showing dazzling disks like that of Mars. Observations were made upon Flora, (8), in 1874, in both hemispheres, from which the value 8″.875 was deduced for the solar parallax. At the time of making these observations the distance of the planet from the earth was about 80 millions of miles. Some of the other planetoids are nearer to the earth than this at the time of favorable opposition; thus, (132), when nearest the earth, is less than 60 millions of miles distant.

JUPITER. ♃.

Magnitude and Form.

192. Jupiter, the fifth principal planet in order of distance from the sun, has been called the *giant planet* of the system; it is greater, both in volume and in mass, than the aggregate of all the other planets together.

Its form is that of an oblate spheroid, considerably compressed at the poles; its equatorial diameter is 87,770 miles, and its polar diameter is 82,570 miles; its mean diameter is therefore equal to nearly 86,000 miles, which is about $\frac{1}{10}$ of the diameter of the sun, and nearly 11 times that of the earth. His bulk is equal to more than 1280 such worlds as ours; his density, however, is so much less than that of the earth that his mass is only 312 times as great. He is always a conspicuous body in the heavens, and though he is occasionally less bright than Venus, he is on the average the most brilliant of all the planets.

Periodic Time, and Synodic Period.

193. Jupiter revolves around the sun in about 11.86 of our years; his synodic period is therefore a little less than 399 days. During this period his motion is retrograde for about 120 days, and direct for about 279 days. His arc of retrogradation is a little less than 10°, the planet being at the middle of this arc when he is in opposition.

Distance from the Sun and from the Earth.

194. The mean distance of Jupiter from the sun is 480 millions of miles, but on account of the excentricity of his orbit he may approach to within 457 millions of miles of that body, and may recede from it to a distance of 503 millions of miles.

His distance from the earth is a minimum at opposition and at a maximum at conjunction. These distances vary from one opposition to another and from one conjunction to another, being dependent upon the positions of both planets in their respective orbits. The least minimum distance is 363 millions of miles, and the greatest minimum distance is 412 millions of miles; the maximum distances vary from 542 to 597 millions of miles. The entire range in the planet's distance from the earth is from 363 to 597 millions of miles, a range which is sufficient to produce a very perceptible change in his apparent brilliancy. Under every circumstance his appearance is considerably brighter than that of any star of the first magnitude.

Telescopic Appearance, and Time of Rotation.

195. The most striking feature presented by the planet, when viewed with a good telescope, is a system of streaks or belts which cross his disk in nearly parallel zones. The equatorial zone is usually occupied by a light-colored belt, from 25° to 30° in breadth, which is bordered by two narrower, dark-colored bands, one in the northern and the other in the southern hemisphere of the planet. Outside of these belts, both toward the north and the south, we find an alternating succession of light and dark stripes, as shown in Fig. 91, which is taken from a drawing by Trouvelot.

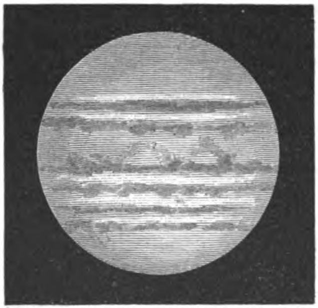

Fig. 91. Telescopic View of Jupiter.

The dark belts, which seem to be composed of dense masses of clouds, are very irregular in outline, and are subject to frequent changes both in form and in position. The spaces intervening between the light and the dark stripes are usually of a whitish color, but they are often tinged with a rose-colored or pinkish hue.

The contrast between the darker and lighter spaces is most strongly marked in the central portions of the disk, gradually fading away as we approach the apparent boundary of the planet. In the polar regions the belts become indistinguishable, and the surface of the planet takes on a uniform grayish tint.

These appearances have been accounted for by supposing Jupiter to be enveloped by a dense atmosphere; the rays coming from the neighborhood of the apparent edge of the planet would have to pass through a greater extent of atmosphere than those from the central regions of the visible hemisphere, and would consequently experience a greater amount of absorption. It is also possible that the disappearance of the belts as we approach the polar regions may be due in part to perspective; being seen more obliquely, the darker stripes would overlap each other, and thus obscure the lighter ones.

Under favorable telescopic conditions the light-colored bands appear slightly mottled, as though covered by a layer of *shining* clouds floating in the planet's atmosphere.

Other Telescopic Phenomena.

196. Besides the belts and stripes already described, other markings on the surface of the planet are occasionally seen. Of these, the most remarkable ones are the white and the colored spots, which have recently attracted the attention of astronomers.

The most curious phenomenon of this kind was the **great red spot** which is now just passing away. It made its appearance in the southern hemisphere of Jupiter in 1878, and with occasional disappearances it continued visible up to the beginning of 1883. It was carefully observed by Pritchett, as well as by many other astronomers. It was so prominent and its color was so decided that it could usually be distinguished even with a small telescope.

In 1880, its shape was nearly elliptical ; its length, according to Trouvelot, was about 8,000 miles, and its greatest breadth was more than 2,000 miles. Its color was of a brilliant rosy red, altogether different from the pinkish tint that is often seen along the dividing lines of the cloud belts, to which reference has already been made. No satisfactory explanation of the cause of the spot has been offered.

Axial Rotation.

197. Observation shows that Jupiter revolves on an axis which is nearly perpendicular to the plane of the ecliptic in about 9 *hours* 55½ minutes.

Certain phenomena connected with the motion of the spots referred to in the last article have led some astronomers to think that the angular velocity of rotation diminishes slightly in passing from the equator towards the poles. This diminution, if it really exists, would seem to indicate a resemblance to the sun, in which body the rapidity of rotation diminishes pretty fast in passing from the equator toward the poles. The rapid changes that take place in the appearances of the belts and spots indicate the existence of forces which can hardly be accounted for, except on the supposition that Jupiter's surface is in a semi-molten condition, at least in his equatorial regions.

In consequence of the planet's great angular velocity of rotation and of his enormous diameter, the actual velocity of a point at his equator amounts to more than 27,500 miles, which is about 27 times as great as that of a point on the earth's equator. The resulting centrifugal force is therefore sufficiently great to account for the enormous compression of the planet.

Another consequence of the rapid rotation of Jupiter on his axis is to make the days and nights on the planet very short; the sun is above the horizon for less than 5 hours and below it for an equal time. We have no data for determining the relative changes in these periods due to refraction, but there is good reason to believe that there is a very dense atmosphere surrounding the planet, and if so there must be a considerable increment in the length of the day at the expense of the night; the length of twilight on the planet must also be so great as to exercise a perceptible influence on the relative amounts of daylight and darkness at any given point.

The equator of Jupiter is but slightly inclined to the plane of the ecliptic, and as a consequence there is but little variation of the seasons ; probably the change is imperceptible at any given place. The days and nights are therefore nearly equal at all seasons of the Jovian year.

On account of the shortness of the days and the length of the year, as compared with those of the earth, the *Jovian year* contains about 10,477 Jovian days.

Satellites of Jupiter.

198. Jupiter in his journey around the sun is accompanied by 4 satellites, which revolve about him in orbits that are nearly circular. Their motions conform to Kepler's laws; that is, their orbits are ellipses having one focus at the centre of the planet, their radii-vectores describe areas which are proportional to the times of description, and the squares of their times of revolution are proportional to the cubes of their mean distances from the central body. The planes of their orbits are nearly coincident with that of the planet, and are consequently but little inclined to the ecliptic; they therefore appear to move back and forth in straight lines, being seen first on one side of Jupiter and then on the other, and never at a very great distance from him.

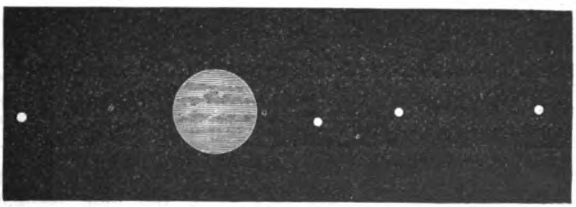

Fig. 92. Jupiter and his Satellites.

Being at different distances from the planet, their greatest elongations as well as their apparent times of oscillation are different from each other; sometimes they are seen lying in a line parallel to the ecliptic, some on one side and some on the other; sometimes they are all on one side of the planet; and not unfrequently one or more disappear for reasons yet to be explained. Fig. 92 shows the planet and its satellites, three on one side and one on the other.

A satellite may disappear by passing into the shadow of Jupiter, in which case it is said to be *eclipsed;* or it may disappear by passing behind the body of the planet, in which case it is said to be *occulted*; or it may disappear, except to a good telescope, by passing between the observer and the disk of the planet, in which case it is projected upon the planet, and its light is confounded with that of the planet itself. In the last case, the satellite may be distinguished by means of a good telescope, especially if it passes over the darker portions of the surface.

The eclipses of Jupiter's satellites are utilized for determining longitudes; it was also from a discussion of the eclipses of these bodies that it was first shown that the motion of light is progressive and not instantaneous.

The satellites, though having proper names, are usually denoted by the Roman numerals, according to their respective distances from Jupiter. The mean distances of the satellites from Jupiter, their periodic times, and their diameters, are shown in the following

TABLE.

Number.	Name.	Distance from Jupiter in miles.	Periodic time.	Diameter in miles.
I......	Io,..........	260,000	1d. 18h. 28m.	2,352
II......	Europa......	414,000	3d. 13h. 15m.	2,099
III....	Ganymede...	661,000	7d. 3h. 43m.	3,436
IV.....	Callisto......	1.162,000	16d. 16h. 32m.	2,929

It will be seen from the table that the second satellite is about the size of our moon, and that the fourth satellite is about as large as Mercury, the third one being larger. All the satellites are easily seen with a telescope of small magnifying power, and were it not for the dazzling brilliancy of Jupiter they might even be seen with the naked eye. In the more powerful telescopes their surfaces bear traces of permanent markings; from certain changes in their brightness it has been conjectured that they rotate on their axes in the same time that they revolve around Jupiter.

Eclipses of Jupiter's Satellites.

199. The eclipses of Jupiter's satellites are analogous to eclipses of our moon, but for various reasons they are of much more frequent occurrence. On account of the superior size of the planet and its greater distance from the sun his shadow is vastly larger than that of the earth; furthermore the dimensions of the satellites are very small in comparison with the diameters of the shadow where they traverse it; and finally the satellites move in orbits which are but little inclined to that of the planet. Hence, it happens that the three inner satellites are eclipsed at every synodic revolution; the outer one is generally eclipsed at each synodic revolution, but occasionally it passes either above or below the umbra, and so escapes eclipse.

Taking all the satellites into account, there is an average of about 30 eclipses a month, but only a part of them are visible from the earth; at the time of Jupiter's conjunction with the sun, the planet and his satellites are invisible on account of the dazzling glare of the solar rays, and at the time of his opposition the shadow is turned directly away from the earth, and for a considerable time both before and after opposition the eclipses are rendered invisible by the glare of the planet. The eclipses are seen to best advantage when the sun and Jupiter are in, or near, quadrature.

It may happen that two or even three of the satellites are eclipsed at the same time, but they cannot all be eclipsed at once, on account of the curious relations that exist between the motions of the three inner ones. The jovi-

centric motions of the first three satellites, that is, their motions as seen from the centre of Jupiter are subject to the following laws :

1°. The mean sidereal motion of the first added to twice that of the third is equal to three times that of the second.

2°. The mean longitude of the first, plus twice that of the third, minus three times that of the second, is equal to 180°.

If the second and third satellites are eclipsed at the same time, the first one must, in accordance with the second law, lie between the planet and the sun; or, if the second and third lie between Jupiter and the sun, the first will be in the shadow of the planet.

At long intervals it happens that all the satellites are all invisible at the same time, some being eclipsed and the others being in transit across the body of the planet. This phenemenon was witnessed by Dawes in 1843, and by Sir W. Herschel in 1802 ; it was again observed in 1868. The observations of Dawes show that all the satellites were invisible in 1843, for a period of 35 minutes.

When a satellite passes between Jupiter and the sun it casts a shadow upon the planet which may be seen traversing the disk as a round, or oval, black spot ; to an observer placed anywhere along the path thus traversed the sun would be totally eclipsed.

Use in Determining Longitudes.

200. An eclipse of one of Jupiter's satellites is a phenomenon which is visible at the same instant in every place which has the planet above the horizon ; hence, if two observers note the local times of its occurrence at their respective places of observation, the difference of these times will be the difference of longitude of the two places.

The Greenwich times of all the eclipses of the satellites that are visible during the year at any place on the earth are computed and laid down in the Nautical Almanac for the use of observers. Hence, an observer has only to find his local time at the instant of the occurrence of one of these eclipses, to be able to get his longitude either east or west from Greenwich.

The principal difficulty in applying this method is to determine the exact instant of the eclipse. The phenomenon is not instantaneous; for, the satellite having an appreciable magnitude, requires a certain length of time to enter the shadow after its advancing limb reaches the umbra, and an equal length of time to emerge from the shadow. During the former period the light of the satellite is gradually growing dim, and the exact time of its disappearance will depend upon the character of the telescope used, and upon the clearness of the atmosphere at the time of observation. A similar difficulty attends the exact determination of the time of emergence. Chauvenet says that the error may amount, in extreme cases, to a minute of time. If both immersion and emersion are observed, which is only possible when the planet is at some distance from conjunction and opposition, the two errors counteract each other, and by combining the results, a fairly approximate value of the longitude may be found. It is to be observed that a more accurate value for the longitude of a place may be found in most cases by the method of lunar distances.

Velocity of Light.

201. The *progressive* motion of light was first shown by Römer, a Danish astronomer, in 1675. In comparing the *observed* with the *computed* times of the eclipses of Jupiter's satellites, he found that they did not correspond; when Jupiter was nearest the earth the *observed times* were *earlier*, and when he was farthest from the earth they were *later* than the *computed times*. He therefore concluded that the motion of light was *progressive*, and not *instantaneous*, as had been previously supposed.

A discussion of a great number of observations led him to the conclusion that the time required for light to travel from the sun to the earth is about 8m. 13.3s. If we accept the mean distance of the earth from the sun to be 92½ millions of miles, Römer's determination would indicate that light travels at the rate 187,500 miles per second, which is fairly in accord with the most recent determination of the velocity of light; this, according to Michelson, is 186,300 miles per second.

SATURN. ♄

Periods. Distances.

202. Saturn is the fifth planet in order of distance from the sun and the next to the largest in order of magnitude. He revolves around the sun in a little less than 29½ years, his mean distance from that body being about 881 millions of miles.

His synodic period is about 378 days; hence, he is in opposition once in 54 weeks. At opposition he is in the middle of his arc of retrogradation, which averages about 6° 48′, and which is passed over in about 137 days. He begins to move westward among the stars a little less than 10 weeks before opposition, and continues his westward motion for an equal time after opposition. In 1883 his opposition period is December 9th, and in 1884 it is December 22d; by the addition of 13 days per year we can find the approximate time of opposition for many years.

The excentricity of Saturn's orbit is .056, and consequently the planet, when in aphelion, is a little more than 930 millions of miles from the sun, and when in perihelion it is a little less than 832 millions of miles from that body.

The distance of Saturn from the earth may vary from 738 to 1024 millions of miles.

Magnitude and Form. Axial Rotation.

203. The form of Saturn is that of an oblate spheroid, or flattened sphere; its compression is greater than that of Jupiter. His greatest, or equatorial, diameter is about 72,980 miles, and his least, or polar, diameter is 65,580 miles; hence, his mean diameter is about 70,366 miles, and his volume a little more than 700 times that of our earth. Notwithstanding his enormous volume, his mass is only 93 times that of the earth; hence, his density is considerably less than that of water.

He rotates on an axis once in 10h. 14m., the plane of the planet's equator being inclined to that of the ecliptic in an angle of about 28°, and to the plane of the planet's orbit by about 26° 49′. Hence, the planet has a succession of seasons similar in point of order to our own, but each season is nearly 30 times as long as with us.

Physical Condition.

204. On account of the great distance of Saturn from the earth, it is very difficult to learn much as to its physical condition. It is observed to be surrounded by belts similar to those of Jupiter, and these belts are found to be parallel to the planet's equator; when the position is such that their planes pass through the eye, which happens twice in 29½ years, they appear to be straight, but at other times they appear, from the principles of perspective, to be elliptical.

It has been inferred from the varying appearances of the belts that the planet has a dense atmosphere loaded with clouds. The very small specific gravity, or density, of the planet has led many astronomers to believe that the matter of which it is composed is intensely heated, but not sufficiently so to render it self-luminous.

The color of the lighter zones of Saturn is of a dull yellowish hue, the darker bands being gray. As in the case of Jupiter, the markings are more distinctly seen in the central portion of the disk than at the limb of the planet; the belts entirely disappear in the neighborhood of the poles.

Rings of Saturn.

205. The telescope shows us that Saturn is surrounded by a broad flat ring, or rather *system of rings*, whose plane is nearly coincident with the plane of his equator.

This ring, for it will often be convenient to speak of the *system* as a single ring, was first seen by Gàlileo, but on account of the imperfection of his telescope he mistook its character. As early as 1610 he announced that Saturn was composed of three bodies that almost touched each other. Other astronomers described the planet as having **ansae**, or *handles*.

It was not till 1656 that Huyghens discovered the real nature of the appendage, which he fully described three years later. Since the time of Huyghens the character of the ring has been carefully studied, and its dimensions and divisions have been measured.

What we have called *the ring* is in reality made up of three concentric rings which lie very nearly in the same plane, and which are separated by intervening spaces, unless indeed the inner one should prove to be, as astronomers are now inclined to believe, an extension of the second or middle one. The two outer rings are *bright*, like the planet, but the inner one is *obscure* or *dark*, presenting an appearance that has been compared to a ring of crape.

This dark ring, which is only visible in a good telescope, was first seen by Bond of Cambridge in 1850, and was discovered independently by Dawes of England only a few days later. For convenience of reference, the outer bright ring is called A, the inner bright ring B, and the dusky ring C.

The diameter of the ring system is enormously greater than its thickness. In round numbers, the greatest diameter of the outer ring is about 170,000 miles, and the breadth of the entire system is nearly 38,000 miles; the thickness of the rings is variously estimated from 40 miles up to 250 miles; it is probable that the true thickness lies somewhere between these limits. The relative dimensions of the rings in comparison with the equatorial section of the planet is shown in Fig. 93.

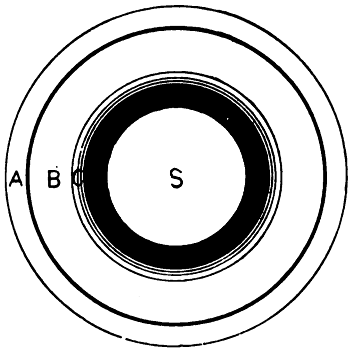

Fig. 93. Projection of Rings and Planet on the plane of his Equator.

DESCRIPTION. — The figure shows the rings and equatorial section of Saturn in their relative dimensions. The ring A, whose outer diameter is 168,590 miles, has a breadth of more than 10.000 miles, and is probably divided into two by a narrow line of separation. The ring B is separated from the ring A by an interval of 1,700 miles; its outer diameter is about 145,750 miles, and its breadth is nearly 18,000 miles. The ring C is a continuation of B, its interior diameter being about 92,000 miles, and its breadth about 8,600 miles. The interval separating the inner edge of the dusky ring and the surface of the planet is between 9,000 and 10,000 miles.

The rings rotate about an axis which is sensibly coincident with the axis of the planet, and in a period which is but little greater than that of the planet's rotation period. They accompany the planet in his journey around the sun, their plane always remaining parallel to itself.

This plane intersects the ecliptic in two points, which are called **the nodes of the ring.** The heliocentric longitudes of the nodes are respectively 167½° and 347½°; the former is called the **ascending node,** because it is the place of the planet where the sun appears to ascend from the southern to the northern face of the ring; and the latter is called the **descending node**, because it is the place of the planet where the sun appears to descend from the northern to the southern face of the ring.

When the planet is exactly at either of the nodes, the plane of the ring passes through the sun, and is only illuminated on its edge; at these times the ring is invisible except in the most powerful telescopes. Whilst the planet is passing from the ascending to the descending node, the sun shines continually on the north face of the ring, and whilst he is passing from the descending to the ascending node, the sun shines continually on the south face of the ring.

The motions and aspects of the ring, as seén from the sun, are similar to those of our equator seen from the same point of view. The aspect of the ring from the time it passes its ascending node till it reaches the descending node is similar to that of our earth's equator whilst passing from the vernal to the autumnal equinox; the aspect of the ring whilst passing back to the ascending node is similar to that of the equator in passing from the autumnal to the vernal equinox. It is to be borne in mind that the celestial pole of the plane of Saturn's ring is only 7° from the north pole of the heavens, a fact which renders the similarity of aspect the more striking.

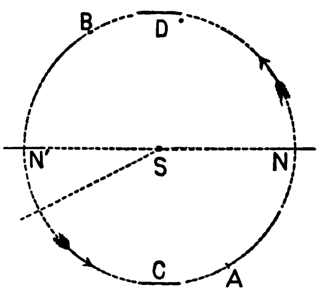

Fig. 94. Illustrating the Motion of the Rings.

Explanation.—A is the perihelion and B is the aphelion point of Saturn's orbit; N′ is the place of the ascending and B is the place of the descending node of the ring.

The motions and aspects of the rings will be understood after a careful study of Fig. 94, which represents the projection of the orbit of Saturn on the plane of the ecliptic, the direction of the vernal equinox being indicated by the dotted line below N'S.

When the ring is at N or N', its plane passes through the sun, and its inclination is such that it passes above D and below C. In moving from N to N', in the direction indicated by the arrow, the sun shines obliquely on the north face of the ring; in moving from N' to N, the sun shines on the south face of the ring.

Phases of the Ring.

206. The orbit of the earth is so small, in comparison with that of Saturn, that the direction of the planet as seen from the earth is always nearly the same as it would be if seen from the sun; hence, in a general description of the **phases**, or *different appearances* presented by the ring during a sidereal revolution, we may suppose the observer to be at the sun.

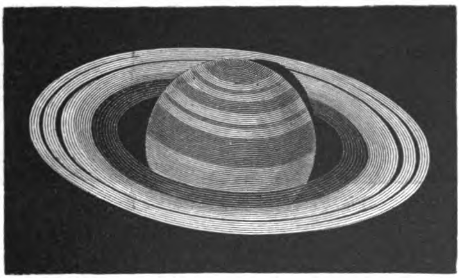

Fig. 95. Saturn and his Rings.

Commencing at N, Fig. 94, the ring is seen edgewise, and in a suitable telescope it has the appearance of a bright straight line inclined to the direction of the planet's motion in an angle of about 26°. As the planet moves on toward D, the ring, being seen obliquely, has the form of an ellipse, which is very much elongated at first, widening out gradually until it reaches D, 90° distant from N; in this position the minor axis becomes nearly, but not quite, one-half as great as the major axis. In this position the northern face of the ring and also the northern hemisphere of the planet are seen to best advantage. This phase is seen in Fig. 95.

As the ring moves on toward N′, the apparent breadth of the ring begins to diminish and continues diminishing till the planet reaches N′, 180° from N, when it again presents itself edgewise, and in a suitable telescope is seen as a straight line.

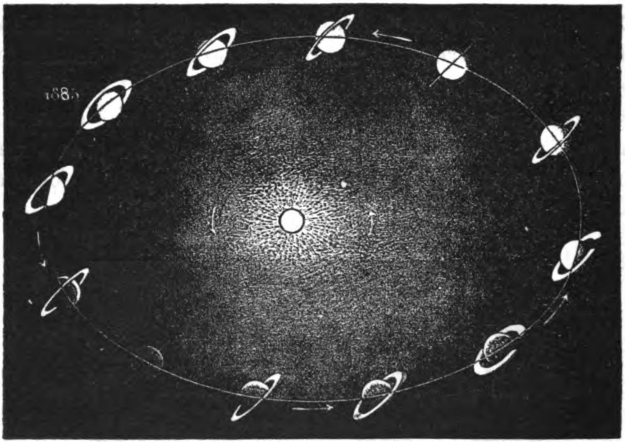

Fig. 96. Phases of Saturn's Ring.

After the planet has passed N′ the ring is again seen as an elongated ellipse, which grows broader continually till it comes to C, 270° from N. At this point the phase is similar to that at D, except that we now have the best view of the southern face of the ring and of the southern hemisphere of the planet.

In returning to N, the elliptical form of the ring continues to grow narrower, and the ellipse becomes more and more elongated till the planet reaches N, when the ring phase again becomes a straight line.

The phases for a complete revolution of Saturn are shown in Fig. 96.

The length of an entire cycle of phases is equal to the periodic time of Saturn, or to nearly 29.46 years. The line of the ring's nodes, NN′, divides the orbit of the planet into two unequal parts, and because "the areas are proportional to the times," the corresponding times are different. The time required for the planet to move from the ring's ascending to its descending node is about 15.75 years, and the time required for him to pass from the descending to the ascending node is about 13.71 years. Hence, the sun shines continuously on the northern face of the ring for 15¾ years, and then on the southern face for nearly 13¾ years.

The last passage of the planet through the *ascending* node of the ring took place on the 18th of May, 1862, and his last passage through the *descending* node was on the 14th of February, 1878; the planet will return to the ascending node on the 29th of October, 1891. The southern face of the ring will be most favorably seen in 1885.

Disappearance of the Ring.

207. In the last article the observer was supposed to be at the sun; the phenomena there described are somewhat modified by the fact that we see them from the earth, and this is more especially the case during the time that the plane of the ring intersects the earth's orbit.

This plane, which is parallel to the line of nodes of the ring, occupies nearly a year in sweeping across the orbit of the earth, and in that interval the ring may be so situated as to pass between the earth and the sun more than once, in which case the ring will disappear because its illuminated face is turned away from us.

The number of disappearances and the duration of each will depend on the position of the earth when the plane of the advancing ring strikes her orbit. The nature of these disappearancces and their manner of occurrence will be understood from the following description of the disappearances that took place about the time of the last passage of the planet through the ascending node of the ring in 1862.

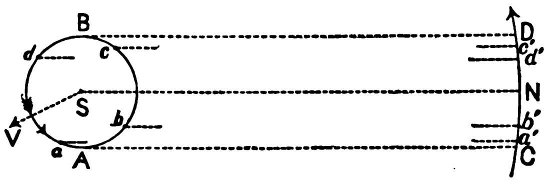

Fig. 97. Disappearance of Rings.

EXPLANATION. In Fig. 97, AB is the earth's orbit; CD, the projection of a part of the orbit of Saturn on the plane of the ecliptic; N is the ascending node of the ring; NS, the intersection of the plane of the ring with the ecliptic; and the parallel lines are different positions of this line. The plane of the rings is inclined so as to pass above B and below A; the observer is supposed to be looking on the north face of the ring.

At the time the plane of the ring struck the earth's orbit at A, the earth was moving toward *a*; on the 23d of November, 1861, the earth met the plane of the advancing ring at *a*, passed through it from the south to the north side, and the ring disappeared; the sun continued to shine on the southern side, and the earth remained on the northern side till February 1, 1862, when the earth overtook the plane of the ring at *b*, passed through it from the north to the south side, and the ring reappeared. It was invisible for 70 days.

The sun and the earth then remained on the south side of the ring, and the ring continued visible till May 18, 1862, at which time the earth was at *c* and Saturn at N; at this time the plane of the ring passed through the sun, and then the northern face began to be illuminated, the earth being on the southern side, and the ring again disappeared; the plane of the ring continued to lie between the earth and the sun till August 13, 1862, when the earth met it at *d*, passed through it from the south to the north side, and the ring again reappeared. At this disappearance it was invisible for 87 days.

The earth and the sun being now on the same side of the plane of the ring, no further disappearance took place till the next passage of the plane of the ring across the earth's orbit, which happened in 1877–8.

Every time that the plane of the ring sweeps across the earth's orbit there *must* be at least one disappearance in consequence of the plane of the ring passing between the earth and the sun, and there *may* be as many as three such disappearances. When a disappearance arises from the cause just mentioned the ring may remain invisible for several months; when it is at the node, in consequence of the passage of its plane through the sun, it only remains invisible for a short time.

Physical Character of the Rings.

208. That the rings A and B are opaque bodies is shown by the fact that they cast shadows on the body of the planet.

The ring C is partially transparent, for the outline of the planet can be seen through it.

The old idea that the rings are solid bodies has long since been abandoned, it having been demonstrated that such a supposition is incompatible with the laws of mechanics; furthermore, the idea of a solid ring is incapable of being reconciled with the changes that have been observed in the rings, that is, changes of form, indicated by the variations of the shadings and other markings that are sometimes noticed.

For a time it was thought by some astronomers that the rings were fluid; but this theory was shown to be erroneous by Maxwell in his prize essay written in 1857. He showed that the only tenable hypothesis in regard to their constitution is that they are made up of myriads of independent bodies revolving around the planet like so many satellites and subject, like other satellites, to multitudinous perturbations. These revolving satellites are so small as to be invisible in the most powerful telescope, and so numerous as to give the impression of a continuous body. According to this view, we may regard the ring C as composed of satellites more widely separated than in the other rings, and possibly less capable of reflecting light.

Recent observations on the form of the shadow which the ball of the planet casts on the surface of the rings have led some astronomers to believe that the rings are not of uniform thickness; that is, that their faces are not parallel planes. Trouvelot, who has devoted a great deal of study to the subject, is of the opinion that the ring A is of uniform thickness, and that the ring B is thickest at its outer limit, growing thinner toward the sun; it is highly probable that the same law of diminution holds good with regard to the ring C.

The brightest part of the entire ring system is the outer zone of the ring B; in approaching the sun the brilliancy slowly diminishes to its inner zone. The ring A is less brilliant than the ring B, and, as we have already seen, the ring C is far less brilliant than either.

Satellites of Saturn.

209. Saturn has 8 satellites, 7 of which revolve around him in orbits that are nearly coincident with the plane of his rings, and consequently with the plane of his equator; the orbit of the other one is inclined to the plane of the rings in an angle of about 10°. *Five* of them were discovered in the 17th century, *two* in the 18th century, and the other one, the seventh in order of distance from Saturn, was not known till 1848, when it was discovered by Bond of Cambridge, and independently by Lassell of England.

The satellites of Saturn are subject to eclipse, but in consequence of the great inclinations of their orbits to the plane of the ecliptic, their eclipses are of less frequent occurrence than those of Jupiter. When the ring is seen edgewise, the first 7 appear to move back and forth with a shuttle-like motion, and have sometimes been seen moving along the bright line of the ring like beads on a string. When the ring is seen obliquely the satellites appear to be scattered as shown in Fig. 98.

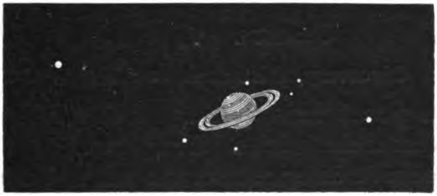

Fig. 98. Saturn and his Satellites.

The names, distances from Saturn, and diameters of the satellites, so far as known, are given in the following table taken from Chambers' Astronomy.

TABLE.

Number.	Name.	Distance from Saturn in miles.	Approximate diameter in miles.	Sidereal Period in days.
I......	Mimas.............	120,800	1,000	0.94
II.....	Enceladus..........	155,015	?	1.37
III....	Tethys.......... ..	191,248	500	1.88
IV.....	Dione..............	245,876	500	2.73
V.....	Rhea...............	343,414	1,200	4.51
VI.....	Titan...............	796,157	3,300	15.94
VII....	Hyperion..........	1,006,656	?	21.29
VIII...	Iapetus............	2,318,835	1,800	79.33

Comparison of Jupiter and Saturn.

210. The planets Jupiter and Saturn resemble each other in many respects. Both are large planets with very small densities, the former being the largest and the latter the next largest of all the planets; they both revolve on their axes in very short periods of time, about 10 hours, and both are very much flattened at the poles; both have dense atmospheres loaded with enormous clouds, which are thrown into belts by currents parallel, or nearly so, to their equators; and it has been suspected that both are, by virtue of internal heat, at a temperature bordering on incandescence.

Uranus. ♅, or ⛢.

Discovery, Distances, and Periods.

211. The planets heretofore described have been known from the most ancient times. Uranus, which is the seventh planet in order of distance from the sun and the fourth in order of magnitude, was not known till 1781, when it was discovered by Sir William Herschel, whilst examining some small stars in the Constellation Gemini.

He at first supposed that it was a comet, and in a paper presented to the Royal Society he described it as such. After considerable discussion it was found to be a planet, and was named by its discoverer the *Georgium Sidus*, in honor of his royal patron George III. Lalande suggested the name Herschel, which was afterward changed, at the suggestion of Bode, to Uranus, by which name it is now universally recognized. The symbol ♅, which was adopted to designate the planet, was simply the initial letter of Herschel's name, with a planet suspended from the cross-bar; but this symbol is passing out of use, being replaced by the less expressive sign ⛢.

Uranus revolves around the sun in 40,687 days, or a little more than 84 years, its mean distance from that body being about 1,771,000,000 of miles. The excentricity of its orbit is a trifle less than that of the orbit of Jupiter, in consequence of which the planet approaches to within 1,689,000,000 miles of the sun, and recedes from that body to a distance 1,853,000,000 of miles. Its changes of distance, both from the earth and from the sun, though enormous in themselves, are so small in comparison with the planet's mean distance from either, that they can have but little effect on the visibility of the planet, or on its relative supply of light and heat. Its synodic period is no more than 370 days.

Magnitude, Rotation, and Physical Condition.

212. The diameter of Uranus is about 31,700 miles, and although it was reported by Mädler to be flattened, the statement is now doubted by the ablest observers. Its volume is about 64 times that of the earth, but its mass is only 14 times as great. Hence, its density is only 1.25, that is, 1¼ times that of distilled water. It is not known whether the planet rotates on an axis, although it is probable that it does so, its axis being perpendicular to the planes of the orbits of the satellites, yet to be described. Of its physical condition we know little or nothing.

Satellites of Uranus.

213. The satellites of Uranus are only visible in a powerful telescope and under favorable circumstances. Four are certainly known to exist, and others have been suspected. Two of the four were discovered by the elder Herschel, and have been studied by various observers. The other two were discovered by Lassell in 1852, under the pure sky of Malta.

Sir William Herschel announced the existence of six satellites, two of which are identical with those already spoken of, but the other four, if they have an actual existence, are not recognized at the present time. Mr. Lassell, during his residence at Malta, examined the region of the heavens about Uranus with great care, and as the result of his observations he says: "I cannot resist the conviction that Uranus has no other satellite except four visible with my eye and optical power. In other words, I am fully persuaded that either he has no other satellite than these four, or if he has, they remain yet to be discovered."

According to Newcomb the planes of the orbits of these satellites are inclined to the ecliptic in an angle of 97° 51′, or nearly 98°. If their planes of revolution were ever coincident with the plane of the ecliptic they must have been turned over till perpendicular to the ecliptic, and then 8° further. Looking down upon the satellites from the north side of the ecliptic they appear to move from east to west; that is, their motion is *retrograde.* It is but reasonable to suppose that rotation of the planet is in the same direction, and if so, this is certainly a strong point against the truth of the nebular hypothesis. The satellites in order of distance, their names, and periodic times, are given in the following table taken from Chambers' Astronomy.

TABLE.

Number.	Name.	Periodic time in days.	Mean distance in miles.
I.	Ariel	2.52	122,849
II.	Umbriel	4.14	171,229
III.	Titania	8.71	280,869
IV.	Oberon	13.46	375,648

NEPTUNE. ♆.

Its Discovery.

214. The eighth planet in order of distance from the sun, and the third in magnitude, is called Neptune. It was first observed on the 23d of September, 1846, by a German astronomer named Galle, but its place in the heavens had been indicated to within less than a *degree* by Le Verrier; to this astronomer, therefore, and to the English mathematician Adams, who also predicted the place of the planet to a great degree of accuracy, must be assigned the honor of the *discovery.*

For many years previous to 1846 irregularities had been noticed in the motion of Uranus, which could only be explained by supposing the existence of an exterior planet, and the minds of scientific men had been directed toward the solution of the problem as to whether such a planet did exist, and if so, where it was to be found.

The nature of the disturbances of Uranus, which led to the discovery of Neptune, will be understood from the diagram, which shows the relative positions of Uranus and the then unknown planet Neptune, from 1781 to 1840.

Explanation. The inner circle represents the orbit of Uranus, and the outer circle that of Neptune, the sun being at S. The corresponding positions of the two planets are indicated by the corresponding dates, and the directions of Neptune's attraction is shown by the arrows.

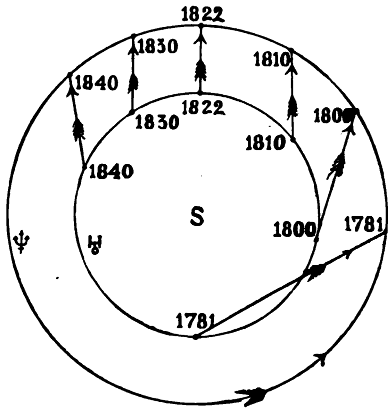

Fig. 99. Relative positions of Uranus and Neptune.

In 1821, at which time Uranus and Neptune were nearly in conjunction, Bouvard published his tables of Uranus, basing them on an orbit of the planet which harmonized with the observations that had been made between 1781 and 1820. After the publication of these tables it was soon found that the observed places of the planet did not conform to those given by the tables, and as the time after 1822 increased, these discrepancies became continually greater.

Adams began his investigations in 1843, and in 1845 he sent to the Astronomer Royal provisional elements of a planet which he thought would account for the perturbations of Uranus, but no active search was made to verify his predictions. In the latter part of 1845 Le Verrier published a memoir to show that the perturbations of Uranus were not due to the sole action of Jupiter and Saturn, and in June, 1846, he published a second memoir to show that an exterior planet was the cause of the unexplained part of the disturbance. He assigned the elements of the orbit of such a planet, as Adams had done a few months previously. In the following August he published a third memoir, in which he indicated the probable place of the disturbing planet in the heavens, which was very nearly the same as that which had been pointed out by Adams.

On the 23d of September, Encke of Berlin received a letter from Le Verrier, requesting him to co-operate in the discovery of the planet. That very night, Dr. Galle, Encke's assistant, turned his telescope to the place indicated, and soon discovered what seemed to be a star of the eighth magnitude, which was not laid down on Bremiker's chart of that region. On the following night he found that it had changed position, a discovery which made it evident that it was in reality the planet sought for. It is unnecessary to say that this discovery, which must ever redound to the honor of both Le Verrier and Adams, is one of the most brilliant achievements of modern science.

Distance, Periods, Magnitude, and Physical Condition.

215. The mean distance of Neptune from the sun is about 2,775 millions of miles; his orbit is but little excentric, his distance from the sun at perihelion being 2,750 millions of miles, and at aphelion 2,800 millions of miles.

His periodic time is nearly 164⅗ years, and his synodic period is only 367½ days; that is, he moves forward among the stars in a year no farther than the earth does in 2¼ days.

The diameter of Neptune is 34,800 miles, so that his volume is 85 times that of the earth. His mass is only 17 times the mass of the earth; hence, his density but little greater than that of water.

We know little or nothing of the physical character of the planet. It probably revolves on an axis, but we are ignorant of the time of his rotation and of the position of his axis of rotation.

Neptune's Satellite.

216. Neptune has one satellite which revolves around the planet in a period of 5.877 days, and in an orbit whose inclination to the ecliptic is a little more than 145°, that is, the motion of the satellite, as seen from the north side of the ecliptic, is from east to west, or *retrograde.* The plane of the orbit of the satellite is turned over, so to speak, with respect to that of the planet, and if we suppose the axial rotation to correspond in direction with that of the motion of the satellite, we are thereby furnished with a still stronger argument against the nebular hypothesis than in the case of Uranus. The mean distance of the satellite from Neptune is about 220,000 miles.

Comparison of Uranus and Neptune.

217. We have seen that the first six planets taken in pairs are somewhat closely allied in their physical conditions; thus, Mercury and Venus resemble each other in many respects; the Earth and Mars are more strikingly alike, and even Jupiter and Saturn have many peculiarities in common. In like manner Uranus and Neptune may be compared; they agree in the fact that neither presents any peculiar markings by which its time of rotation can be determined; the strongest point of resemblance, however, consists in the peculiarity of the motion of their satellites, the plane of motion in both cases being overturned, as it were, so that the apparent motions of the satellites are retrograde. We know little or nothing about the physical condition of either.

XI. COMETS AND METEORS.

Comets Members of the Solar System.

218. Besides the bodies already described, hundreds of other bodies called **comets** are recognized by astronomers as belonging to the *solar system.*

They differ from the planets in many respects: their orbits are greatly elongated and are often highly inclined to the plane of the ecliptic; in fact, they make every possible angle with that plane; their motions are sometimes direct and sometimes retrograde; they generally contain but little matter, and are often, perhaps generally, surrounded by nebulous envelopes and accompanied by trains of similar nebulous matter, though in the latter respect there is a wide difference between different individuals.

They resemble the planets in conforming to the Newtonian law of universal gravitation: their orbits are always conic sections, having one focus in each case at the sun; the radius-vector of each describes areas which are proportional to the times of description, but in consequence of their extreme tenuity they are greatly disturbed in their motions by the attractions of the planets, and they are often thrown from their normal orbits and forced to take up new ones.

Definition.

219. The word *comet,* which is derived from the Greek, signifies a hairy or bearded star, that is, a star with a nebulous surrounding that resembles a bunch of hair, or a beard.

Before the true character of comets was discovered, they were objects of popular dread; they were considered as omens of the wrath of Heaven and as "harbingers of war and famine, of the dethronement of monarchs and the dissolution of empires;" nor have these popular notions entirely disappeared, for even at the present day, the appearance of a comet is regarded by many with fear and apprehension.

Elements of a Comet's Orbit.

220. It has been stated that the orbit of a comet is some one of the conic sections. Of course no comet can return periodically unless its orbit is an ellipse; but it usually happens, even when a comet's orbit is elliptical, that its excentricity is so great that we may regard that portion of it along which the comet is visible as sensibly coincident with a parabola having the same focus, and the same perihelion distance.

Hence, when a new comet appears, astronomers are in the habit of regarding its orbit as a parabola, inasmuch as the labor of computing the elements of a parabolic orbit is much less than is required for computing the elements of an elliptical orbit. The parabolic elements thus found are generally sufficient to show whether the comet in question corresponds to any one that has appeared before, and if so an elliptic orbit may then be computed. If the parabolic elements do not indicate the identity of the comet with any one previously observed, they will be sufficient to enable us to predict the motions of the body until a sufficient number of observations have been made to determine a more accurate orbit.

The elements of a parabolic orbit are five in number, and these may be determined from three good observations of the body taken at intervals of one or two days. They are as follows:

1°. The heliocentric longitude of the ascending node:

2°. The inclination of the plane of the orbit to that of the ecliptic;

3°. The heliocentric longitude of the perihelion;

4°. The epoch, or time, of perihelion passage; and,

5°. The perihelion distance, or the distance from the sun at the epoch.

The Number of Comets.

221. The number of comets that have been noticed and recorded is very great, amounting to many hundreds. Of these only the most conspicuous ones had been observed up to the time of the discovery of the telescope, and even they can hardly be said to have been *observed* in the modern sense of that term. Within a few years, however, great attention has been paid to cometary astronomy, and already from *two* to *three hundred* have been catalogued, that is, the elements of their orbits have been determined, with greater or less accuracy, and the results have been registered for future reference.

Besides those that have been *catalogued* in modern times, great numbers must have escaped notice either from their minuteness, or because their paths were in that portion of the heavens which happened to be illuminated by the sun at the time of their nearest approach to the earth and consequently were above the horizon only in the daytime.

On an average, when long periods are considered, there are 26 or 27 comets per century that are visible with the naked eye. The number of telescopic comets is vastly greater.

General Description of a Comet.

222. Comets differ so much in appearance that no single description is applicable to them all. In general, however, a comet may be said to consist of three parts: 1°, a shining stellar point called the **nucleus**; 2°, a surrounding mass of nebulous matter called the **coma**; and 3°, an extension, or prolongation, of the coma called the **tail**. The nucleus and coma together make up the **head** of the comet.

The *nucleus*, which appears to be composed of matter in a state of incandescence, and which may or may not be solid, varies greatly in brilliancy in different comets. Sometimes it shines like a star of the first magnitude, sometimes it is so faint as hardly to be discernible, and in some cases there is no trace of a luminous centre. Sometimes the stellar point is sharp and clear, but more frequently it is hazy and badly defined.

The *coma* consists of a vapor-like mass of matter somewhat condensed toward the nucleus, but greatly diffused toward its outer surface; its outline is very indistinct, and at a little distance from the nucleus it is so tenuous that stars may be seen through it. Its bulk is often enormous, but the quantity of matter that it contains is very small, as is shown by the readiness with which it yields to the disturbing forces of the planets and the little influence it exerts upon them in return. The extreme tenuity of the coma is shown by its enormous bulk in comparison with its mass.

The *tail*, which is even more tenuous than the coma, is turned away from the sun, and in many instances it extends to an enormous distance from the nucleus; in other cases it is comparatively insignificant, and not infrequently it is totally wanting. In no respect do comets differ more from each other than in respect to this appendage; the great comet of 1843 had a tail that extended over an arc of 65°, and which was not less than 150,000,000 of miles in length, while the bright comets of 1665 and 1682 are described by Cassini as being round and well-defined like Jupiter. Some brilliant comets have very short tails, and some faint comets have very long ones.

Some comets have been noticed with several tails, or diverging streams of nebulous matter: the great comet of 1774 is described as having had six tails spreading out like a fan and covering an angular space of 30°; the smaller comet of 1823 had two tails making an angle with each other of 160°, the brighter and principal one being directed away from the sun, while the lesser one lay in nearly an opposite direction. It is to be observed that telescopic comets, as a general thing, have no tails, or at most only short ones; their bodies usually appear as simple spherical or slightly elongated masses of vapor.

Brilliancy and Visibility.

223. Comets have every degree of brilliancy, from those magnificent specimens that are visible with the naked eye in broad daylight down to the almost evanescent wisps of nebulous matter that can only be seen with a powerful telescope.

Many comets have been seen in the daytime: the great comet of 1843 was thus seen when it was within 2° of the sun; the great comet of 1861 was seen just before sunset; the great comet of 1882 was also seen in close proximity to the sun; and to these examples many others might be added.

It has often happened that comets have been seen during the time of a solar eclipse: such an event occurred during the eclipse of 63 B.C.; in 418 A.D. a large comet was seen during the eclipse of that year; and also during the eclipse of 1882, which was observed by Lockyer and others in Egypt, a comet was seen and photographed.

It has already been stated that the average interval between the appearances of comets, large enough to be seen with the naked eye, is about 4 years. Some of them remain in sight but a few days, and others are visible for longer periods, up to several months. Not to go too far back into astronomical history, we may give a few examples of recent comets that remained visible either to the naked eye or to the telescope for long periods of time.

The great comet of 1811, one of the most conspicuous of modern times, remained visible for 17 months; the bright comet of 1815 was visible for nearly 6 months; the comet that was first seen in the latter part of 1825 was visible for nearly a year; the great comet of 1843 was observed for 7 weeks; Donati's comet, one of the finest comets of the century, was a conspicuous object in the heavens during the autumnal months of 1858, and did not finally disappear in the telescope till the following March; and finally the remarkable comet of 1882 was visible to the naked eye for many weeks.

Mass and Tenuity.

224. It has been stated that the smallness of a comet's mass is shown by the great disturbance it experiences from the action of the planets; the following instance will illustrate the subject more fully than further description:

A comet appeared in 1770, which was found to move in an elliptical orbit, with a periodic time of about 5½ years; it is known in history as Lexell's comet. The wonder was why it had never been seen before, and so great was the interest of astronomers in the matter that the French Institute offered a prize for a complete investigation of its history. As a result of this investigation, it was found that it had been greatly disturbed by the attraction of Jupiter.

In tracing its orbit backward, it was found that in 1767, it had come within the influence of Jupiter, in whose neighborhood it had remained for several months, and when it finally left that planet it had been thrown into a 5½-year orbit. Previously it had moved in a 50-year orbit, whose perihelion distance was nearly equal to that of Jupiter, and for this reason it had never been seen before.

Strangely enough, the comet at a later period again fell in with Jupiter, and after being detained for a few months in that neighborhood it was thrown into a 20-year orbit, with a perihelion distance of between 200 and 300 millions of miles, and unless it is again disturbed it will, on account of its great distance, remain forever invisible to us. During all these changes in the path of the comet, the orbits of Jupiter's satellites were not changed in any perceptible degree. Laplace concluded that the mass of this comet could not exceed the 5,000th part of that of the Earth. The curious history of this comet suggests an explanation of many strange anomalies that have been observed in this class of bodies.

As illustrations of the extreme tenuity and almost perfect transparency of cometary bodies, the following cases may be mentioned: In 1824 Struve saw a star of the twelfth magnitude when it was so near the centre of an intervening comet that it could not have been more than 2″ from the densest portion, and yet the star experienced no sensible diminution in brightness. Again, in 1829, the same astronomer saw what he thought to be a comet with a stellar nucleus, but which turned out to be only a star of the eleventh magnitude shining through the head of the comet. In October, 1874, the comet discovered by Miss Mitchell of Nantucket passed over a star of the fifth magnitude so centrally that it could not be decided on which side the nebulosity was greatest, even with a magnifying power of 100, and yet the light of the star was not perceptibly enfeebled.

Mr. A. B. Biggs, in writing from Tasmania of the great comet of 1882, says:

"On Monday evening at 10 o'clock I perceived a minute star (ninth magnitude) in the advancing edge of the comet's coma, which I foresaw would be crossed centrally by the nucleus—a rare opportunity which I determined not to miss. At 11 o'clock the star was fairly in the centre of the nucleus. The nucleus was perfectly transparent. I watched the star until it had well crossed, and never lost sight of it even when a slight atmospheric haze obscured the comet itself. The light of the star was not even sensibly diminished, except so far as being seen upon the light background of the comet."

Prof. Young, in a recent lecture, said: "Encke's comet, when I was observing its spectrum, passed so centrally over a star that I thought something had happened, because I saw that there was a stellar spectrum; but ten minutes afterward it had passed by. Yet the star was not dimmed at all. Afterward I had a candle placed so that its light should shine on the object-glass of the telescope, making the field of view about as bright as the comet was, and I found this light dimmed the star as much as the 50,000 miles of comet did. A comet is a mere airy nothing."

It may be observed that the slightest fog or haze is sufficient to obscure a star of the magnitude referred to. The facts just given suggest the idea that the nuclei of bright comets may not be solid, nor even very dense bodies.

Appearance of the Tail.

225. As we have already seen, the appearances presented by the tails of different comets are exceedingly diverse. The normal or average type, however, consists of a slightly diverging brush of light, extending away from the sun, being brightest near its borders and darkest along the central line or axis.

The dark shade of the axial line can be accounted for by supposing the tail to be a greatly elongated and hollow paraboloidal envelope, having its focus at the centre of the nucleus. The portion of this envelope which is turned toward the sun is in fact a part of the coma, and its prolongation beyond the nucleus is the real tail.

In viewing such an envelope it is easily seen that the portions along the axis would appear darkest, while those near the border would seem to be brightest. Let A B, Fig. 100, represent a cross-section of such an envelope, made by a plane perpendicular to its axis; and suppose the space between the two circles to be filled with diffused luminous matter. It is evident that a line of vision, CD, through the centre, O, will contain fewer luminous particles than one through EF, and consequently to an eye situated below the section it will appear to be brighter at F than it does at D.

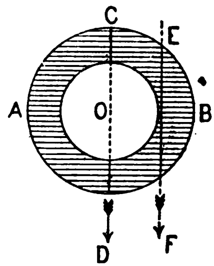

Fig. 100. Ideal Cross-section of a Comet's Tail.

When we come to the study of Donati's comet we shall see that the tail is made up of several such hollow envelopes, a fact that will somewhat modify the above conclusion, without in any manner impairing its validity. The differences that are noticed in the tails of different comets and in the tails of the same comet at its different returns will be considered hereafter.

Curvature of Comets' Tails.

226. The tails of most comets appear to be curved somewhat like a Turkish scimetar, the concavity of the curve being turned toward that part of the orbit which has already been traversed by the comet. The bending, as a general rule, takes place in the plane of the orbit, and as a consequence the *apparent* curvature will depend not only upon the actual amount of bending, but also upon the position from which it is viewed; if seen from a point in, or nearly in, the plane of the comet's orbit, the tail will appear nearly straight; if seen obliquely, the amount of curvature will obviously vary with the degree of obliquity.

The curved form of a comet's tail is well shown in Fig.

101, which represents the great comet of 1858, usually known as Donati's comet.

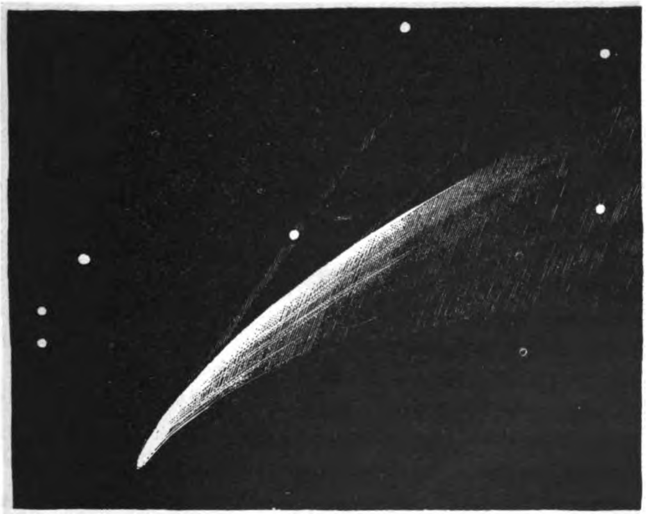

Fig. 101. Donati's Comet, 1858.

The explanation of this curved appearance depends on a theory that has been advanced to account for the formation of the coma and tail. The theory in question supposes that a portion of the comet becomes vaporized in approaching the sun, and that the vapors thus formed are repelled both by the comet and by the sun. By virtue of the comet's repulsion these vapors rise in the form of envelopes surrounding the comet, and by virtue of the sun's repulsion they are elongated and driven away from the nucleus to form the tail.

The manner in which the successive envelopes are formed and driven off is shown in Fig. 102, which represents the head and a portion of the tail of Coggia's comet of 1874, as drawn by Trouvelot.

This theory being accepted, the curvature of the tail is easily explained. The particles driven off at any instant,

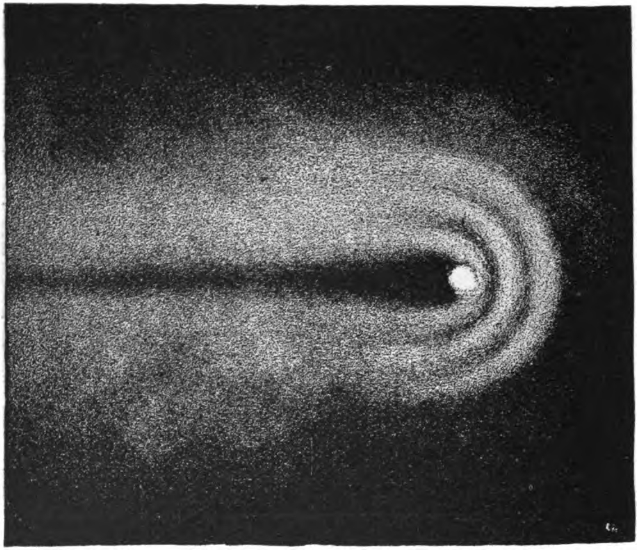

Fig. 102. Coggia's Comet, 1874.

moving under the action of inertia and the sun's repellent force, will describe paths which, for the purpose of description, we may regard as normal to the comet's orbit. Of all the particles driven off during a given period, those first repelled will have moved to the greatest distance from the orbit, those next in order will have moved to a less distance, and so on to the last, which will have moved to the least distance; it is obvious that the aggregate appearance of all these points at any time will be similar to that shown in Fig. 101.

The explanation just given is not dissimilar to that which would account for the formation of the curved and ever-widening train of smoke that is seen to follow a moving steamer. The smoke emitted at each instant is forced upward by the buoyant effort of the air, expanding as it rises, until it finally becomes so tenuous as to be invisible. The aggregate appearance of all the smoke emitted has at any instant a shape that is not unlike the curved tail of a comet, lying outside of, and curved toward the path of the steamer.

Volume of some Comets.

227. The famous comet of 1811 was one of the largest of which we have any record; the diameter of its head was about 600,000 miles, and its tail extended to a distance of more than 60,000,000 of miles, so that its entire volume was nearly or quite as great as that of the sun itself. The great comet of 1769 was 500,000 miles in diameter, and its tail not less than 50,000,000 of miles in length. As we have already stated, the great comet of 1843 had a tail whose length was 150,000,000 of miles.

In this connection several important questions arise: *first*, is it possible that the attraction of the head of the comet is sufficient to gather up all the matter that is thrown off to form the tail? *secondly*, if not, would the quantity of matter thus expended bear any appreciable proportion to that which remained? and *thirdly*, if the matter were not gathered up and condensed upon the body of the comet, would it condense by itself so as to form a new comet?

Varying Dimensions of the same Comet.

228. It is a well established fact that some comets actually diminish in bulk as they approach the sun, and expand again as they recede from that body. In other cases the change observed is exactly the reverse. These facts have suggested the idea that the condition of the matter in these two classes of comets is in some way quite different. The former set of facts has suggested the idea of a medium growing denser toward the sun, which acts by its pressure to condense the cometic matter in its approach to that body and permitting it to expand when receding; the latter set of facts would seem to render this idea untenable.

Grant, in his History of Physical Astronomy, says: "A more probable explanation has been suggested by Sir John Herschel. According to that astronomer, as the comet approaches perihelion the action of the solar heat will be constantly transforming the nebulous matter of which it is composed into the condition of a transparent invisible gas; and as this process necessarily takes place at the exterior of the nebulosity, where the solar rays impinge, the immediate consequence will be a diminution of the volume of the comet. After the passage of the perihelion the radiation of heat from the surface of the more condensed portion of the comet will not be sufficiently compensated by the solar heat received, and the difference of temperature thence arising will occasion a precipitation on the surface of the nebulous matter suspended in a gaseous state in the atmosphere of the comet. This precipitation of nebulous matter will continue to go on under the influence of the cooling process occasioned by the increasing distance of the comet from the sun, and the manifest result will be a rapid enlargement of the visible dimensions of the comet."

Source of a Comet's Light.

229. The question has been raised whether comets shine by their own or by reflected light. Arago undertook to settle the matter by experiment, making use of the optical principle that light emanating from a self-luminous body is not polarized, whereas reflected light is always more or less polarized. He found that cometic light was partially polarized, and from this he inferred that comets are opaque bodies shining by reflected light. This conclusion is obviously illogical, though the conclusion arrived at is in most cases probably true. It is plain that a comet might be self-luminous and yet reflect a certain amount of solar light, and this, mingled with emitted light, might give rise to a partial polarization.

It is the opinion of astronomers that some comets are self-luminous under certain circumstances, especially when they are near the sun. In receding from the sun, however, they diminish in brightness more rapidly than they would if they shone by their own light only.

According to a law of optics the brightness should vary inversely as the square of the distance the light has to travel to reach the eye. Now, in the case of a self-luminous body the distance traveled by the light is equal to its distance from the earth, but in the case of a body shining by reflected solar light the distance traveled is equal to that from the sun to the body and thence to the earth. When a body of this class is moving directly away from both the sun and the earth, the distance traveled by reflected light increases twice as fast as its distance from the earth, and consequently the brilliancy of the body decreases four times as fast as it would if self-luminous.

Distribution of Cometary Orbits.

230. The orbits of about 250 comets have been computed with considerable accuracy. Of these, according to Young, 5 or 6 are *hyperbolas,* about 50 are *ellipses,* and the rest are *parabolas.*

When the orbit is elliptical, the comet must return with due regularity ; but when it is either hyperbolical or parabolical, the comet after passing its perihelion, will continually recede from the sun, and ultimately must pass beyond the limits of his attraction, never to return.

Observations can only be made on a comet when it is comparatively near its perihelion, and then from the nature of the case they must be more or less imperfect. Inasmuch as there is little difference in the shape of a parabola and a very elongated ellipse in the neighborhood of their vertices, it may happen that many orbits which have been classed as parabolas are in reality elongated ellipses.

When a comet passes near one of the large planets, its orbit is greatly disturbed, and often completely changed in form. This influence is manifested, to a certain extent, by

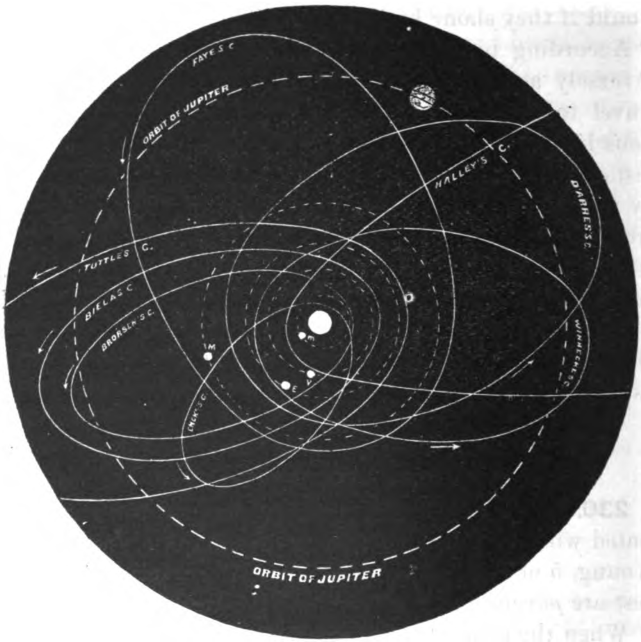

Fig. 108. Projections of a few Cometary Orbits on the Plane of the Ecliptic.

the grouping of those comets with which we are most familiar into classes, each of which corresponds to one of the large planets. Thus, the *Jovian* group contains 12 comets whose periodic times range from 5 to 8 years, and whose aphelion points are tolerably near the orbit of Jupiter, some within and some without; the *Saturnian* group consists of 2 comets, with periods of from 12 to 15 years, and whose aphelia are at a distance from the sun nearly equal to the mean distance of Saturn; the *Uranian* group contains 3 comets with periods of about 33 years, and whose aphelion distances are nearly the same as that of Uranus; the *Neptunian* group consists of 6 comets, whose periods range in the neighborhood of 75 years, and whose aphelion distances are all a little greater than the mean distance of Neptune. These groups embrace nearly one-half of all the comets whose orbits are certainly known to be elliptical.

The order of grouping of a few of the periodic comets is shown in Fig. 103, in which their orbits are projected on the plane of the ecliptic.

The orbits of comets are inclined to the ecliptic at almost every angle from 0° up to 90°, and their motions are about as likely to be *retrograde* as direct; of a catalogue of 201 comets given by Arago, 102 have a direct motion; that is, they move from west to east, and 99 have a retrograde motion. From a comparison of a large number of orbits, Chambers reaches the following general conclusions:

1°. "With comets revolving in elliptical orbits there is a strong and decided tendency to direct motion; the same obtains with the hyberbolic orbits; with the parabolic orbits there is a rather large preponderance the other way; and taking all the calculated orbits together, the numbers are too nearly equal to afford any indication of the existence of a general law governing the direction of motion.

2°. "There is a decided tendency in the periodic comets to revolve in orbits but little inclined to the ecliptic, and therefore a low inclination is an eminently favorable indication of a periodic comet.

3°. "There is a decided disposition in the orbits to congregate in and around planes inclined 50° to the ecliptic.

4°. "There is an evident tendency in the perihelions to crowd together in two opposite regions, between 60°–120°, and 240°–300°."

Disintegration of Comets.

231. Comets have sometimes been known to separate into two or more fragments. Grant, in his History of Physical Astronomy, says: "Seneca relates that Ephorus, an ancient Greek author, makes mention of a comet which, before vanishing, was seen to divide itself into two distinct bodies. The Roman philosopher appears to doubt the possibility of such a fact; but Kepler, with characteristic sagacity, has remarked that its actual occurrence is exceedingly probable.

"The latter astronomer further remarked that there were some grounds for supposing that two comets, which appeared in the same region of the heavens in the year 1618, were fragments of a comet that had experienced a similar dissolution. Hevelius states that Cysatus perceived in the head of the great comet of 1618 unequivocal symptoms of a breaking up of the body into distinct fragments. The comet when first seen in the month of November appeared like a round mass of concentrated light. On the 8th of December it seemed to be divided into several parts. On the 20th of the same month it resembled a multitude of small stars. Hevelius states that he himself witnessed a similar appearance in the head of the comet of 1661."

Biela's comet, having a period of about 6¾ years, and which was discovered in 1826, was seen in 1846 to separate into two distinct comets which continued to travel together at a distance of from 3′ to 4′ during the entire remaining period of their visibility. At this time the nuclei were separated by a distance of only 160,000 miles.

On its return in 1852, the comet was still divided, but the component parts had separated to a distance of a million and a half of miles. It was not seen either in 1859, 1865, or 1872. In the latter year, however, the earth passed through what was supposed to be the debris of the comet, and there is good reason to believe that the passage of some of its fragments through our atmosphere produced the meteoric shower of November 27th. This shower had been predicted, and the results verified the prediction.

The great comet of 1882 showed many indications of disruption, which were variously described by different astronomers. This comet passed its perihelion on the 17th of September. On the 4th of October the nucleus had become much elongated, and by the 10th of the same month it had taken on the appearance of an irregular string "of 6 or 8 starlike knots of luminosity connected and veiled by shining haze."

Prof. Young says, in speaking of this comet: "Another curious thing about the comet is the observation by Prof. Schmidt of flocculent masses of light moving in the same direction as the comet; these were seen by Schmidt from October 8 to October 11, and were also observed by Barnard of Tennessee, and by Brooks of New York. These cloud-like masses were very faint, not visible to the naked eye, quite large, and they moved on in the same direction and finally disappeared. The probability is that they were debris of the comet's large tail following around and finally coming into the neighborhood of the comet itself."

From these and other similar facts it has been thought by some that comets are frequently broken up into numerous fragments, which become scattered by disturbing forces both laterally and along the track of the comet, where they continue to revolve in the form of a stream of meteoric elements.

Remarkable Comets.

Halley's Comet.

232. This comet is of special interest to astronomers, as it was the first one whose return had been predicted by means of mathematical computation. It appeared in 1682, and Halley calculated, by Newton's method, the elements of its orbit. He found that the inclination of its orbit was 17°42′, the longitude of its perihelion 302°16′, the longitude of its node 50°21′, and its perihelion distance 54,000,000 of miles, its motion being retrograde.

He in like manner computed the elements of the comet of 1607, which he found to be almost identical with those given above. Again, by testing the observations made on the comet of 1531, he likewise found that *its* elements were also very nearly the same. He therefore inferred that the comets of those years were not different individuals, but so many reappearances of the same body, and he ventured to predict its return towards the end of 1758 or the beginning of 1759, allowing a few months for the changes in its orbit produced by the perturbations of the planets.

Clairaut, a French astronomer, undertook the laborious calculations necessary to determine the changes that would be produced in its orbit by the perturbations of Jupiter and Saturn, and as the result of his investigations, he announced that the comet would reappear within 30 days, one way or the other, of the middle of April, 1759. The comet actually passed its perihelion on the 13th of March, 1759, that is, about three days outside the limit assigned by the illustrious computer. This was, for these times, a wonderful triumph of science, particularly as the effects of perturbation were such as to cause a change of more than 600 days in the comet's entire period.

Damoiseau, with new elements, computed the time of its next return, and assigned November 4, 1835, as the date of its perihelion passage. Pontecoulant also made the computations and fixed upon November 13 as the time of its return to perihelion. In 1834, the path of the expected comet and its predicted positions for various dates from the 20th of August to the 26th of December were published in the *Annuaire du Bureau des Longitudes.* True to prediction, the comet appeared on the 5th of August, followed its assigned path, but a little behind time, and actually passed its perihelion on the 16th of November, only three days later than was predicted.

The following table shows the dates of the comet's successive returns to perihelion for 500 years, from which we may infer the great changes produced by planetary perturbation:

Perihelion passage.	*Time of revolution.*
1. Nov. 8, 1378.	
2. June 8, 1456	77 *yrs.* 212 *days.*
3. Aug. 25, 1531	75 *yrs.* 78 *days.*
4. Oct. 26, 1607	76 *yrs.* 62 *days.*
5. Sept. 14, 1682	74 *yrs.* 323 *days.*
6. March 12, 1759	76 *yrs.* 189 *days.*
7. Nov. 16, 1835	76 *yrs.* 249 *days.*

From this table we see that the length of its time of revolution is greatly affected by perturbation; the average time for six periods being 76 *yrs.* 62 *days.*

Previous to the 2d of October, 1835, the comet presented a round nebulous disk with a faint nucleus at its centre. On the evening of that day the nucleus had become very bright, and according to Bessel a cone of light appeared to issue from the side next the sun, which, after extending for a short distance from the head, was observed to curl backward, as if impelled by a force of great intensity directed from the sun. This was the beginning of the formation of a tail. The nebulous matter, which in the first instance was repelled from the comet towards the sun, rising in the form of an envelope, was afterward repelled by a powerful force driving it away from the sun.

The comet was observed by Sir John Herschel, after passing the perihelion. On the 25th of January it presented no trace of a tail, but resembled a round nebulous body about 2′ in diameter, surrounded by a coma of great extent. Within the disk was a small bright point, from which there issued in a direction opposite the sun, a ray of highly condensed light. The comet seemed to contain within it another miniature comet with a head and tail of its own.

As the comet receded from the sun the head began to dilate and its light to grow fainter; in consequence of successive additions to the length of its tail, the comet gradually assumed a paraboloidal form. The head and paraboloidal envelope enlarged with great rapidity, and at the same time the comet diminished in brightness until it finally ceased to be visible for want of light.

Donati's Comet.

233. This comet was discovered by Donati at Florence June 2, 1858; it was then about 200 millions of miles from the sun, and at a still greater distance from the earth. By the 13th of June *approximate elements* had been determined and its future path predicted. By the middle of August its orbit had been determined with much accuracy. Traces of a tail became visible on the 20th of August, and on the 29th of that month the comet, which had hitherto been telescopic, became visible to the naked eye, and for several weeks thereafter continued to be a conspicuous object in the northern heavens.

It was observed in this country by Bond of Cambridge, who published an account of his observations in the Mathematical Monthly, from which article we gather some of the more important facts of its history.

Bond says that the nucleus had a diameter of about 2000 miles on the 8th of September, with a surrounding nebulosity of about 3000 miles in diameter, while a diffused light extended for 40,000 or 50,000 miles toward the sun. At this time its tail was about 16 millions of miles in length. On the 20th of that month the train or tail was plainly bifurcated, the nebulous matter issuing from the head in two streams, of which the southern one was the brighter; its general outline was in the shape of an elongated hyperbola or parabola. By the 23d of September the nucleus had become as bright as a large star of the first magnitude, and it was about this time that Bond began to notice the formation of *successive* envelopes, which became so marked a feature in the history of this comet; its tail at this period was about 6° or 8° long, even in the presence of bright moonlight. In the telescope the nucleus appeared to be diminished in diameter, and its light was very intense; outside of this, and about 6,400 miles distant, was a bright envelope, and still outside of this was a fainter envelope; the tail was slightly curved.

By the 25th a new envelope was thrown off, which became clearly visible on the 27th, and as it expanded the tail received a new appendage in the shape of a ray of light nearly straight, and apparently tangent to the curved part of the tail, as shown in Fig. 101. On the 29th the comet was 50 millions of miles from the sun and 70 millions of miles from the earth, and its tail had become 26 millions of miles in length. At this time the nebulous matter was being thrown off with commotion, the jets streaming forth in various directions, but blending together and becoming more symmetrical as the matter rose from the comet.

The comet passed its perihelion on the 29th of September, and was nearest the earth on the 10th of October. Its rapid passage to the southern hemisphere rendered it invisible in the northern hemisphere after the end of October, though it was seen in the southern hemisphere as late as March 4, 1859.

After its perihelion passage new envelopes continued to be thrown off, and the nucleus continued to diminish in size. When at its brightest five distinct envelopes could be seen at the same time, separated from each other by dark bands. Rays or jets of luminous matter were numerous, each shooting forth from the convex side of the tail, which at its maximum was about 57,000,000 of miles in length.

At this time the comet's appearance, as drawn by Bond, is shown in Fig. 101.

In many respects this is the most remarkable comet that has been seen in modern times, and furthermore, it was more carefully studied than any previous comet.

Its orbit was computed by various astronomers, but the results of their labors were somewhat discordant: the periodic time was variously assigned from 1,620 up to 2,470 years; from this discrepancy we may infer the great difficulty of the problem of determining the exact orbit of such a comet.

Comparison of Halley's and Donati's Comets.

234. Phenomena similar to those just described were noticed at the last appearance of Halley's comet. The conclusions deduced by Sir John Herschel are apparently confirmed and strengthened by the observations made on Donati's comet. These conclusions, as summarized by Herschel in his Outlines of Astronomy, are as follows:

1°. That the matter of the nucleus is powerfully excited and dilated into a vaporous state by the sun's rays, escaping in streams and jets at those points of its surface which oppose least resistance, and in all probability throwing the nucleus into irregular motions in the act of escaping, thus altering its direction.

2°. That this process takes place in that portion of the nucleus which is turned toward the sun, the vapor escaping chiefly in that direction.

3°. That when so emitted it is prevented from proceeding in the direction of the force of emission by some force directed *from* the sun, which drifts it back and carries it out to a vast distance behind the nucleus, forming the tail, or so much of the tail as can be considered as consisting of material substance.

4°. That the force, whatever may be its nature, acts unequally on the materials of the comet, the greater portion of which remains unvaporized, a considerable part of the vapor actually produced remaining in the neighborhood to form the coma.

5°. That the force thus acting on the material of the tail cannot possibly be identical with gravitation, being centrifugal, or repulsive with respect to the sun, and of an energy far exceeding the gravitating force toward that body.

6°. That unless the matter of the tail thus repelled from the sun be retained by a peculiar and highly energetic attraction toward the nucleus, differing from and exceptional to gravitation, it must leave the nucleus altogether; it is therefore conceivable that a comet may lose at each approach to the sun a portion of that peculiar matter, whatever it may be, on which the production of the tail depends, the remainder being of course less excitable by solar action and more impassive to his rays, and therefore more nearly approximating to the nature of the matter of planetary bodies.

7°. That considering the immense distances to which some of the matter of the tail is carried from the comet, it is quite inconceivable that the whole of that matter should be reabsorbed, and therefore that it must lose during its perihelion passage some portion of its matter; and if, as would seem far from improbable, that matter should be of a nature to be repelled from, not attracted by, the sun, the remainder will by consequence be more energetically attracted to the sun than the mean of both. If, then, the orbit be elliptic, it will perform each revolution in a shorter time than the preceding one, until at length the whole of the repulsive matter will be thrown off.

The Great Comet of 1882.

235. This comet was first seen and observed in the southern hemisphere on the 7th or 8th of September, 1882.

On the 17th, the day of its perihelion passage, it was observed at the Cape of Good Hope in broad daylight, and when in the immediate neighborhood of the sun. Mr. Gill says: "The comet was followed by two observers with separate instruments right up to the sun's limb, when it suddenly disappeared at 4h. 50m. 58s. mean local time." After passing to the west of the sun it continued visible by daylight for a day or two, and was seen by various astronomers in all parts of the world. A few days after its perihelion passage it became a conspicuous object in the eastern heavens before daylight, and continued visible, with diminishing brightness, for several weeks.

In passing its perihelion, which it did at a distance of only 300,000 miles from the sun's surface, its orbital velocity was so great that it moved through an angle of 180° in less than 4 hours; it must have passed through the sun's coronal atmosphere at the rate of about 300 miles per second.

On the 2d of October its nucleus was as bright as a large star of the *first* magnitude, and the coma and tail were well developed, with a clearly marked dark streak extending backward from the nucleus. It was noticed at this time that the nucleus, instead of being round, was elongated in the direction of the comet's radius-vector; it continued to elongate, and in about a week it presented the appearance of a string of knotted star-like points. Its tail was very broad and bright, with a slight curvature; its length on the 15th of October was about 60 millions of miles, which corresponded to an arc of 18° of the heavens.

The spectroscopic observations of Thollon and others indicated the presence of incandescent sodium in the nucleus; the nucleus also gave a nearly continuous spectrum in which the Frauenhofer dark lines were quite inconspicuous, showing that but little of the comet's brilliancy was due to reflected solar light. Ricco of Palermo saw, besides the bright sodium line, several other bright lines, but for want of suitable means was unable to locate their position in the spectrum.

When the elements of this comet were compared with those of preceding comets, they were found to bear a striking resemblance to those of the comets of 1880, of 1843, and of 1668. From the computed lengths of the periods of these comets, it seemed almost impossible to believe that it could be a return of any one of them; we are therefore led to the conclusion that it is one of a group or family which are revolving in nearly the same orbit. This conclusion will not appear improbable when we come to consider the relation between comets and meteor streams.

Prof. Young, in writing on this comet, notices a phenomenon somewhat similar to that already spoken of as having been seen in connection with Halley's comet. He says that Ricco's drawing of the comet as it appeared on the 4th of October shows something resembling a bright comet enveloped in a fainter one. He further says: "Prof. Smith of Kansas University noticed on the 9th a pale stream of light with parallel edges, and nearly as wide as the tail of the comet, extending towards the sun. On the 15th this phenomenon had become much more conspicuous. The streamer was now one-half a degree in width, well defined at both edges, of nearly uniform brightness throughout, though nowhere as bright as even the faintest portion of the tail, and extended from its origin, a degree or two above the nucleus, to a distance of two or three degrees below the head, where it faded out."

The comet remained visible in the telescope till May; it was observed on the 6th of April by Ricco, at which time it was about 5 hours west of the sun.

Encke's Comet.

236. This comet, which was first noticed by Pons of Marseilles, derives its name from the astronomer who first computed its orbit. From the observations made in the latter part of 1818 and the beginning of 1819, Encke found that the comet revolved around the sun in an elliptical orbit in the short period of about 3⅓ years.

In comparing the elements of this comet with those of the comets that were visible in 1795 and 1805, he concluded that they were identical, and he also inferred that it would return in 1822; but at the date assigned its position in the heavens was such as to prevent its being seen in the northern hemisphere, but it was seen and observed by M. Rümker of Paramatta for about three weeks. The observations thus obtained enabled Encke to predict its next return, which he found would occur on the 16th of September, 1825.

It was seen at this return, and also to better advantage on its return in 1828. On the 30th of November, or more than a month before its perihelion passage, it was visible to the naked eye as a star of the 6th magnitude, and a week later it appeared as a star of the 5th magnitude. In the telescope it appeared to be a slightly oval mass of nebulous matter with a nucleus excentrically situated on the side nearest the sun.

This comet is rendered remarkable by the continued diminution of its periodic time, which amounts to about 2½ hours at each successive return. This peculiarity had been noticed by Encke, who suggested that space was filled with a rare ethereal medium, sufficiently dense to produce by its resistance an effect on the motion of the comet, but of such tenuity as to exercise no sensible effect on the motions of the more massive planets.

"The contraction of the orbit must be continually progressing, if we suppose the existence of such a medium, and we are naturally led to enquire, what will be the final consequence of this resistance. Though the final catastrophe may be retarded for many ages by the powerful attraction of the larger planets, especially Jupiter, will not the comet be at last precipitated on the sun? The question is full of interest, though altogether open to conjecture."

The rate of diminution is shown in a table constructed by Encke, and which may be found in Chambers' Astronomy. From this table we see that the diminution has progressed with great regularity; in 1795 the periodic time was 1212.55d., in 1822 it was 1211.66d., in 1852 it was 1210.65d., and in 1865 it was reduced to 1210.22d.

It would seem, if the retardation spoken of, and which acts to diminish the periodic time, is due to a resisting medium, that it would produce similar effects on other comets; but no such effect has been shown. The question of the existence of a resisting medium is, and must remain, unsettled until further investigations have been made.

Meteorites.

237. Besides the bodies already described as members of our system, there are undoubtedly multitudes of cosmical bodies which are embraced within the limits of the sun's attraction, but which on account of their minute size must remain forever invisible and unknown to us, except when they come so near the earth as to be involved in her atmosphere; then, in accordance with well-known physical laws, they become heated to such an extent as to make them luminous and consequently visible. These bodies will be considered under the general name of **meteorites**; as we shall see hereafter, these bodies, as well as the planets, are subject to the law of universal gravitation; they also possess all the attributes of terrestrial matter, and like it are subject to the same physical laws.

When a very small meteorite enters our atmosphere it becomes incandescent and is visible for a short time, as it moves along its path, constituting what is called a **shooting star.** When the meteorite is larger and when it becomes involved in a denser portion of the atmosphere, it presents the appearance of a brilliant planet; it is frequently followed by a *train* of greater or less extent, and oftentimes it explodes with more or less violence; it is then called a **fire-ball**. When the meteorite is still larger it frequently escapes destruction in the atmosphere and falls to the earth, either as a unit, or, after one or more explosions, in fragmentary portions; the masses that reach the earth are called **aerolites**. All these phenomena are styled **meteoric**, and it is probable that they are all essentially identical.

Shooting Stars.

238. The phenomenon of a *shooting star* is by no means a rare one. It is within the experience of every one who has watched the heavens for a single hour that shooting stars are of constant occurrence.

Ordinarily a bright point of light, resembling a star, shoots along the sky for a certain distance and then disappears from view. Sometimes it leaves a faint train behind it which continues visible for a short time after the *stellar point*, or *nucleus*, has disappeared, much as a rocket marks its course by the train of light which it leaves along its path. Shooting stars of this kind can be seen every fair evening, and usually as many as four or five are visible every hour. At certain times they are so numerous as to constitute what is called a **meteoric shower**.

Meteoric Showers.

239. Many meteoric showers have been noticed, the most striking of which are of periodical occurrence. Among the most remarkable of these periodic showers is that which takes place about the 13th of November, and that which happens about the 10th or 11th of August. The November meteors are most numerous at intervals of 33 or 34 years; the August meteors are visible every year; the reasons of these variations will be apparent when we come to explain the theory of their occurrence.

Ordinary shooting stars are believed to be due to individual meteorites; meteoric showers are accounted for by supposing that innumerable streams of meteorites are revolving around the sun in regular orbits, and subject, like other bodies of the solar system, to planetary perturbation. These streams are often of enormous breadth, perhaps millions of miles, and the meteorite masses are supposed to be distributed along them, either uniformly, or in condensed groups. It is further supposed that the earth's orbit intersects some of these streams, and that meteoric showers occur when the earth is passing these points of intersection.

When the earth passes through a part of the stream where the meteorites are sparsely distributed, the corresponding shower is inconspicuous; but when it passes through the denser regions of the stream, the meteoric display is exceedingly brilliant.

It is undoubtedly the case that there are multitudes of these streams which are not intersected by the earth's orbit, as well as others which are just grazed by it, or through which it passes excentrically.

The cause of a meteor's becoming luminous is easily explained. Whenever a meteorite enters the Earth's atmosphere, which it usually does with planetary velocity, it experiences a resistance, whether by friction or by collision with the aerial particles, by virtue of which its velocity is diminished; and in accordance with a law of physics a portion of the body's energy of motion is converted into heat, which soon renders the body incandescent.

The varied circumstances of size, velocity, and direction of motion serve to explain all the irregularities of appearance presented by these remarkable bodies. There is good reason to believe that a great majority of them are very small, in fact mere particles of cosmical dust; these are totally consumed in their transit through the atmosphere.

Some are larger, and they may be either consumed in the atmosphere, or they may escape total destruction and continue their motion through space; others again may enter our atmosphere in such a direction that their relative velocity with respect to the earth is comparatively small, and these may fall to the earth with little or no physical change.

November Meteors and Tempel's Comet.

240. A remarkable shower of meteors took place on the 13th of November, 1799. It was visible over the greater part of North and South America, having been witnessed by the Moravian missionaries in Greenland, and by Humboldt, who was then traveling in South America.

In Humboldt's description of the phenomenon, he says: "Towards the morning of the 13th we witnessed a most extraordinary scene of shooting meteors. Thousands of bodies and falling stars succeeded each other for four hours. Their direction was very regular from north to south. From the beginning of the phenomenon there was not a space in the firmament equal in extent to 3 diameters of the moon which was not filled every instant with bodies or falling stars. All the meteors left luminous traces or phosphorescent bands behind them, which lasted seven or eight seconds."

Mr. Ellicott, who witnessed the display from a vessel in the Gulf of Mexico, says: "The phenomenon was grand and awful. The whole heavens appeared as if illuminated with sky-rockets, which disappeared only with the light of the sun, after daybreak. The meteors, which at any one instant of time appeared as numerous as the stars, flew in all possible directions, except *from* the earth, *towards* which they were all inclined, more or less; and some of them descended perpendicularly over the vessel we were in, so that I was in constant expectation of their falling on us."

Meteoric showers took place on the 13th of November, in 1831 and 1832, but the most interesting display was on the 13th of November, 1833. It was, like the shower of 1799, visible over a large part of America, especially in the United States, where it commenced about midnight and continued till morning.

Its character was similar to that described by Humboldt; its effect on the minds of the negroes is thus described by a Southern planter: "I was suddenly awakened by the most distressing cries that ever fell on my ears. Shrieks of horror and cries for mercy I could hear from most of the negroes of three plantations, amounting in all to about 600 or 800. While earnestly listening for the cause, I heard a faint voice near my door calling my name. I arose, and taking my sword, stood at the door. At this moment I heard the same voice still beseeching me to rise, and saying 'Oh, my God, the world is on fire!' I then opened the door, and it is difficult to say which excited me most, the awfulness of the scene or the cries of the distressed negroes. Upwards of one hundred lay prostrate on the ground, some speechless, and some with the bitterest cries, with their hands raised, imploring God to save the world and them. The scene was truly awful, for never did rain fall much thicker than the meteors towards the earth; east, west, north, and south, it was the same."

From about 2 o'clock for a period of two or two and a half hours the number of meteors which fell was too great for computation. They were of all sizes, from mere phosphorescent points up to the most magnificent fire-balls. It was found, by tracing back their luminous paths, that they all seemed to emanate from the neighborhood of the star γ Leonis, and this without reference to its altitude. The various reports of this meteoric display were collated by Prof. Olmstead of New Haven, and by Prof. Newton, who was led to examine the previous records of similar showers. Abundant evidence was found to establish the belief that the

November meteor showers were of a periodic character, and a return of the phenomenon was predicted in 1866. At this time, the heavens were carefully watched by many observers on both continents.

The number of meteors seen in America was not as great as had been expected, but the display in Europe, though not so grand as those that have been described, was exceedingly striking. It was estimated that 10,000 meteors were observed at Greenwich, all of which seemed to radiate from a point between γ and ϵ Leonis. Mr. Dawes, who observed the phenomenon, says that 2,800 meteors were counted by himself and one assistant looking toward the east in the course of 2¼ hours, while another assistant looking west counted about 400 an hour until he became bewildered by six or seven bursting out simultaneously.

From all the data that can be gathered it appears that the great November showers occur at intervals of 33 or 34 years, but that minor showers take place on the 13th of November for a few years both before and after the maximum displays. From these facts it is inferred that the November meteors are due to a ring or stream of meteorites circulating around the sun, through which the earth passes on or about the 13th of November each year; the extraordinary showers are supposed to correspond to the passage of the earth through a part of the stream where the meteorites are densely packed, and which is believed to be some 40 or 50 millions of miles in length; in ordinary years the path of the earth is through portions where the meteorites are fewer in number.

The orbit of this stream of meteorites has been computed with considerable accuracy, and it is found to be very nearly the same as that of Temple's comet, which passed its perihelion in January, 1866, as will be seen from the following table :

	Meteors.	*Comets.*
Longitude of perihelion..........	56°26′	60°28′
Longitude of ascending node......	231°28′	231°26′
Inclination to ecliptic............	17°45′	17°18′
Excentricity......................	0.9046	0.9054
Perihelion distance..............	0.9873	0.9765
Period.........................	32.25y.	32.18y.
Motion.........................	retrograde	retrograde.

Its aphelion distance is somewhat greater than the distance of Uranus, so that this meteoric stream and its accompanying comet belong to the Uranian group.

The fact of the comet's orbit coinciding so nearly with that of the meteoric stream seems to indicate a connection of some kind: whether the comet consists of a compacted mass of the meteorites constituting the stream, or whether the meteorites have resulted from the disintegration of a comet which was once far larger than Tempel's comet, is perhaps undecided.

The August Meteors and the Third Comet of 1862.

241. The August meteors are less striking than those of November, but they are more regular in their appearance. Every year from the 9th to the 12th of August an unusual number of meteors may be seen, whose paths on being traced back are found to intersect at a point in the constellation Perseus. This point, which is called the *radiant point*, has caused the August meteors to be called *Perseids*, and for a similar reason the November meteors, which radiate from a point in Leo, are called *Leonids.*

It is inferred that the August meteors are due to a stream of meteorites of enormous extent through which the earth passes about the 10th or 11th of August; it is also believed that the meteorites which constitute this stream are more equably distributed than in the November stream.

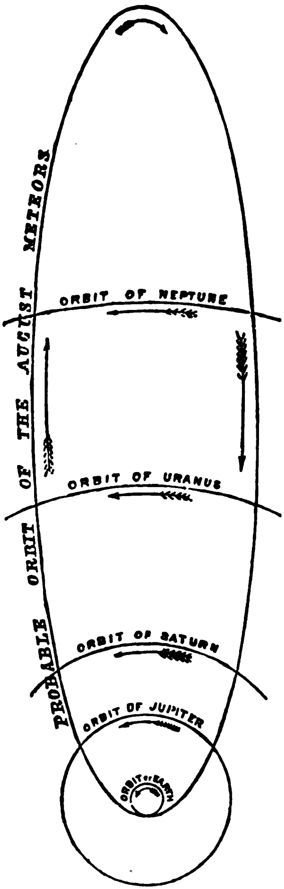

Fig. 104. Orbit of the August meteors.

The orbit and the extent of this stream, which is shown in Fig. 104, were investigated by Schiaparelli, who found that in some of its elements it was closely analogous to the *third* comet of 1862, sometimes called Tuttle's comet. The extent of this resemblance is shown in the following table of elements:

	Tuttle's comet.	*August meteors.*
Longitude of perihelion.....	344°40′	343°38′
Longitude of ascending node	138°15′	137°27′
Incline to ecliptic.....	66°25′	63°8′
Perihelion distance..........	.9626	.9643

The excentricity of the meteoric orbit is such as to throw its aphelion point beyond the orbit of Neptune, so that this group of meteorites, and perhaps also Tuttle's comet, belong to what we have already spoken of as the Neptunian group of comets.

It is believed that other meteoric streams are, in like manner, closely related to corresponding comets.

Heights at which Shooting Stars are Seen.

242. The most systematic attempt to ascertain the height above the earth at which a shooting star may be seen was that made by the officers of the U. S. Naval Observatory on the occasion of the November shower in 1867, and which is alluded to by Prof. Newcomb in his *Popular Astronomy.*

He says that Prof. Harkness was sent to Richmond to map the apparent paths of the brighter meteors there visible, which were afterwards compared with their apparent paths as seen from Washington. Prof. Newcomb says: "The general result was that they were first seen at an average height of 75 miles, and disappeared at a height of 55 miles. There was no positive evidence that any meteor commenced at a height much greater than 100 miles."

Motions of Shooting Stars Described.

243. Some shooting stars move so rapidly that the eye can scarcely follow them, whilst others remain visible for a considerable fraction of a minute, moving so slowly that their path can easily be traced out amongst the stars. Some move at the rate of 40 to 50 miles a second, whilst others travel no more than one-fourth or one-fifth as fast.

Some describe arcs of but a few degrees in extent, others are visible through more than 90° of arc. Some are so small as to be almost evanescent, others are more brilliant than the brightest star or planet.

It is to be noted that meteors, as a general rule, and this is especially the case with those constituting a meteoric shower, are more numerous after midnight than before. This fact is explained by the circumstance that we are at that time on the hemisphere of the earth which is turned toward the direction in which the earth is moving in its journey around the sun.

Fire-balls.

244. Fire-balls, as already intimated, are similar to shooting stars, only much larger. They often appear to be nearly as large as the moon, with long and brilliant trains, and sometimes they appear to burst like a rocket. Not infrequently they are so bright as to be seen in broad daylight. Arago gives a list of more than 650 fire-balls, of which nearly half have appeared during the present century.

The following quotation from his list shows some of the leading characteristics of this peculiar species of meteor: "1836, February 12, at 6h. 27m. in the morning, a fire-ball was seen at Cherbourg moving from the east. Its appearance was that of a ball of fire, and to the naked eye it seemed to have a disk nearly equal to that of the full moon.

"It was of a purplish color, and its light was intense enough to illumine the entire horizon, so that people could read in the streets as though it were broad day. It was surrounded by a whitish envelope, which was obscured at a single point by vapor emitted from the ball. It seemed to be no more than 900 feet above the hills over which it passed. On its first appearance it moved at the rate of half a league per minute with a well-marked rotation on an axis.

"It seemed to stop for a time, and then moved on with the speed of an arrow, falling to the earth at the distance of 12 leagues with an explosion similar to that of a salvo of artillery. It had a train of a whitish color that narrowed down to a point."

Chambers quotes the following description of a fire-ball seen by Rev. T. W. Webb in Herefordshire, England, on the 12th of November, 1861: "About 5h. 45m. . . . we were walking, a party of three persons, along a wide turnpike road, fully lighted by a moon 10 days old, when we were surrounded and startled by an instantaneous illumination, not like lightning, but rather resembling the effect of moonlight suddenly coming out from behind a dark cloud in a windy night; it faded very speedily, but on looking up we all perceived at a considerable altitude, perhaps 60° or 70°, a superb mass of fire, sweeping onward and falling slowly in a curved path down the southwestern sky.

"Its form was that of a pear, or more precisely an inverted balloon, and its size probably 30′ by 15′ at first, if not more; but it gradually diminished, and by the time it had attained the middle of its course it may not have exceeded 20′ by 10′. Its light was a beautiful blue, resembling, though far surpassing in vivid intensity, the hue of the asteroid Flora as we saw it many years ago with the 7-inch object-glass of the telescope now at the Greenwich Naval School.

"Ruddy sparks, of the color of glowing coals, were left behind at its smaller end, and its path was marked by a long pale streak of little permanency. . . . The whole duration may have been as much as 5 seconds. Its aspect was decidedly that of a liquefied and inflamed mass, and the immediate impression was that of rapid descent; but as its apparent magnitude diminished so much, it is not improbable that it was in reality moving in a course not greatly inclined to the surface of the earth."

Humboldt, after saying that smoking luminous fire-balls are sometimes seen, even in the brightness of tropical daylight, equaling in size the diameter of the moon, gives the following fact: "A friend of mine was in the year 1788 at Popayan, a city which is in 2° 26′ N. lat. and at an elevation of 5,583 ft. above the sea, and at noon when the sun was shining brightly in a cloudless sky, saw his room lighted up by a fire-ball. He had his back turned to the window at the time, and on turning around perceived that a great part of its path was still illuminated by the brightest radiance."

In the month of July, 1860, a remarkable fire-ball passed over the State of New York and part of New England in the early evening, which was seen by thousands of people.

It entered the United States near Niagara Falls, and moving a little south of east crossed the entire State of New York, leaving it in the neighborhood of Yonkers; it was seen passing over the southwestern part of Connecticut and across Long Island Sound, and was finally seen at sea nearly 400 miles east of Montauk Point.

To the observers along its path it seemed on the point of falling to the earth, but it is believed that it escaped destruction, and after passing through our atmosphere continued its path through space. This body was of enormous size, some observers of good judgment estimating its actual diameter to be as great as half a mile.

Aerolites.

245. In most cases the material substances constituting shooting stars are so far consumed that no part reaches the earth, unless it be in the form of an impalpable powder or dust. Occasionally, however, solid metallic or mineral masses fall to the earth, giving us an opportunity to study the physical constitution of these extra-terrestrial masses of cosmical matter.

The chemical elements of which aerolites are composed are the same as are found in terrestrial bodies; some of the most important of these are iron, nickel, cobalt, manganese, chromium, copper, arsenic, zinc, potassium, sodium, sulphur, phosphorus, and carbon. The manner in which these elements are combined is in some cases such as to give a somewhat peculiar feature to the mineral compounds which are found in these bodies, and it is frequently the case that the forms of crystalline aggregation which they offer are different from our terrestrial minerals. These peculiarities have enabled scientists to identify many mineral masses that have been found, from time to time, as belonging to the class of meteorites.

The crystalline structure of some of the aerolites is shown in Fig. 105.

In many specimens the principal elements are iron and nickel; in some cases the amount of iron is no less than 96 per cent. of the entire mass; they are also frequently richer in nickel than our finest nickel ores. In other specimens the elements are principally of an earthy character, scarcely 2 per cent. of iron being present. Somė are largely composed of phosphorus, iron, and nickel, and some of compounds of sulphur and magnetic pyrites. But in no case has any element been discovered that is not recognized as a terrestrial substance.

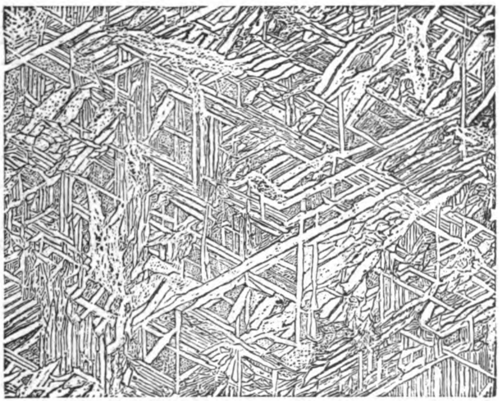

Fig. 105. Copy of a Print.

EXPLANATION. Fig. 105 is a copy of a print made by using a section of an aerolite which had been acted upon by an acid.

As an illustration of the composition of the ferruginous class of aerolites, we may cite the case of a meteoric body that was found by Gen. Carlton, of the U. S. Army, in Arizona. This body was found in 1864, and is now in possession of the Society of Pioneers of San Francisco. It is over 4 feet in length, and it weighs 632 lbs.; at the time of its discovery it was used by the Indians as a sort of anvil, on which they hammered out their rude copper implements. A portion of this aerolite has been analyzed by Prof. Brush of Yale College, with the following result:

	Per cent.
Iron	81.56
Nickel	9.17
Cobalt	0.44
Copper	0.08
Phosphorus	0.49
Silica	3.63
Protoxide of Iron	0.12
Lime	1.10
Magnesia	2.43
	99.02

with traces of alumina, chlorine, sulphur, and chromium. Most aerolites when found are coated by a thin crust of fused material, which has a glossy, pitch-like appearance; this crust is indicative of the sudden and intense heat to which they have been exposed in their transit through our atmosphere. The crust is usually separated from the interior mass by a well-marked surface, and as a general thing the interior nucleus bears no trace of fusion.

Size of Aerolites.

246. The sizes of aerolites vary from the minutest particles up to masses weighing hundreds of pounds. An immense one was discovered in Siberia weighing 1,680 lbs., which now forms an attractive feature in the Imperial Museum of St. Petersburgh. A specimen weighing about 1,400 lbs. was found in Brazil and sent to England, being at present in the British Museum; this is supposed to be only a fragment of an enormous body, of which a still larger portion has never been removed. The great aerolite found in Arizona, and already referred to, weighs more than 600 lbs.

The aerolites above mentioned were not seen to fall, but are known to belong to this class of bodies by their physical characteristics. Besides these and numbers of others of like character, there are multitudes scarcely less in magnitude which have been seen to strike the earth.

Arago gives a catalogue of 237 which have fallen since the beginning of the Christian era, most of which belong to modern times. Of these we may mention an aerolite which fell at Vouille in 1831, and which weighed 45 lbs.; one fell at Chantourney in 1812, weighing 76 lbs.; one at Juvenas in 1821, whose weight was 207 lbs., and one in New Grenada in 1810, which weighed 1,688 lbs. The last was composed of 92 parts of iron and 8 parts of nickel; it had no external crust and was only a fragment.

The fall of these bodies has not been unattended with danger to property and to life. A stone is said to have fallen in China in the year 606, which killed *ten* men and did other damage. In 1764 an aerolite fell on the deck of a ship in the Dutch East India service, which killed *two* sailors. About the same time one fell in Milan, killing a Franciscan monk.

The chemist Laugier left in his cabinet a splinter of an aerolite which was said to have fallen in Rockford (in the United States); this stone killed a farmer, destroyed a cottage, and was buried six feet in the earth. On the 7th of March, 1618, the Palais de Justice, in Paris, was burned, supposed to have been set on fire by a falling meteor; and in 1761 a house was burned at Chambleau, having been set on fire in like manner. Many other instances of accidents from these bodies have been recorded.

Remarkable falls of Aerolites.

247. The following instances of remarkable falls of aerolites are taken from Prof. Kirkwood's valuable work on Comets and Meteors:

In 1795 a large meteoric stone fell in Yorkshire, England. Several persons heard the report of an explosion in the air, followed by a hissing sound, and afterward felt a shock as of a heavy body falling to the ground. A plowman saw a stone fall, throwing up the mould on every side. It penetrated the soil, lodging in the chalk rock below. When raised it was found to weigh 56 lbs. The noise of the explosion was heard over a considerable district.

A fall of aerolites happened at L'Aigle, France, on the 26th of April, 1803. At 1 o'clock a tremendous noise was heard, and at the same time an immense fire-ball was seen moving through the atmosphere with great rapidity. A violent explosion followed, which was heard for seventy miles around. A great number of meteoric stones fell to the earth, of which about 3,000 were picked up; the largest of them weighed 17 pounds.

Early in the present century a large meteor exploded over Weston, Connecticut, just after daybreak. Its apparent diameter was half that of the full moon, and its time of flight was about 30 seconds. Within less than a minute from the time of its disappearance three distinct reports like discharges of artillery were heard, and each explosion was followed by a fall of stony fragments, which when first found were so soft as to be easily pulverized between the fingers.

On the 1st of May, 1860, a shower of meteoric stones fell in Guernsey county, Ohio. The meteor passed over at 1 o'clock, P.M., and was disrupted by a succession of explosions. As a result, a shower of stony fragments fell over an area of about ten miles in length and three miles in width. The largest piece picked up weighed 103 lbs.; it struck the earth at the foot of an oak tree, and after cutting off two roots, one five inches in diameter, and grazing a third, it penetrated a bed of hard clay to a depth of two feet and ten inches.

XII. THE SUN AND THE STARS.

The Sun's Rank among the Stars.

248. The sun is one among a vast host of similar bodies that we have called *fixed stars*, and it is not supposed that he differs in any material respect from the other individuals of his class.

It is believed with good reason that he is neither one of the largest nor one of the smallest of these bodies; so that if he were removed to a distance from us equal to that of the other stars he would appear no brighter than they.

If he were placed at a distance from us equal to that of the nearest star, he would subtend an angle of less than a *hundredth part* of a second of arc, that is, he would appear no larger than would a globe one foot in diameter at a distance of 4,000 miles; hence, his disk would have no *appreciable* diameter even in the most powerful of our telescopes.

Apparent Proper Motions of the Stars.

249. As stated in Art. 42, many of the stars have proper motions sufficiently great to admit of measurement. This fact was suspected as early as 1717 by Halley, who compared the places of the three prominent stars, *Sirius, Arcturus,* and *Aldebaran,* as determined by the observations of the early Alexandrian astronomers, with their known positions at the time of making the comparison.

After making due allowance for changes in the positions of the vernal equinox and the equinoctial, the result indicated that these stars had moved in the interval through arcs of 37′, 42′, and 33′, respectively. Inasmuch as the ancient observations must have been very defective, but little reliance could be placed on the corresponding *rates* of motion; the fact that the stars had actually moved through considerable distances was, however, undeniable.

Observations made since the time of Halley, with improved instruments, show that many other stars have an apparent proper motion, though but few have been discovered whose annual change of position exceeds a single second of arc. Of these the following are some of the most conspicuous. The star 1830 of Groombridge's catalogue moves at the rate of more than 7″ per year; the star μ Cassiopeiæ moves more than half as fast; and the star α Centauri has a motion nearly equal to that of μ Cassiopeiæ.

Among the rapidly moving double stars we may mention 61 Cygni, whose components are separated by an arc of about 15″. It is found that the apparent proper motion of each of the components is more than 5″ a year, but that the distance between them remains unchanged.

Secchi, in speaking of the relation between proper motions and magnitudes, says that there are some quite small stars that have a large proper motion; but when a great number of stars are considered, he lays it down as a general rule that the largest stars have the largest proper motions, and for equal magnitudes that double stars have a greater proper motion than single ones.

The directions in which different stars are moving are widely different. Mr. Proctor, who has bestowed much attention on the subject, thinks that he has discovered a tendency among stars belonging to certain natural groups to move in a common direction. Thus, he finds that five of the seven stars forming the dipper, viz., β, γ, δ, ε, and ζ, are moving in a common direction, while the other two, α and η, are moving in the opposite direction; the first five, with certain minor companions, constitute a common system to which the other two do not belong. Again, in the

Pleiades about one-half of the stars are moving in a common direction, and the remaining ones in an entirely different direction.

These various motions are so small that their effects are scarcely perceptible in a single generation, but in the course of ages they must cause a complete change in the aspect of the heavens.

Applications of Photography.

250. The relative motions of the stars were, until quite recently, determined by the ordinary methods of right ascensions and declinations, or else by the aid of the position micrometer. Within a few years, however, the method of photography has been gradually coming into use, and for many purposes it bids fair to supersede all others.

Photography has been employed in the investigation of solar phenomena, with continually increasing success, for more than a quarter of a century. By its use in this direction, under the lead of such men as Rutherford and De la Rue, new light has been thrown on the question of periodicity in the changes of the sun's surface, eclipse phenomena have been investigated, the solar spectrum has been mapped even beyond its visible limit, and recently, under the skilful manipulation of Janssen, photographs of the solar photosphere have been obtained, which afford facilities for the study of that important envelope that can be attained in no other way.

Its application to the study of the stars received its first great impulse in 1864, when Mr. Rutherford began the construction of an object-glass which should be corrected for *actinic* or *photographic rays* in the same way that an ordinary objective is corrected for visual rays. When finished this lens had an aperture of 11¼ inches and a focal length of nearly 14 feet. Lockyer says: "With this he obtained impressions of ninth magnitude stars, and within an area of a square degree in Præsepe in Cancer twenty-three stars were photographed in three minutes' exposure. Castor gave a strong impression in one second, and stars of 2″ distance showed as double. But even with this method Mr. Rutherford was not satisfied. Coming back to the 11¼-inch object-glass which he had used at first, he determined to see whether or not the addition of a meniscus lens outside the front lens would not give him the requisite shortness of focus and bring the actinic rays absolutely together. By this arrangement he got a telescope which can be used for all purposes of astronomical research, and he has also eclipsed all his former photographic efforts."

To describe the details of photographing groups and clusters would exceed our assigned limits; suffice it to say, that his process enabled him to obtain impressions of stars down to the tenth magnitude with such distinctness that their relative positions could be determined to the greatest degree of accuracy by means of an ingenious arrangement of powerful microscopes.

This method of photography cannot fail to be of the utmost value to future astronomers in determining the apparent motions of the stars.

Proper Motion of the Sun.

251. We have seen that many of the stars appear to be moving through space, and it is but reasonable to suppose that a part, at least, of their seeming motions is due to an actual motion of the sun, and consequently of the entire solar system.

If the stars were absolutely at rest and the sun moving in a definite direction, it is obvious, from the principles of perspective, that the stars would *appear* to move in paths *diverging from* the point of the celestial sphere toward which the sun was moving and *converging* to the opposite point. The stars, however, are not at rest, but are moving, as we have reason to believe, in every possible direction; it seems highly probable that these motions are such as to neutralize each other's effects so far as regards the sun's proper motion in space. Hence, if we find that the *average tendency* of the stellar motions is *away from* some definite point of the heavens and *toward* the opposite point, we may fairly infer that the former point is that toward which our system is drifting.

Sir William Herschel investigated the matter in 1783, and from the slender data at his command, he concluded that the sun is moving toward a point near the star λ Herculis. More than half a century later, Argelander, from more reliable data, inferred that the sun is moving toward a point also in the constellation Hercules, but at a little distance from that indicated by Herschel. These conclusions have been substantially confirmed by the more recent investigations of Strüve, Galloway, Airy, and other eminent astronomers.

It is now pretty generally conceded that the entire solar system is moving toward some point of the constellation Hercules; according to Airy, its annual rate of motion is 158 millions of miles.

Distances of the Stars.

252. It is shown in Art. 70 that the distance of a fixed star from the sun is equal to 92,500,000 miles *divided by* the star's annual parallax. Hence, the determination of a star's distance must depend upon our ability to measure its parallax. In attempting this measurement, astronomers have generally directed their attention to those stars which have a large proper motion, and which are at the same time in the immediate neighborhood of others that have no appreciable proper motion, and which are therefore presumably without a parallax.

The ordinary method of proceeding consists in measuring the directions and distances of the star in question from two or more of the immovable ones, at all seasons of the year, by means of the position micrometer, or by some equivalent method; from these measurements the parallactic path, and consequently the parallax of the star, may be deduced.

In this manner it has been found that the star *a* Centauri has a parallax of 0″.913 ; 61 Cygni has a parallax of 0″.348; *a* Lyræ, one of 0″.261; Sirius, one of 0″.230; Arcturus, one of 0″.127 ; and Polaris, one of less than 0″.1. It is to be noted that the parallaxes above given are only approximate.

A parallax of 1″ corresponds to a distance so great that it would require 3.22 years for light to traverse it. Hence, the stars named above are so far distant that their light only reaches us after the following intervals: *a* Centauri, 3½ years; 61 Cygni, 9⅛ years; *a* Lyræ, 12⅛ years; Sirius, 14 years; Arcturus, 25⅛ years; and Polaris, more than 32⅛ years.

Sir John Herschel, in speaking of the distribution of the stars, says that it is but fair to conclude that there are innumerable individuals that were visible as stars in the great telescope which was employed by his father and himself in gauging the heavens, whose light must have occupied 2,000 years in reaching us.

Velocity of the Stars.

253. The actual path of a star in space is generally oblique to the line of vision, that is, to the line drawn from the star to the observer; we may therefore regard its velocity as made up of two components, *one* at right angles to the line of vision and the *other* coinciding with it.

The *former* component can easily be found when we know the distance of the star and its corrected proper motion, that is, its apparent proper motion corrected for the actual proper motion of the sun. The only known method of finding the *latter* component is by means of the spectroscope. This method is based on principles that are easily understood.

The color of a homogeneous ray of light, and consequently its degree of refrangibility, depends upon the number of vibrations that strike the eye in a given time, say in one second. If the number of these vibrations is increased in any manner, the ray becomes more refrangible, and when deviated by a prism it will be thrown forward toward the violet end of the spectrum; if the number of vibrations is diminished, the ray becomes less refrangible, and when deviated it is thrown backward toward the red end of the spectrum.

Now, let us suppose a star to contain some known physical element, say hydrogen. If the star is at rest, any one of the corresponding dark lines in its spectrum will occupy a definite position; if the star is moving *toward* the observer, the number of vibrations that fall upon the prism in a second will be increased, and the dark line in question will be thrown forward toward the violet end of the spectrum; if the star is moving *away from* the observer, the number of vibrations in a second will be diminished, and the dark line will be thrown backward toward the red end of the spectrum.

In any given case, the direction and the amount of displacement are determined by a comparison spectroscope: then, the velocity of the star, either to or from the observer, is computed in accordance with the principles of optics.

The total velocity is equal to the square root of the sum of the squares of its two components. The direction in which the star is actually moving may be found by the simple principles of geometry.

Spectroscopic Classification of Stars.

254. Secchi divided the stars into four classes, which he called **types**, the basis of classification being the character of their spectra.

I. The first class embraces the white or azure-tinted stars, such as Sirius, *α* Lyræ, and all the stars of the dipper except *α*.

The spectra of these stars are almost continuous, with the exception of four strongly marked black lines which are the absorption lines of hydrogen; they also show traces of the sodium, magnesium, and iron lines.

II. The second class includes the yellow stars, such as Capella, *α* Ursæ Majoris, Pollux, and the Sun.

The spectra of these stars are perfectly similar to the well-known solar spectrum; they are characterized by a great number of fine black lines, among which those of sodium, hydrogen, and iron are very conspicuous.

III. The third class includes the orange-colored and the ordinary red stars, such as *α* Scorpionis, *β* Pegasi, *α* Herculis, *α* Orionis, and the like.

Their spectra are formed of lines and zones, or cloudy bands. Secchi says that this kind of spectrum ought to be considered as made up of two spectra, one superposed upon the other; one of them is formed of broad zones or bands gradually deepening in cloudiness so as to produce the effect of the lights and shades of a fluted column, and the other is formed of the black absorption lines of the metals.

IV. The fourth class embraces the blood-red stars, most of which belong to the telescopic magnitudes.

Their spectra are marked by three bands similar to those of the preceding class, but twice as wide. They have, however, the brighter and well-defined sides of their channellings turned toward the violet, whereas in the preceding class they are turned toward the red. These spectra somewhat resemble the spectrum of carbon as seen at the middle of the voltaic arc between two carbon points, except that in the stellar spectra the well-defined edges of the bands are turned toward the violet, whereas in the carbon spectrum they are turned toward the red.

There are a few stars that are not embraced in any of the four classes: of these, the star γ Cassiopeiæ gives the lines of hydrogen *direct*, that is, not reversed: this spectrum is not known to be given by any other star in the heavens, although something like it was presented by the temporary star which appeared in the northern crown in the year 1866.

It is inferred from the nature of these various spectra, as compared with those obtained in laboratory work, that stars of the first class are much hotter than those of the other classes, and that those of the fourth class are of far inferior temperature to any of the others, and furthermore that they are surrounded by dense vaporous atmospheres.

Law of Distribution of Stars.

255. In treating of the distribution of stars, Sir John Herschel says: "If we confine ourselves to the three or four brightest classes, we shall find them distributed with a considerable approach to impartiality over the sphere; a marked preference, however, being observed, especially in the southern hemisphere, to a zone or belt following the direction of a great circle passing through ε Orionis and *α* Crucis.

"But if we take in the whole amount visible to the naked eye, we shall perceive a great increase of number as we approach the borders of the Milky Way. And when we come to telescopic magnitudes, we find them crowded beyond imagination along the extent of that belt and of the branches which it sends off; so that in fact its whole light is composed of nothing but stars of every magnitude, from such as are visible to the naked eye down to the smallest point of light perceptible with the best telescopes."

Form of the Stellar System.

256. "These phenomena agree with the supposition that the stars of our firmament, instead of being scattered indifferently through space, form a stratum of which the thickness is small in comparison with its length and breadth; and in which the sun occupies a place somewhere near the point where it subdivides into two principal laminæ.

"It is certain that, to an eye so situated, the apparent densities of the stars, supposing them to be pretty equally scattered through the space they occupy, would be least in the direction of a visual ray perpendicular to the lamina, and greatest in the directions of its length and breadth, and increasing rapidly in passing from one to the other direction, just as we see a slight haze in the atmosphere thickening into a decided fog-bank near the horizon by the rapid increase of the mere length of the visual ray.

"Such is the view of the construction of the starry firmament taken by Sir William Herschel, whose powerful telescopes first effected a complete analysis of this wonderful zone and demonstrated the fact of its entirely consisting of stars.

"So crowded are they in some parts of it, that by counting the stars in a single field of his telescope he was led to conclude that 50,000 had passed under his view in a zone two degrees in breadth during a single hour's observation.

"In that part of the milky way which is situated in 10 hours 30 minutes of right ascension, and between the 147th and the 150th degree of north polar distance, upwards of 5,000 stars have been reckoned to exist in a square degree. The immense distances at which the remoter regions are situated will sufficiently account for the vast preponderance of small magnitudes which are observed in it."

The Nebular Hypothesis.

257. The **nebular hypothesis** is an explanation of the manner in which the solar system *may have been* evolved from a vast nebula by the action of known forces. The fundamental idea of the theory was elaborated by Kant, but it owes most of its scientific importance to the reasoning of La Place, whose name it usually bears.

According to this eminent scientist, the sun was, at some remote epoch, the central nucleus of an intensely heated nebula, extending to a distance greater than the remotest planet, and having a general motion of rotation from west to east. As this fiery mass cooled down it would contract in volume, and as a consequence its angular velocity would increase.

A time would ultimately come when the centrifugal forces acting on its outer molecules would exactly balance the central forces of attraction; then, as the process of contraction went on, these molecules would be left behind, forming a great equatorial ring revolving around the interior nucleus.

At subsequent epochs, and for similar reasons, other separations would take place, giving rise to a succession of distinct rings, all revolving in the same direction and situated very nearly in one plane.

The rings thus formed, with a single exception, were supposed to be made up of matter unequally distributed; consequently, in cooling down they would contract irregularly and would finally break up into unequal fragments, all revolving in the same direction as the original nebula; in each case, the largest fragment would attract to itself all the others belonging to the same ring, and in this way there would result a number of revolving nebulous masses which would slowly condense into planets. In the exceptional case the matter may have been more uniformly distributed, so that the contraction would be more regular, and the fragments into which it separated would be more nearly equal; these fragments, condensing around separate centres, would form a ring, or zone, of planetoids.

The planets, in condensing from their vaporous condition, would experience changes analogous to those that were supposed to have taken place in the original nebula; these changes are supposed to have resulted in the formation of the various satellites and the ring of Saturn.

Admitting that the assumed transformations are in accordance with mechanical and physical laws, of which there is considerable doubt, this theory of the *evolution* of the solar system would explain many observed facts. Thus, it would explain why the planets and planetoids revolve in the same direction that the sun turns on its axis; but it is difficult to see how it would account for the great inclinations of the planes of axial rotation, very strongly marked in the cases of the Earth, Mars, and Saturn, and still more conspicuous in the cases of Uranus and Neptune. It would explain why the angular velocities of the planets increase as their distances from the sun diminish; but it would totally fail to account for the fact that the angular velocity of the inner satellite of Mars is more than three times that of the planet itself.

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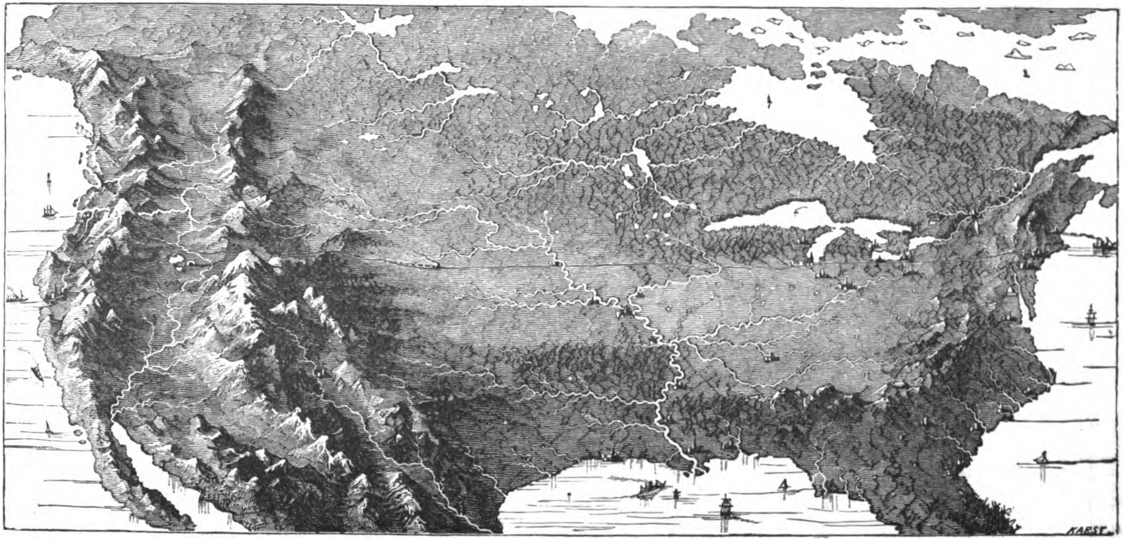

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GEOGRAPHY — *Continued.*

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1. **PRACTICAL OBJECT-TEACHING.** — The infant scholar is first introduced to *a picture* whence he may derive notions of the shape of the earth, the phenomena of day and night, the distribution of land and water, and the great natural divisions, which mere words would fail entirely to convey to the untutored mind. Other pictures follow on the same plan, and the child's mind is called upon to grasp no idea without the aid of a pictorial illustration. Carried on to the higher books, this system culminates in Physical Geography, where such matters as climates, ocean currents, the winds, peculiarities of the earth's crust, clouds and rain, are pictorially explained and rendered apparent to the most obtuse. The illustrations used for this purpose belong to the highest grade of art.

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GEOGRAPHY — *Continued.*

9. **SUPERIOR GRADATION.** — This is the only series which furnishes an available volume for every possible class in graded schools. It is not contemplated that a pupil must necessarily go through every volume in succession to attain proficiency. On the bontrary, *two* will suffice, but *three* are advised ; and, if the course will admit, the whole series should be pursued. At all events, the books are at hand for selection, and every teacher, of every grade, can find among them one *exactly suited* to his class. The best combination for those who wish to abridge the course consists of Nos. 1, 2, and 3 ; or, where children are somewhat advanced in other studies when they commence geography, Nos. 1*, 2, and 3. Where but *two* books are admissible, Nos. 1* and 2*, or Nos. 2 and 3, are recommended.

A Sheep Ranch in Montana.
[Specimen Illustration from McNally's New Geography.]

GEOGRAPHY — *Continued.*

Monteith's Physical Geography.

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During the period alluded to, many authors and editors in this department have started into public notice, and, by borrowing ideas and processes original with Dr. Davies, have enjoyed a brief popularity, but are now almost unknown. Many of the series of to-day, built upon a similar basis, and described as "modern books," are destined to a similar fate; while the most far-seeing eye will find it difficult to fix the time, on the basis of any data afforded by their past history, when these books will cease to increase and prosper, and fix a still firmer hold on the affection of every educated American.

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3d. It is exclusively used in the public schools of the National Capital.

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5th. Our great soldiers and sailors commanding the national armies and navies were educated in this system. So have been a majority of eminent scientists in this country. All these refer to "Davies" as authority.

6th. A larger number of American citizens have received their education from this than from any other series.

7th. The series has a larger circulation throughout the whole country than any other, being *extensively used in every State in the Union.*

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OPTIONAL OR CONSECUTIVE.

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At first the authors play with the little learner for a few lessons, by object-teaching and kindred allurements; but he soon begins to realize that study is earnest, as he becomes familiar with the simpler operations, and is delighted to find himself master of important results.

The second part reviews the Fundamental Operations on a scale proportioned to the enlarged intelligence of the learner. It establishes the General Principles and Properties of Numbers, and then proceeds to Fractions. Currency and the Metric System are fully treated in connection with Decimals. Compound Numbers and Reduction follow, and finally Percentage with all its varied applications.

An Index of words and principles concludes the book, for which every scholar and most teachers will be grateful. How much time has been spent in searching for a half-forgotten definition or principle in a former lesson!

Davies and Peck's Complete Arithmetic.

This work certainly deserves its name in the best sense. Though complete, it is not, like most others which bear the same title, *cumbersome*. These authors excel in clear, lucid demonstrations, teaching the science pure and simple, yet not ignoring convenient methods and practical applications.

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Peck's First Lessons in Numbers.

This book begins with pictorial illustrations, and unfolds gradually the science of numbers. It noticeably simplifies the subject by developing the principles of addition and subtraction simultaneously; as it does, also, those of multiplication and division.

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This book is designed especially for those who seek sufficient instruction to carry them successfully through practical life, but have not time for extended study.

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This completes the series but is a much briefer book than most of the complete arithmetics, and is recommended not only for what it contains, but also for what is omitted.

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These two works constitute a *complete arithmetical course in two books.*

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which begins with the most elementary notions of numbers, and proceeds, by simple steps, to develop all the fundamental principles of Arithmetic.

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Algebra. The student's progress in Algebra depends very largely upon the proper treatment of the four *Fundamental Operations*. The terms *Addition*, *Subtraction*, *Multiplication*, and *Division* in Algebra have a wider meaning than in Arithmetic, and these operations have been so defined as to *include* their arithmetical meaning; so that the beginner is simply called upon to *enlarge* his views of those fundamental operations. Much attention has been given to the explanation of the negative sign, in order to remove the well-known difficulties in the use and interpretation of that sign. Special attention is here called to "A Short Method of Removing Symbols of Aggregation," Art. 76. On account of their importance, the subjects of *Factoring*, *Greatest Common Divisor*, and *Least Common Multiple* have been treated at greater length than is usual in elementary works. In the treatment of *Fractions*, a method is used which is quite simple, and, at the same time, more general than that usually employed. In connection with *Radical Quantities* the roots are expressed by fractional exponents, for the principles and rules applicable to integral exponents may then be used without modification. The *Equation* is made the chief subject of thought in this work. It is defined near the beginning, and used extensively in every chapter. In addition to this, four chapters are devoted exclusively to the subject of *Equations*. All *Proportions* are equations, and in their treatment as such all the difficulty commonly connected with the subject of Proportion disappears. The chapter on Logarithms will doubtless be acceptable to many teachers who do not require the student to master Higher Algebra before entering upon the study of Trigonometry.

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The briefest treatises on these subjects now published. Adopted by the great Universities: Yale, Harvard, Columbia, Princeton, Cornell, &c.

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A standard work of the very highest grade, presenting the most elaborate attainable survey of the subject.

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HISTORY — *Continued.*

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A well-proportioned outline of leading events, condensing the substance of the more extensive text-books in common use into a series of statements so brief, that every word may be committed to memory, and yet so comprehensive that it presents an accurate though general view of the whole continuous life of nations.

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Mill's History of the Ancient Hebrews.

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Gilman's First Steps in General History.

A "suggestive outline" of rare compactness. Each country is treated by itself, and the United States receive special attention. Frequent maps, contemporary events in tables, references to standard works for fuller details, and a minute Index constitute the " Illustrative Apparatus." From no other work that we know of can so succinct a view of the world's history be obtained. Considering the necessary limitation of space, the style is surprisingly vivid, and at times even ornate. In all respects a charming, though not the less practical, text-book.

Baker's Brief History of Texas.

Dimitry's History of Louisana.

Alison's Napoleon First.

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The salient points in the history of the world arranged catechetically for class use or for review and examination of teacher or pupil. By John Lord, LL.D. 12mo, 300 pages.

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Topographical Maps and Chronological Charts of every battle, with 3 steel portraits of Washington. 8vo, cloth.

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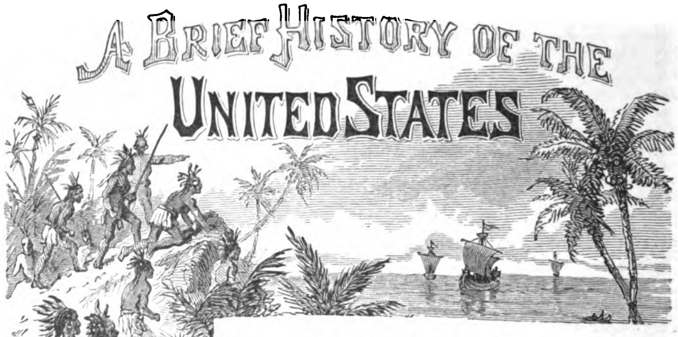
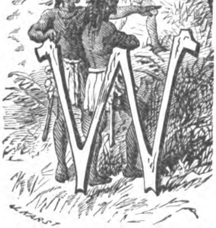
For theological and historical students this book has an intrinsic value. It gives the history of all the English translations down to the present time, together with a careful review of their influence upon English literature and language.

BARNES'S ONE-TERM HISTORY SERIES.





A Brief History of the United States.

This is probably the MOST ORIGINAL SCHOOL-BOOK published for many years, in any department. A few of its claims are the following: —

1. **Brevity**. — The text is complete for grammar school or intermediate classes, in 290 12mo pages, large type. It may readily be completed, if desired, in one term of study.

2. **Comprehensiveness**. — Though so brief, this book contains the pith of all the wearying contents of the larger manuals, and a great deal more than the memory usually retains from the latter.

3. **Interest** has been a prime consideration. Small books have heretofore been bare, full of dry statistics, unattractive. This one is charmingly written, replete with anecdote, and brilliant with illustration.

4. **Proportion of Events**. — It is remarkable for the discrimination with which the different portions of our history are presented according to their importance. Thus the older works, being already large books when the Civil War took place, give it less space than that accorded to the Revolution.

5. **Arrangement**. — In six epochs, entitled respectively, Discovery and Settlement, the Colonies, the Revolution, Growth of States, the Civil War, and Current Events.

6. **Catch Words**. — Each paragraph is preceded by its leading thought in prominent type, standing in the student's mind for the whole paragraph.

7. **Key Notes**. — Analogous with this is the idea of grouping battles, &c., about some central event, which relieves the sameness so common in such descriptions, and renders each distinct by some striking peculiarity of its own.

8. **Foot-Notes**. — These are crowded with interesting matter that is not strictly a part of history proper. They may be learned or not, at pleasure. They are certain in any event to be read.

9. **Biographies** of all the leading characters are given in full in foot-notes.

10. **Maps**. — Elegant and distinct maps from engravings on copper-plate, and beautifully colored, precede each epoch, and contain all the places named.

11. **Questions** are at the back of the book, to compel a more independent use of the text. Both text and questions are so worded that the pupil must give intelligent answers IN HIS OWN WORDS. "Yes" and "No" will not do.

HISTORY — *Continued.*

12. **Historical Recreations.** — These are additional questions to test the student's knowledge, in review, as: "What trees are celebrated in our history?" "When did a fog save our army?" "What Presidents died in office?" "When was the Mississippi our western boundary?" "Who said, 'I would rather be right than President'?" &c.

13. **The Illustrations,** about seventy in number, are the work of our best artists and engravers, produced at great expense. They are vivid and interesting, and mostly upon subjects never before illustrated in a school-book.

14. **Dates.** — Only the leading dates are given in the text, and these are so associated as to assist the memory, but at the head of each page is the date of the event first mentioned, and at the close of each epoch a summary of events and dates.

15. **The Philosophy of History** is studiously exhibited, the causes and effects of events being distinctly traced and their inter-connection shown.

16. **Impartiality.** — All sectional, partisan, or denominational views are avoided. Facts are stated after a careful comparison of all authorities without the least prejudice or favor.

17. **Index.** — A verbal index at the close of the book perfects it as a work of reference.

It will be observed that the above are all particulars in which School Histories have been signally defective, or altogether wanting. Many other claims to favor it shares in common with its predecessors.

TESTIMONIALS.

From PROF. WM. F. ALLEN, *State University of Wisconsin.*

"Two features that I like *very much* are the *anecdotes* at the foot of the page and the '*Historical Recreations*' in the Appendix. The latter, I think, is quite a *new* feature, and the other is *very* well executed."

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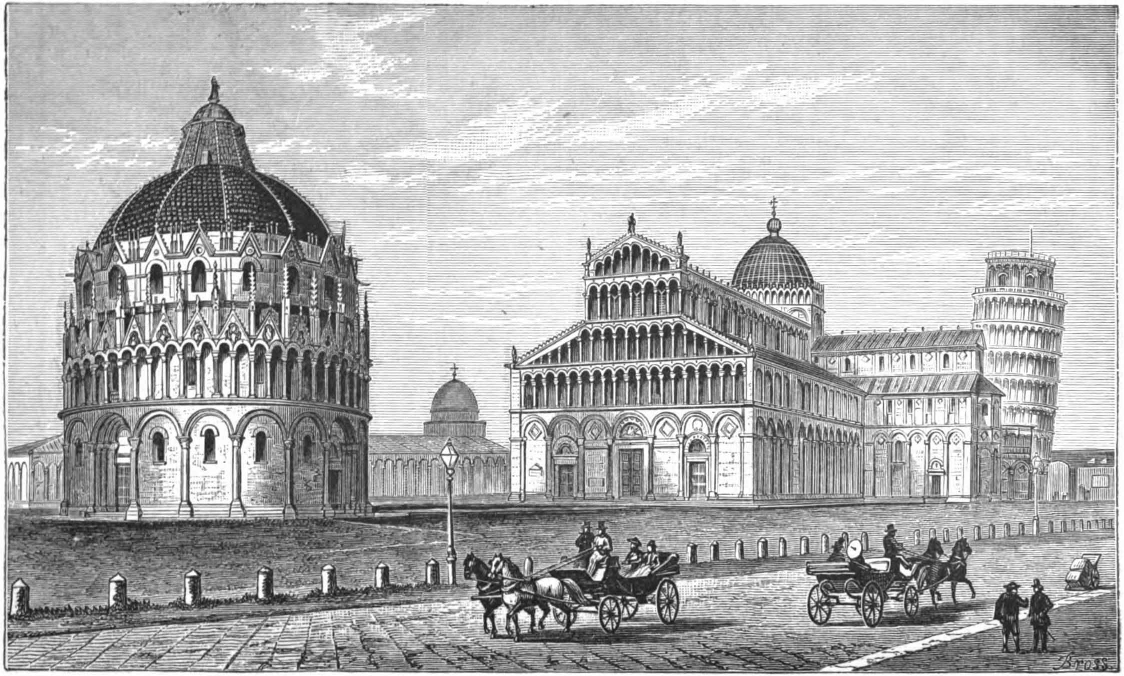

BAPTISTRY, CATHEDRAL, AND LEANING TOWER OF PISA.
[Specimen Illustration from Steele's Sciences.]

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This book was originally edited from Ganot's "Popular Physics," by William G. Peck, LL.D., Professor of Mathematics and Astronomy, Columbia College, and of Mechanics in the School of Mines. It has recently been revised by Levi S. Burbank, A. M., late Principal of Warren Academy, Woburn, Mass., and James I. Hanson, A.M., Principal of the High School, Woburn, Mass.

Of elementary works those of M. Ganot stand pre-eminent, not only as popular treatises, but as thoroughly scientific expositions of the principles of Physics. His "Traité de Physique" has not only met with unprecedented success in France, but has been extensively used in the preparation of the best works on Physics that have been issued from the American press.

In addition to the "Traité de Physique," which is intended for the use of colleges and higher institutions of learning, M. Ganot published this more elementary work, adapted to the use of schools and academies, in which he faithfully preserved the prominent features and all the scientific accuracy of the larger work. It is charcterized by a well-balanced distribution of subjects, a logical development of scientific principles, and a remarkable clearness of definition and explanation. In addition, it is profusely illustrated with beautifully executed engravings, admirably calculated to convey to the mind of the student a clear conception of the principles unfolded. Their completeness and accuracy are such as to enable the teacher to dispense with much of the apparatus usually employed in teaching the elements of Physical Science.

After several years of great popularity the American publishers have brought this important book thoroughly up to the times. The death of the accomplished educator, Professor Burbank, took place before he had completed his work, and it was then taken in hand by his friend, Professor Hanson, who was familiar with his plans, and has ably and satisfactorily brought the work to completion.

The essential characteristics and general plan of the book have, so far as possible, been retained, but at the same time many parts have been entirely rewritten, much new matter added, a large number of new cuts introduced, and the whole treatise thoroughly revised and brought into harmony with the present advanced stage of scientific discovery.

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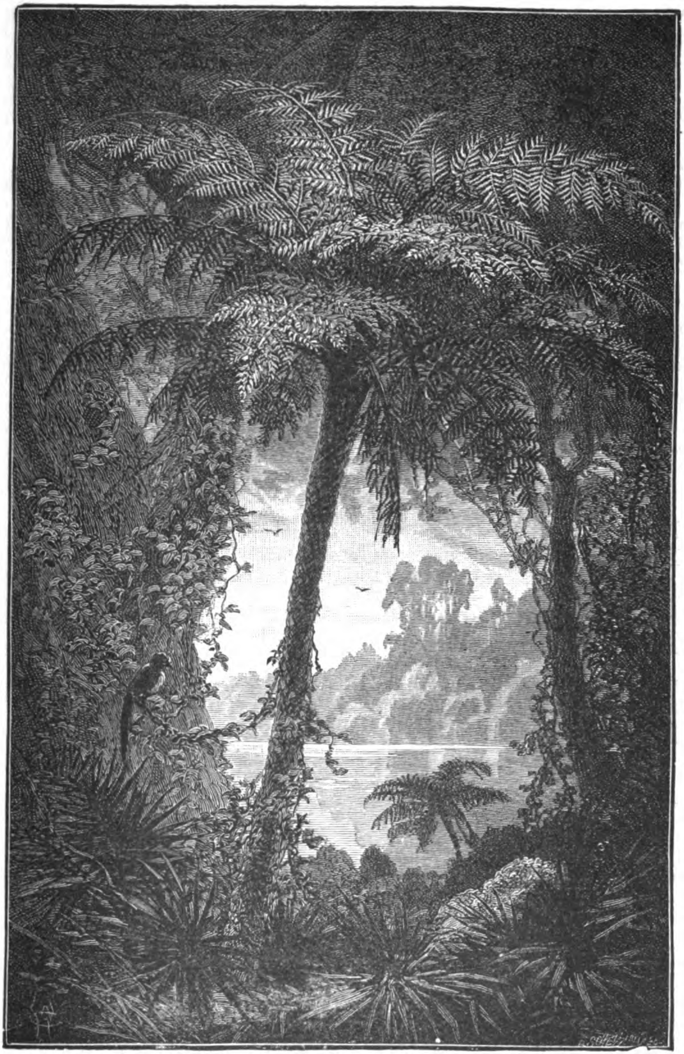

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See page 33.

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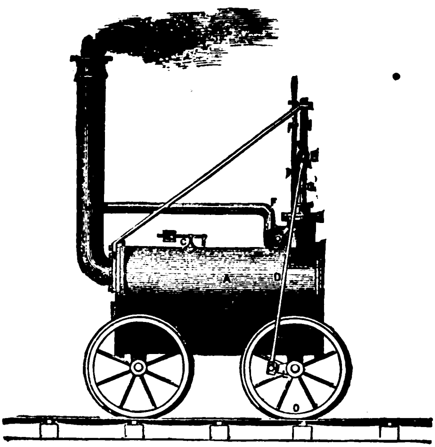

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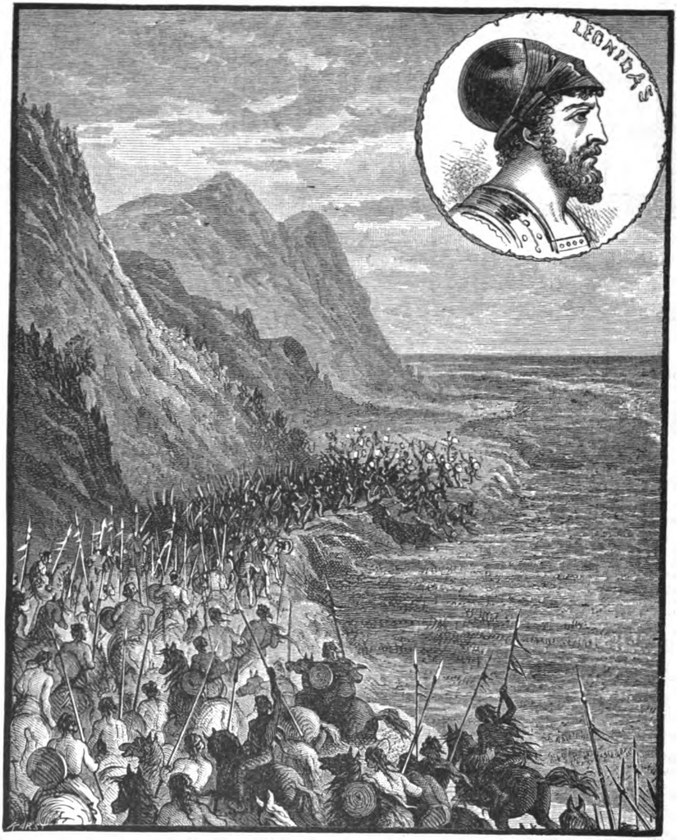

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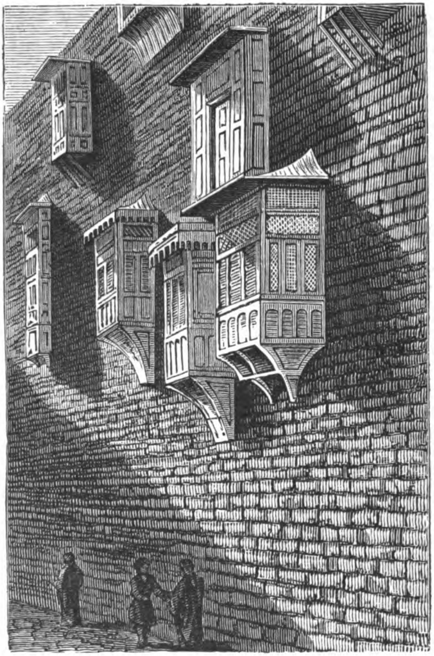

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