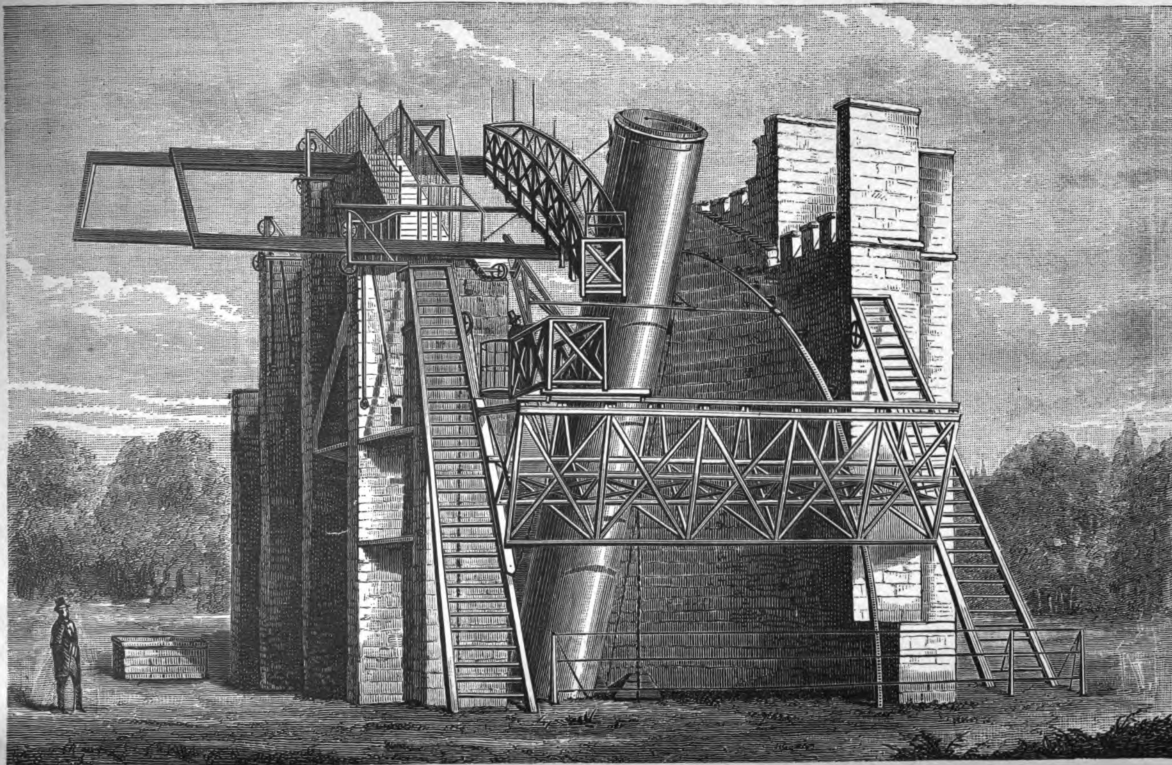

LORD ROSSE'S GREAT REFLECTING TELESCOPE, SIX FEET IN DIAMETER

POPULAR

ASTRONOMY

BEING THE NEW DESCRIPTIVE ASTRONOMY

BY

JOEL DORMAN STEELE, PH.D.,

REVISED AND BROUGHT DOWN TO DATE

BY

MABEL LOOMIS TODD

Author of 'Corona and Coronet,' 'Total Eclipses of the Sun,' etc., etc.

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POPULAR ASTRONOMY.

W. P. 2

PREFACE

In revising Steele's *Descriptive Astronomy* I have aimed to preserve all the highly desirable features of the author's original work, making but few excisions of importance. Nor have essentials been modified, either in style or in general arrangement.

In bringing the book well down to the present date, the necessary changes and additions have been numerous, on account of the rapid advance of practical and physical astronomy during the last fifteen years. Principally they relate to Rowland's research on the solar spectrum; Secchi's and Pickering's classification of stellar spectra; Hale's and Deslandres's researches on the sun; Spoerer's law of sun-spot zones; solar eclipses, past and future; standard time and change of the day; new methods for finding the sun's distance; transits of Mercury; researches on the surfaces of planets and satellites; Chandler's variation of terrestrial latitudes; Eros, the nearest planet; Pickering's ninth satellite of Saturn; Keeler's constitution of Saturn's rings; Bredichin's theory of cometary tails; observations of the Gegenschein, or counterglow; Nova Aurigæ of 1892; See's researches on the cosmogony; and Kapteyn's theory of the visible universe.

The valuable list of 'questions for class use' has been made to accord with all these changes and additions, and the astronomical constants have been modified to suit the more trustworthy results of recent research. Also the list of interesting telescopic objects, arranged by constellations, has been thoroughly revised and supplemented. The Index shows the pronunciation of all difficult names.

The excellent system of star maps has been retained. A number of the less worthy illustrations have been replaced by better ones, and several new illustrations have been added, — partly from the *New Astronomy* by Professor Todd, to whom, indeed, I have been constantly indebted for assistance without which the revision would have been comparatively valueless. Also Messrs. Little, Brown & Co. of Boston, publishers of his *Stars and Telescopes*, have courteously loaned the blocks of illustrations from that work.

To bring to most modern date the book from which in early youth I received my first school instruction about the stars has been an especial pleasure.

M. L. T.

Observatory House,
Amherst, August, 1899.

SUGGESTIONS TO TEACHERS

This work is designed to be recited in the topical method. On hearing the title of a paragraph, the pupil should be able to draw upon the blackboard the diagram, and to state in substance what is contained in the book. It will be noticed that *the order of topics*, in treating of the planets and also of the constellations, is uniform. If, each day, a portion of the class write their topics in full upon the blackboard, it will be found a valuable exercise in spelling, punctuation, and composition. Every point which can be illustrated in the heavens should be shown to the class. No description or apparatus can equal the reality in the sky. After a constellation has been traced, the pupil should practice star-map drawing.

The section on 'Celestial Measurements,' near the close of the work, should be constantly referred to during the term. In the figures, and especially in the star maps, it should be remembered that the right-hand side represents the west; and the left-hand the east. To obtain this idea correctly, the book should in general be held up toward the southern sky.

For the purpose of more easily finding the heavenly bodies at any time, a planisphere, either Poole's, Harrington's, or Goldthwaite's, is of great service. A small telescope, or even an opera glass, will be useful. A good star map, and as many advanced works upon astronomy as can be secured, should be included in the teacher's outfit.

The pupil should, at the outset, get a distinct idea of the circles and planes of the celestial sphere. The subject of angular measurements can easily be made clear in this relation. A circle contains 360°; 90° reach from horizon to zenith; 180° produce opposition; while smaller distances can be shown in the sky (see pp. 226, 238).

Never let a pupil recite a lesson, nor answer a question, except it be a mere definition, *in the language of the book*. The text is designed to interest and instruct the pupil; the recitation should afford him an opportunity of expressing what he has learned in his own style and words.

READING REFERENCES

Todd's *New Astronomy*. Chambers's *Astronomy*. Young's *The Sun*. Ball's *Elements of Astronomy*. Newcomb's *Popular Astronomy*. Lockyer's *Spectrum Analysis*. Proctor's *Other Worlds than Ours, Saturn, The Moon*, etc. Lockyer's *Elements of Astronomy*. Herschel's *Outlines of Astronomy*. Mitchel's *Popular Astronomy*. Arago's *Popular Astronomy*. Airy's *Lectures on Astronomy*. Hind's *Solar System*, and *Introduction to Astronomy*. Lockyer's *Elementary Lessons in Astronomy*. Proctor's *Star Atlas*. Sharpless and Phillips's *Astronomy*. Schellen's *Spectrum Analysis*. Winchell's *World-Life*. Flammarion's *Wonders of the Heavens*. Guillemin's *The Heavens*, revised by Proctor. Loomis's *Elements of Astronomy*. Proctor's *Easy Star Lessons*. Olmsted's *Letters on Astronomy*. Clerke's *System of the Stars*. Gore's *The Visible Universe*. Fowler, Clerke, and Gore's *Astronomy — The Concise Knowledge Library*. Ball and Newcomb's *Astronomy*. Lockyer's *Primer of Astronomy*. Bowen's *Astronomy by Observation*. Ball's *The Story of the Heavens*. Langley's *The New Astronomy*. Green's *Birth and Growth of Worlds*. Ball's *Time and Tide*. Proctor's *Old and New Astronomy*. Clerke's *History of Astronomy in Nineteenth Century*. Todd's *Total Eclipses of the Sun*. Chambers's *The Story of the Stars*. Flammarion's *Popular Astronomy*. Ball's *The Story of the Sun*. Chambers's *The Story of the Solar System*. Colas's *Celestial Handbook*. Gibson's *Amateur Telescopist's Handbook*. Proctor's *Stories of Starland*. Howe's *Study of the Sky*. Lowell's *Mars*. Darwin's *The Tides*. Todd's *Stars and Telescopes*.

TABLE OF CONTENTS

(III) THE SIDEREAL SYSTEM

(IV) APPENDIX

e
s,
e
is
al
of

is
is
e
n-
d
y
n-
ır
d,

e
of
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er
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THE STUDY OF ASTRONOMY

Astronomy (*astron*, star; *nomos*, law) treats of the heavenly bodies — the sun, moon, planets, comets, stars, and, as our globe is a planet, of the earth also. It is above all others a science that cultivates the imagination. Yet its theories and distances are based upon rigorous mathematical demonstrations. Thus the study has at once the beauty of poetry and the exactness of geometry.

The great dome of the sky, filled with glittering stars, is one of the most sublime spectacles in nature. To enjoy this fully, a night must be chosen when the air is clear and the moon is absent. We then gaze upon a deep blue, an immense expanse studded with stars of varied color and brilliancy. Some shine with a vivid light, perpetually changing and twinkling; others, more constant, beam tranquilly and softly upon us; while many just tremble into our sight, like a wave that, struggling to reach some far-off land, dies as it touches the shore.

In the presence of such weird and wondrous beauty, the tenderest sentiments of the heart are aroused. A feeling of awe and reverence, of softened melancholy mingled with a thought of God, comes over us, and awakens the better nature within us. Those far-off lights seem full of meaning to us, could we but read their message; they become real and sentient, and, like the soft eyes in pictures, look lovingly and inquiringly upon us. We come into communion with another life, and the soul asserts its immortality more strongly than ever before. We are humbled as we gaze upon the infinity of suns, and strive to comprehend their enormous distances and their possible retinues of worlds. The powers of the mind are aroused, and eager questionings crowd upon us. What are those glittering fires? What is their distance? Are they worlds like our own? Do living, thinking beings dwell upon them? Are they promiscuously scattered through space, or is there a system in the universe? Can we hope ever to fathom those mysterious depths, or are they closed to us forever?

Some of these problems have been solved; others yet await the astronomer whose eye shall be keen enough to read the mysterious scroll of the heavens. Two hundred generations of study have revealed to us such startling facts that we wonder how man in his feebleness can grasp so much, see so far, and penetrate so deeply into the mysteries of the universe. Astronomy has measured the distance of a few stars, and of all the planets; computed the mass, size, days, years, seasons, and many physical features of the planets; made a map of the moon; tracked many of the comets in their immense sidereal journeys; and at last analyzed the structure of sun and stars, and announced the very elements of which they are composed.

Observing for several evenings those stars which shine with a clear, steady light, we notice that they change their position with respect to the others. They are therefore called *planets* (literally *wanderers*). But nearly all remain immovable in relation to one another, and shine with a shifting, twinkling light. They are termed the *fixed stars*, although it is now known that they also are in rapid motion, but at such immense distances from us that they seem to us to be stationary. Then, too, diagonally girdling the heavens, is a whitish, gauzy belt, the *Milky Way*. This is composed of millions upon millions of suns so far removed from us that their light mingles and makes only a fleecy whiteness.

This magnificent panorama of the heavens is before us, inviting our study, and waiting to make known to us the grandest revelations of science.

I

INTRODUCTION

INTRODUCTION

- (I) History
  - (1) Among the Chinese
  - (2) Among the Chaldeans
  - (3) Among the Greeks
    - (*a*) Thales
    - (*b*) Anaximander
    - (*c*) Pythagoras
    - (*d*) Anaxagoras
    - (*e*) Eudoxus
    - (*f*) Hipparchus
  - (4) The Egyptians
    - (*a*) The School at Alexandria
    - (*b*) Ptolemy and his Theory
  - (5) The Saracens
  - (6) Astrology
  - (7) The Copernican System
  - (8) Tycho Brahe
  - (9) Kepler's Laws
  - (10) Galileo
    - (*a*) His Telescope
    - (*b*) His Discoveries
    - (*c*) Their Reception
  - (11) Newton and the Law of Gravitation
    - (*a*) Laws of Motion
    - (*b*) Application to the Moon
    - (*c*) The Result
- (II) Space
  - (1) Celestial Sphere
  - (2) The Three Systems of Circles
    - (*A*) The Horizon
      - Principal Circle
      - Subordinate Circles
      - Points
      - Measurements
    - (*B*) The Equinoctial
      - Principal Circle
      - Subordinate Circles
      - Points
      - Measurements
    - (*C*) The Ecliptic
      - Principal Circle
      - Subordinate Circles
      - Points
      - Measurements
  - (3) The Zodiac

SIR ISAAC NEWTON (1643–1727)

I. THE HISTORY

Astronomy is the most ancient of the sciences. The study of the stars is doubtless as old as man himself, and hence many of its discoveries antedate authentic records, and are found amid the mysteries of tradition. In tracing its history, we shall speak only of those prominent facts that will enable us to understand its progress and glorious achievements.

The Chinese boast much of their astronomical discoveries. Indeed, their emperor claims a celestial ancestry, and styles himself the 'Son of the Sun.' They possess an account of a conjunction of four planets and the moon, which occurred in the twenty-fifth century before Christ. They also claim to have the first record of an eclipse of the sun; and one of their emperors put to death the chief astronomers Ho and Hi for failing to announce a solar eclipse, about B.C. 2150.

The Chaldeans. — The Chaldean shepherds, watching their flocks by night under a sky famed for its clearness and brilliancy, could not fail to become familiar with many of the movements of the heavenly bodies. Their priests were astronomers; their temples, observatories. When Alexander took Babylon (B.C. 331), he found a record of their observations reaching back nineteen centuries. Many astronomical inscriptions have been found in the ruins of Nineveh. In the public library of that city there was a series of about seventy-two volumes, called the Observations of Bel. One book treated of the polar star (then Alpha in the constellation of the Dragon), another of Venus, and a third of Mars. The earliest of these records are thought to date back as far as B.C. 2540. The Chaldeans divided the day into hours, invented the sun-dial, and discovered the Saros, a period of time in which eclipses of the sun and the moon repeat themselves in the same order.

The Greeks. — Though the Asiatics were patient observers, they did not classify their knowledge and lay the basis of a science. This became the work of the occidental mind.

THALES (B.C. 640–548), one of the seven sages of Greece, has been styled the 'Father of Astronomy.' He taught that the earth is round, and that the moon receives her light from the sun. He determined when the equinoxes and the solstices occur, and also predicted an eclipse of the sun that is famous for having terminated a war between the Medes and the Lydians. These nations were engaged in a fierce battle, but the awe produced by the darkening of the sun was so great that both sides threw down their arms and made peace.

ANAXIMANDER (B.C. 611–547) invented the sun-dial, and explained the cause of the moon's phases.

PYTHAGORAS (B.C. 582–500) founded a celebrated astronomical school at Crotona, Italy, where were educated hundreds of enthusiastic pupils. He was emphatically a dreamer. He conceived a system of the universe, in many respects correct; yet he advanced no proof, made few converts to his views, and they were soon well-nigh forgotten. He held that the sun is the center of the solar system, the planets revolving about it in circular orbits; that the earth rotates daily on its axis, and revolves yearly round the sun; that Venus is both morning and evening star; that the planets are placed at intervals corresponding to the scale in music, and that they move in harmony, making the 'music of the spheres,' but that this celestial concert is heard only by the gods,— the ears of man being too gross for such divine melody. Pythagoras also believed that the planets are inhabited.

ANAXAGORAS (B.C. 500–428) taught that there is but one God, and that the sun is only a fiery globe, and should not be worshiped. He attempted to explain eclipses and other celestial phenomena by natural causes, saying that there is no such thing as chance or accident, these being only names for unknown laws. For his audacity and impiety, as his countrymen considered it, he and his family were doomed to perpetual banishment.

EUDOXUS, who lived in the fourth century B.C., invented the theory of Crystalline Spheres. He held that the heavenly bodies are set, like gems, in hollow, transparent, crystal globes, which are so pure that they do not obstruct our view, while they all revolve around the earth; and that the planets are placed in one globe, but have a power of moving themselves, each under the guidance of a tutelary genius who resides in it and rules over it as the mind rules over the body.

HIPPARCHUS, who flourished in the second century B.C., has been called the 'Newton of Antiquity.' He was the most celebrated of the Greek astronomers. He calculated the length of the year to within six minutes, discovered the precession of the equinoxes, and made the first catalogue of stars — 1080 in number.

The Egyptians. — Egypt as well as Chaldea was noted for its knowledge of the sciences long before they were cultivated in Greece. It was the practice of the Greek philosophers, before aspiring to the rank of teacher, to travel for years through these countries, and gather wisdom at its fountain head. Pythagoras spent thirty years in this kind of study.

Two hundred years after Pythagoras, the celebrated school of Alexandria was established. Here were concentrated in vast libraries and princely halls nearly all the wisdom and learning of the world. Here flourished the sciences and arts, under the patronage of munificent kings.

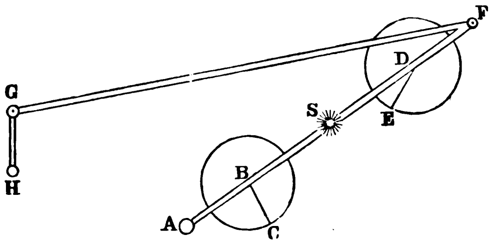
At this school, Ptolemy (A.D. 120), a Greek, wrote his great work, the *Almagest*, which for fourteen centuries was the text-book of astronomers. In this work was given what is known as the Ptolemaic System. It was founded largely upon the materials gathered by previous astronomers, such as Hipparchus, whom we have already mentioned, and Eratosthenes, who computed the size of the earth by means even now considered the best — the measurement of an arc of a terrestrial meridian.

Ptolemaic System. — To the early astronomers, the movements of the planets seemed extremely complex. Venus, for instance, was sometimes seen as evening star in the west, and then again as morning star in the east. Sometimes she appeared to be moving in the same direction as the sun, then, going apparently behind the sun, she seemed to pass on again in a course directly opposite. At one time, she would recede from the sun more and more slowly, until she would appear entirely stationary; then she would retrace her steps, and seem to meet the sun. An attempt was made to account for all these facts by an incongruous system of 'cycles and epicycles,' as it is called. Milton refers to this when he speaks of the heavens as —

> 'With centric and eccentric scribbled o'er,
> Cycle and epicycle, orb in orb.'

The advocates of this theory assumed that every planet revolves in a circle, and that the earth is the fixed center around which the sun and other heavenly bodies move. They then conceived that a bar, or something equivalent, is connected at one end with the earth; that at some part of this bar the sun is attached; while between that and the earth Venus is fastened — not to the bar directly, but to a sort of crank; and further on, Mercury is hitched on in the same way.

Let A be the earth; S, the sun; ABDF, the bar (real or imaginary); BC, the short bar or crank to which Venus is tied; DE, another bar for Mercury; FG, a fourth bar, with still another short crank, at the end of which, H, Mars is attached. Thus they had a complete system. They did not exactly understand the nature of these bars, whether they were real or only imaginary, but they *did* comprehend their action, as they thought; and so they supposed the bar revolved,



SCHEME OF THE PTOLEMAIC SYSTEM

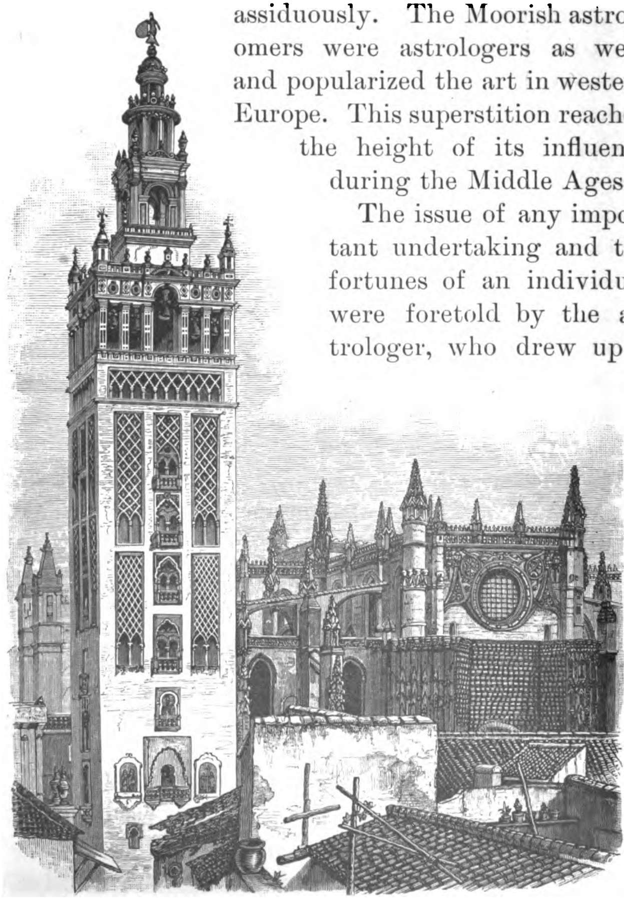
carrying the sun and planets along in large circles [cycles] about the earth; while all the short cranks kept flying around, thus sweeping each planet through a smaller circle [epicycle].

By this theory, we can see that the planets would sometimes go in front of the sun and sometimes behind; and their places were so accurately predicted that the error could not be detected by the rude instruments then in use. As soon as a new motion of one of the heavenly bodies was discovered, a new crank, and of course a new circle, was added to account for the fact. Thus the system became more and more complicated, until at last a combination of five cranks and circles was necessary to make the planet Mars keep pace with the Ptolemaic theory. No wonder that Alfonso of Castile, a celebrated patron of astronomy, revolted at the cumbersome machinery, and cried out, 'If I had been consulted at Creation, I could have done better than that.'

The Saracens. — After the destruction of the library at Alexandria, learning found a home among the Mohammedans. Bagdad on the Tigris, and Cordova on the Guadalquivir, became centers of science, literature, and art. The treasures of Grecian knowledge were eagerly gathered by the caliphs, and we are told that it was not uncommon to see, entering the gates of Bagdad, a whole train of camels loaded with Greek manuscripts. Gerbert, afterward Pope Sylvester II, learned the elements of astronomy at the University of Cordova, going, after the custom of the time, to Spain for instruction, as formerly philosophers had gone to Egypt. In the Moorish schools, geography was already taught by the use of the globe. The first observatory in Europe was erected at Seville in 1196. Fragments of Saracenic learning that have come down to us show that the Arabs had constructed astronomical tables, and endeavored to perfect them by means of systematic observation of the heavens. With the downfall of the Moors, and the 'Revival of Learning,' Spain ceased to take the lead in scientific study.

Astrology. — During all these centuries, astronomy owed its development quite as much to a desire of foretelling the future as to a love for science. It was the prevalent belief that the stars rule the destinies of men. The Chaldeans scanned the heavens for purposes of divination, so that Chaldean and astrologer became synonymous. Tiberius, Emperor of Rome, practiced astrology. Hippocrates himself, the Father of Medicine (B.C. 400), ranked this among the most important branches of knowledge for the physician. The mysterious study possessed a peculiar fascination for the Arabians, and they cultivated it assiduously. The Moorish astronomers were astrologers as well, and popularized the art in western Europe. This superstition reached the height of its influence during the Middle Ages.

The issue of any important undertaking and the fortunes of an individual were foretold by the astrologer, who drew up a



THE GIRALDA (he-rahl'dah), MOORISH OBSERVATORY AT SEVILLE *horoscope* representing the position of the sun, moon, and planets at the beginning of the enterprise, or at the birth of the person. It was a complete and complicated system, and contained regular rules which guided the interpretation, and which were so abstruse as to require years for their mastery. Venus foretold love; Mars, war; the Pleiades (plē′ya-dēz), storms at sea.

The ignorant were not the only dupes of this visionary system. Lord Bacon believed in it most firmly. Kepler, by casting nativities, eked out his miserable pittance as royal astronomer. So late even as the reign of Charles II, Lilly, a famous astrologer, was called before a committee of the House of Commons to give his opinion on the probable issue of some enterprise then under consideration. However foolish the system of astrology may have been, it preserved the science of astronomy during the Dark Ages, and prompted to accurate observation and diligent study of the heavens.

The Copernican System. — About the commencement of the sixteenth century, Copernicus, breaking away from the theory of Ptolemy, which was still taught in the institutions of learning in Europe, revived the theory of Pythagoras. He saw how beautifully simple is the idea of considering the sun the grand center about which revolve the earth and the planets. He noticed how constantly, when riding swiftly, we forget our own motion, and think that the trees and fences are gliding by us in the contrary direction. He applied this thought to the movements of the heavenly bodies, and maintained that, instead of all the starry host revolving about the earth once in twenty-four hours, the earth simply turns on its own axis, and thus produces the apparent daily revolution of the sun and stars; while the yearly motion of the earth about the sun, transferred in the same manner, would account for the solar movements.

Though Copernicus thus simplified the Ptolemaic theory, he yet found that the idea of circular orbits for the planets would not explain all the phenomena, and therefore retained the 'cycles and epicycles' Alfonso had so heartily condemned. For forty years this illustrious astronomer carried on his observations in the upper part of a humble, dilapidated farmhouse, through the roof of which he had an unobstructed view of the sky. The work containing his theory was published just in time to be laid upon his deathbed.

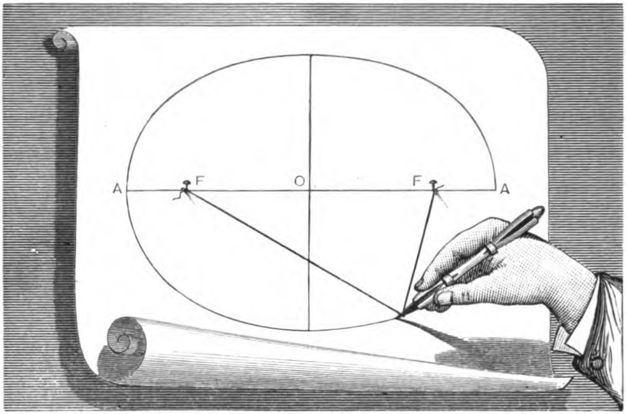
Tycho Brahe, a celebrated Danish astronomer, next propounded a modification of the Copernican system. He rejected the idea of cycles and epicycles, but, influenced by certain passages of Scripture, maintained with Ptolemy that the earth is the center, and that all the heavenly bodies daily revolve about it in circular orbits. Brahe was a nobleman of wealth, and, in addition, received large sums of money from the government. He erected a magnificent observatory, and made many beautiful and rare instruments. Clad in his robes of state, he watched the heavens with the intelligence of a philosopher and the splendor of a king. His indefatigable industry and zeal resulted in the accumulation of a vast fund of astronomical knowledge. His pupil, Kepler, saw these facts, and in his fruitful mind they were generalized into three great truths, called Kepler's laws. These form one of the most precious conquests of the human mind. They are the three arches of the bridge over which astronomy crossed the gulf between the Ptolemaic and Copernican systems.

Kepler's Laws. — Kepler, from the observations of his master, Tycho Brahe, determined to find the exact shape of the orbits of the planets. He adopted the Copernican theory—that the sun is the center of the system. At that time, all believed the orbits to be circular. They reasoned thus: the circle is perfect; it is the most beautiful figure in nature; it has neither beginning nor ending; therefore, it is the only form worthy of God, and He must have used it for the orbits of the worlds He has made.

Imbued with this romantic view, Kepler commenced with a rigorous comparison of the places of the planet Mars as observed by Tycho Brahe, with the places as stated by the best tables that could be computed on the circular theory. For a time they agreed, but in certain portions of the orbit the observations of Tycho Brahe would not fit the computed place by eight minutes of a degree. Believing that so good an astronomer could not be mistaken as to the facts, Kepler exclaimed, 'Out of these eight minutes we will construct a new theory that will explain the movements of all planets.'

He resumed his work, and for eight years continued to imagine every conceivable hypothesis, and then patiently to test it—'hunt it down,' as he called it. Each in turn proved false, until nineteen had been tried. He then determined to abandon the circle and to adopt another form. The *ellipse* suggested itself to his mind. Let us see how this figure is made.

Attach a thread to two pins, as at FF in the next figure; then move a pencil along with the thread, the latter being kept tightly stretched, and the point will mark a curve, flattened in proportion to the length of



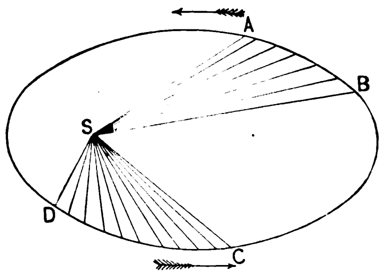
How to describe an Ellipse

the string, — the longer the string, the nearer a circle will the figure become. This figure is an *ellipse*. The two points FF are called the *foci* (singular, *focus*). We can now understand Kepler's attempt, and the triumph which crowned his years of unflagging toil.

First Law. — With this figure he constructed an orbit having the sun at the center, and again followed the planet Mars in its course. But very soon there was as great a discrepancy between the observed and computed places as before. Undismayed by this failure, Kepler assumed another hypothesis, and determined to place the sun at one of the foci of the ellipse. Once more he 'hunted down' the theory. For a whole year he traced the planet along the imaginary orbit, and it did not diverge. The truth was discovered at last, and Kepler in 1609 announced his first great law —

Planets revolve in ellipses, with the sun at one focus.

Second Law. — Kepler knew that the planets do not move with equal velocity in the different parts of their orbits. He next set about establishing some law by which a planet's speed could be determined, and the place of the planet computed. He drew an ellipse, and once more marked the various positions of the planet Mars. He soon found that when at its *perihelion* (point nearest the sun) its motion is fastest, but when at its *aphelion* (point furthest from the sun) its motion is slowest. Again he 'hunted down' various hypotheses, until at last he discovered that although the planet goes from B to A in the same length of time as from D to C, and hence moves more slowly in going from B to A than in going from D to C, yet the area inclosed between the arc and the lines SB and SA is equal to that similarly inclosed between SD and SC. Hence the second law —



AN ELLIPSE WITH ONE FOCUS AT S

A line connecting the center of the planet with the center of the sun passes over equal areas in equal times.

THIRD LAW. — Kepler, not satisfied with the discovery of these laws, now determined to ascertain if there were not some relation existing between the times of revolution of the planets around the sun and their distances from that body. With the same wonderful patience, he took the figures of Tycho Brahe, and began to compare them. He tried them in every imaginable relation. Next he took their squares, then he tried their cubes. Here was the secret; but he toiled around it, made a blunder, and waited for months, until once more his patience triumphed, and in 1619 he published the third law —

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

For example: The square of Jupiter's period is to the square of Mars's period as the cube of Jupiter's distance is to the cube of Mars's distance.

In rapture over the discovery of these three laws, so marked by that divine simplicity which pervades all the laws of nature, Kepler exclaimed, 'Nothing holds me. The die is cast. The book is written, to be read now or by posterity, I care not which. It may well wait a century for a reader, since God has waited six thousand years for an observer.'

Galileo. — Contemporary with Kepler was the great Florentine philosopher, Galileo. He discovered the laws of the pendulum and of falling bodies, so important in physics. He was, however, educated in and believed in the Ptolemaic system. A disciple of the Copernican theory happening to come to Pisa, where Galileo was teaching as professor in the University, drew his attention to its simplicity and beauty. His clear, discriminating mind perceived its perfection, and he henceforth advocated it with all the ardor of his unconquerable zeal. Soon after, he learned that a Dutch watchmaker had invented a contrivance for making distant objects appear near. With his profound knowledge of optics and philosophical instruments, Galileo caught the idea, and soon had a telescope completed. It was a very simple affair — only a piece of lead pipe with a lens set at each end; but it was destined to overthrow the old Ptolemaic theory, and revolutionize the science of astronomy.

DISCOVERIES MADE WITH THE TELESCOPE.—Galileo now examined the moon. He saw her mountains and valleys, and watched the dense shadows upon her plains. On January 7, 1610, he turned the telescope toward Jupiter. Near it he saw three bright stars, as he considered them, which were invisible to the naked eye. The next night he noticed that they had changed their relative positions. Astonished and perplexed, he waited three days for a fair night in which to resume his observations. The fourth night was favorable, and he found the three stars had again shifted. Night after night he watched them, discovered a fourth star, and finally found that they were revolving around Jupiter, each in its appropriate orbit, with its own rate of motion, and all accompanying the planet in its journey around the sun. Here was a miniature Copernican system hung up in the sky for every one to see and examine for himself.

RECEPTION OF THE DISCOVERIES.—Galileo met with the most bitter opposition. Many refused to look through the telescope lest they might become victims of the philosopher's magic. Some prated of the wickedness of digging out valleys in the fair face of the moon. Others doggedly clung to the theory they had held from their youth.[1] But the truth of the Copernican system

[1] Of the arguments adduced against the new system, the following by a learned mediæval writer is a fair specimen: 'There are seven windows in the head, through which the air is admitted to the body, to enlighten, to warm, and to nourish it,—two nostrils, two eyes, two ears, and one mouth. So in the heavens there are two favorable stars, Jupiter and Venus; two unpropitious, Mars and Saturn; two luminaries, the Sun and Moon; and Mercury alone, undecided and indifferent. From which,

was now fully established. Philosophers gradually adopted this view, and the Ptolemaic theory became a relic of the past.

Newton, a young man of twenty-four years, was spending the summer of 1666 in the country, on account of the plague which prevailed at Cambridge, England, his place of residence. One day while he was sitting in a garden, an apple chanced to fall to the ground near him. As he reflected upon the strange power that causes all bodies thus to descend to the earth, and remembered that this force continues, even when we ascend to the tops of high mountains, the thought occurred to his mind, 'May not this same force extend to a great distance out in space? Does it not reach as far as the moon?'

LAWS OF MOTION.—To understand the reasoning that now occupied the mind of Newton, let us apply the laws of motion as we have learned them in physics. When a body is set in motion, it will continue to move forever in a straight line, unless another force is applied. As there is no friction in space, the planets do not lose any of their original velocity, but move now as always in the past. But this would make them all pass along straight lines, and not circular orbits. What causes the curve? Obviously, another force. For example: I throw a stone into the air. It does not move in a straight line, but in a curve, because the

and from many other phenomena in Nature, such as the seven metals, etc., we gather that the number of planets is necessarily seven. Moreover, the satellites are invisible to the naked eye, can exercise no influence over the earth, and would be useless, and therefore do not exist. Besides, the week is divided into seven days, which are named from the seven planets. Now, if we increase the number of planets, this whole system falls to the ground.'

attraction of the earth constantly bends it downward, while the resistance of the air checks its velocity.

APPLICATION.—So, too, the moon is moving around the earth, not in a straight line, but in a curve. Can it not be that the earth bends the moon's path inward, just as it does the stone downward? Newton knew that a stone falls toward the earth sixteen feet the first second. He conceived, after a careful study of Kepler's laws, that the attraction of the earth might diminish as the square of the distance from its center increases.

We can measure the force of gravity by finding how far it makes a body fall in one second of time. Newton was well aware that the moon is distant 60 semidiameters of the earth; so that, if his supposed law were to hold true, the force of the earth's gravity at the moon's distance must be $\frac{1}{60 \times 60}$, that is, $\frac{1}{3600}$ of what it is at the earth's surface, or such that a body would, at the moon's distance, fall toward the earth only about $\frac{1}{20}$ of an inch (exactly 0.053 inch) in one second. For Newton it was an easy problem in geometry to find whether or not the moon's orbit really bends 0.053 inch away from a straight line each second. But the earth's diameter accepted in his day was 6870 miles; so that the moon seemed to fall toward the earth, not 0.053 inch in a second, as his theory would require, but only 0.047 inch.

Clearly, then, thought Newton, his theory must be wrong, and he said, 'I laid aside at that time any further thought of the matter.' The force of terrestrial gravity appeared to be too strong — perhaps, indeed, it was not after all the force that holds the moon in its orbit. His disappointment was intense, but he never mentioned it to any one. Before laying aside his calculations, however, he repeatedly reviewed them, though without finding a mistake anywhere.

After nearly twenty years, while in London, he learned of a more accurate calculation of the distance from the circumference to the center of the earth. He hastened home, inserted this new value in his calculations, and soon found that the result would be correct. Overpowered by the thought of the grand truth just before him, his hand faltered, and he called upon a friend to complete the computation.

From the moon, Newton passed on to the other heavenly bodies, calculating and testing their orbits; and, by reasoning equally conclusive, proved that the attraction of that great central orb, the sun, compels all the planets to revolve about it in elliptical orbits, and holds them irresistibly in their appointed paths.[1] At last, he announced his law of universal gravitation: *Every particle of matter in the universe attracts every other particle of matter with a force directly proportional to the product of their masses, and decreasing as the square of the distance between them increases.*

[1] 'Do not understand me at all as saying there is no mystery about the planets' motion. There is just one single mystery,—gravitation,—and it is a very profound one. How it is that an atom of matter can attract another atom, no matter how great the distance, and no matter what intervening substance there may be, how it will act upon it, or at least behave as if it acted upon it,—I do not know, I cannot tell. Whether they are pushed together by means of an intervening ether, or what is the action, I cannot understand. It stands with me along with the fact, that, when I will my arm to rise, it rises. It is inscrutable. All the explanations that have been given of it seem to me merely to darken counsel with words and no understanding. They do not remove the difficulty at all. If I were to say what I really believe, it would be that the motion of the spheres of the material universe stand in some such relation to Him in whom all things exist, the ever-present and omnipotent God, as the motions of my body do to my will: I do not know how, and never expect to know.'—YOUNG.

II. SPACE

We now in imagination pass into space, which stretches out in every direction, without bounds or measure. We look up to the heavens, and try to locate some object among the mazes of the stars. Bewildered, we feel the necessity of some system of measurement. Let us try to understand the one adopted by astronomers.

The Celestial Sphere. — The blue dome of the sky, as it appears to be spread over us, forms half of the *Celestial Sphere*. There are two points to be noticed here.

First, that so far distant is this imaginary arch from us, that if any two parallel lines from different parts of the earth were drawn to this sphere they would apparently coalesce. Of course, this could not be the fact; but the distance is so immense that we are unable to distinguish the little difference of four or even eight thousand miles, and the two lines would seem to unite: so we must consider this great earth as a mere speck or point at the center of the celestial sphere.

Second, that we must neglect the entire diameter of the earth's orbit, so that if we should draw two parallel lines, one from each end of the earth's orbit, to the celestial sphere, although these lines would be 186,000,000 miles apart, yet they would appear to pierce the sphere at the same point; which is to say, that, at the enormous distance of the sphere's center from its surface, 186,000,000 miles shrink to a point. Consequently, in all parts of the earth and in every part of the earth's orbit, we see the fixed stars in essentially the same place.

This sphere of stars surrounds the earth on every side.

In the daytime we cannot see the stars because of the superior light of the sun illumining our atmosphere; but with a telescope they can be traced, and an astronomer will find certain stars quite as well at noon as at midnight. One half of the sphere is constantly visible to us.

On the concave surface of the celestial sphere are imagined to be drawn three systems of circles: the HORIZON, the EQUINOCTIAL, and the ECLIPTIC SYSTEMS. Each of these has (1) its *Principal Circle*, (2) its *Subordinate Circles*, (3) its *Points*, and (4) its *Measurements*.

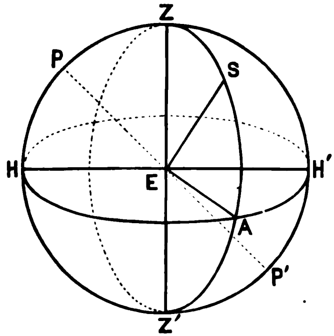
(A) THE HORIZON SYSTEM

(*a*) **The Principal Circle** is the *Rational Horizon.* This is the great circle whose plane, passing through the center of the earth, separates the visible from the invisible heavens. The *Sensible Horizon* is parallel to the rational horizon, but distant from it the semidiameter of the earth. No two places have the same sensible horizon: any two, on opposite sides of the earth, have the same rational horizon. On the celestial sphere the sensible and rational horizons coalesce.

(*b*) **The Subordinate Circles** are the *Prime Vertical* and the *Meridian.* A vertical circle is one passing through the poles of the horizon (zenith and nadir). The meridian is that vertical circle which passes through the pole of the heavens, P. Its intersection with the horizon at H and H′ gives the north and south points. The vertical circle at right angles to the meridian is called the prime vertical, and its intersection with the horizon gives the east and west points.

(*c*) **The Points** are the *Zenith*, the *Nadir*, and the

N., S., E., and W. points. The zenith is the point directly overhead, and the nadir, the one directly underfoot, as indicated by a plumb line at rest. They are the poles of the horizon — *i.e.* the points where the axis of the horizon pierces the celestial sphere. The N., S., E., and W. points are familiar.



E, CENTER OF EARTH; Z, ZENITH; Z', NADIR; PP', AXIS OF CELESTIAL SPHERE; HAH', HORIZON; S, A STAR; ZSZ', VERTICAL CIRCLE PASSING THROUGH S; AS, ALTITUDE OF STAR; ZS, ZENITH DISTANCE OF STAR; H'A, AZIMUTH OF STAR

(*d*) **The Measurements** are *Azimuth*, *Amplitude*, *Altitude*, and *Zenith Distance.*

AZIMUTH is the distance (that is, the angular distance) from the south point, measured westward on the horizon, to a vertical circle passing through the object.

AMPLITUDE is the distance from the prime vertical, measured on the horizon, north or south.

ALTITUDE is the distance of an object from the horizon, measured on a vertical circle, toward the zenith.

ZENITH DISTANCE (the complement of altitude) is the distance from the zenith, measured on a vertical circle, toward the horizon.

The horizon system is the one used in observations with alt-azimuth instruments.

(B) THE EQUINOCTIAL SYSTEM

(*a*) **The Principal Circle** is the *Equinoctial.* This is the *Celestial Equator*, or the plane of the earth's equator extended to meet the celestial sphere. At all places on the earth's surface, the celestial equator is inclined to the horizon at an angle equal to the distance of the zenith of the place from the pole. The latitude of a place is its distance from the terrestrial equator, and this equals the distance of the zenith of the place from the equinoctial. Hence, having given the latitude of a place, to find the height of the celestial equator above its horizon, subtract the latitude from 90°, and the remainder is the required angular distance. In like manner, the latitude subtracted from 90° gives the co-latitude of the place, or the complement of the latitude.

(*b*) **The Subordinate Circles** are the *Hour Circles* (right ascension meridians), the *Colures*, and the *Declination Parallels*.

THE HOUR CIRCLES are thus located: The equinoctial is divided into 360°, equal to twenty-four hours of time — thus making 15° equal to one hour of time. Through these divisions run twenty-four meridians, each representing an hour of time, or 15° of space. The hour circles may be conceived as meridians of terrestrial longitude (15° apart) whose planes are extended to the celestial sphere. Also, the meridian passing through any star is called its hour circle.

THE COLURES are two principal hour circles: the *Equinoctial Colure* is the hour circle passing through the equinoxes; the *Solstitial Colure* is the hour circle passing through the solstitial points.

THE DECLINATION PARALLELS are small circles of the celestial sphere parallel to the Equinoctial.

(*c*) **The Points** are the *Celestial Poles* and the *Equinoxes*.

THE CELESTIAL POLES are the points where the axis of the earth extended pierces the celestial sphere. They are the extremities of the celestial axis, as the poles of the earth are the extremities of the earth's axis. The north celestial pole is very near the North Star. Every direction *from* this pole is south, and every direction *toward* it is north, however it may conflict with our ideas of the terrestrial points of the compass as referred to the horizon.

THE EQUINOXES are the points where the equinoctial and the ecliptic (the sun's apparent path through the heavens) intersect (page 101).

(*d*) **The Measurements** are *Right Ascension* (R. A.), *Declination*, and *North Polar Distance*.

RIGHT ASCENSION is distance from the vernal equinox, measured on the equinoctial eastward to the hour circle passing through the body. R. A. corresponds to terrestrial longitude, though it may extend to 360° east, instead of 180° both east and west as longitude does on the earth. R. A. is never measured westward. The starting point is the hour circle passing through the vernal equinox, as the meridian passing through Greenwich is the point from which terrestrial longitude is measured.

DECLINATION is distance of a body from the equinoctial, measured on its hour circle north or south. It corresponds to terrestrial latitude.

NORTH POLAR DISTANCE is the distance from the north celestial pole, measured on an hour circle. It can never exceed 180°.

The equinoctial system is largely used by modern astronomers in their observations with the equatorial telescope, meridian circle, sidereal clock, and chronograph.

(C) THE ECLIPTIC SYSTEM

(*a*) **The Principal Circle** is the *Ecliptic.* This is the yearly apparent path of the sun in the heavens. It is inclined to the equinoctial $23\frac{1}{2}°$ ($23° 27' 8''.26$, January 1, 1900), which measures the inclination of the earth's equator to its orbit, and is called the *obliquity of the ecliptic.* The inclination of the ecliptic to the horizon, unlike that of the equinoctial, varies at different times of the day. The angle that the ecliptic makes with the horizon is greatest when the vernal equinox is on the western horizon and the autumnal on the eastern; it is least when the vernal equinox is on the eastern horizon and the autumnal on the western. In the former instance, the angle is equal to the co-latitude plus $23\frac{1}{2}°$ (the obliquity of the ecliptic); and, in the latter, the co-latitude minus $23\frac{1}{2}°$. Thus, at the latitude of New York, it varies from $90° - 41° + 23\frac{1}{2}° = 72\frac{1}{2}°$; to $90° - 41° - 23\frac{1}{2}° = 25\frac{1}{2}°$. In the one case, the summer solstice is on the meridian of the place, and, in the other, the winter solstice.

(*b*) **The Subordinate Circles** are *Circles of Celestial Longitude*, and *Parallels of Celestial Latitude.*

THE CIRCLES OF CELESTIAL LONGITUDE are now seldom employed. They are perpendicular to the ecliptic, as hour circles are perpendicular to the equinoctial.

THE PARALLELS OF CELESTIAL LATITUDE are little used. They are small circles drawn parallel to the ecliptic, as parallels of declination are drawn parallel to the equinoctial.

(*c*) **The Points** are the *Poles of the Ecliptic*, the *Equinoxes*, and the *Solstices.*

THE POLES OF THE ECLIPTIC are the points where a perpendicular to the earth's orbit meets the celestial sphere.

THE EQUINOXES are the points where the ecliptic intersects the equinoctial. The place where the sun crosses the equinoctial in going north, which occurs about the 21st of March, is called the Vernal Equinox. The place where the sun crosses the equinoctial in going south, which occurs about the 21st of September, is called the Autumnal Equinox. At either equinox, the sun is commonly said to 'cross the line.' The *Solstices* are the two points of the ecliptic most distant from the celestial equator; or they may be considered to mark the sun's farthest declination north and south of the equinoctial. The Summer Solstice occurs about the 21st of June; the Winter Solstice occurs about the 21st of December.

(*d*) **The Measurements** are *Celestial Longitude* and *Celestial Latitude*.

CELESTIAL LONGITUDE is distance from the vernal equinox, measured on the ecliptic, eastward.

CELESTIAL LATITUDE is distance from the ecliptic, measured on a circle of celestial longitude, north or south.

THE ZODIAC

A belt of the celestial sphere, 8° on each side of the ecliptic, is styled the *Zodiac*. This is of very high antiquity, having been in use among the Hindus and Egyptians several thousand years before Christ. The zodiac is divided into twelve equal parts — of 30° each — called Signs, to each of which a fanciful name is given, as shown below; the names are given in order, beginning at the vernal equinox and passing eastward around the ecliptic.

SIGNS OF THE ZODIAC

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

'The first, ♈, indicates the horns of the Ram; the second, ♉, the head and horns of the Bull; the barb attached to a sort of letter, ♏, designates the Scorpion; the arrow, ♐, sufficiently points to Sagittarius; ♑ is formed from the Greek letters, *τρ*, the two first letters of *τράγος*, *a goat*. Finally, a balance, the flowing of water, and two fishes tied by a string, may be imagined in ♎, ♒, and ♓, the signs of Libra, Aquarius, and Pisces.' (See pages 220, 311.)

PRACTICAL QUESTIONS

1. How high is the North Star above your horizon?

2. What is the sun's right ascension at the autumnal equinox? At the vernal equinox?

3. What was the first discovery made by the telescope?

4. How high above the horizon of any place are the equinoctial points when they pass the meridian?

5. Jupiter revolves around the sun in twelve of our years. Assuming the earth's distance from the sun to be 93,000,000 miles, compute Jupiter's distance by applying Kepler's third law.

6. The latitude of Albany is 42° 39′ N.; what is the sun's meridian altitude at that place when it is on the celestial equator?

7. What is the co-latitude of a place?

8. What is the declination of the zenith of the place in which you reside?

9. Why are the stars generally invisible by day?

10. Why is the ecliptic so called?

11. Who first taught that the earth is round?

12. What is astrology?

13. How can we distinguish fixed stars from planets?

14. How long was the Ptolemaic system accepted?

15. In what respect did the Copernican system differ from the one now received?

16. For what is astronomy indebted to Galileo? To Newton?

17. What is the amount of the obliquity of the ecliptic?

18. Define zenith. Nadir. Azimuth. Altitude. Equinoctial. Right Ascension. Declination. Equinox. Ecliptic. Colure. Solstice. North polar distance. Zenith distance. The zodiac.

19. If the R. A. of the sun be 80°, in what sign is he then located? 160°? 280°?

20. Why does the angle which the ecliptic makes with the horizon vary?

21. Why is the angle which the celestial equator makes with the horizon constant?

22. If the sun's meridian altitude is observed to be 68°, and if the north declination is + 21°, what is the latitude of the place of observation?

23. What is meant by the term 'crossing the line'?

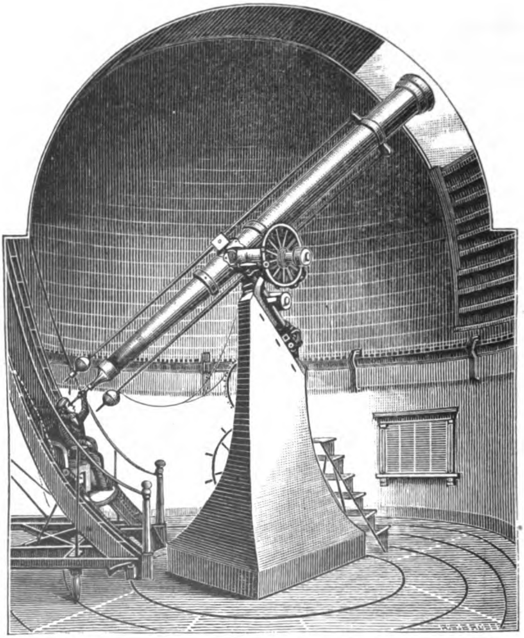
24. How often each year does this occur? Which way is the sun moving at each time?

25. Define celestial longitude. Celestial latitude.

26. If the sun's longitude is 90°, what is its right ascension? Its declination?

27. Name the signs of the zodiac.

28. How are their symbols derived?



Equatorial Telescope of Harvard College Observatory
(the Largest Telescope in New England)

II

THE SOLAR SYSTEM

'*In them hath He set a tabernacle for the sun.*'

'*This world was once a fluid haze of light*
Till toward the center set the starry tides
And eddied into suns, that wheeling cast
The planets.' — TENNYSON.

THE SOLAR SYSTEM

- (I) The Sun
  - (1) Distance
  - (2) Light & Heat
  - (3) Apparent Size
  - (4) Real Dimensions
  - (5) Solar Spots..
    - (*a*) Discovery
    - (*b*) Number and Location
    - (*c*) Size
    - (*d*) Parts
    - (*e*) Motion across Disk
    - (*f*) Change in Rate
    - (*g*) Prove the Rotation of Sun
    - (*h*) Synodic and Sidereal Revolution
    - (*i*) Path of Spots
    - (*j*) Individual Motion
    - (*k*) Change in Form
    - (*l*) Periodicity of Spots
    - (*m*) Planetary Influence
    - (*n*) Influence on Terrestrial Heat, etc.
    - (*o*) Heat of Spots
    - (*p*) Depression of Spots
    - (*q*) Brightness of Spots
    - (*r*) Faculæ, Rice Grains, etc.
  - (6) Physical Constitution ...
    - (*a*) Wilson's Theory
    - (*b*) Present Theory (Kirchhoff)
  - (7) How Solar Heat is Produced
- (II) The Planets
  - Introduction ...
    - (*a*) Common Characteristics
    - (*b*) Comparison of Planets
    - (*c*) Properties of the Ellipse
    - (*d*) Planetary Orbits
    - (*e*) Comparative Size of Planets
    - (*f*) Conjunction of Planets
    - (*g*) Are Planets Inhabited?
    - (*h* to *p*) Division of Planets, etc.
  - (1) Mercury .....
    - (*a*) Description
    - (*b*) Motion in Space
    - (*c*) Distance from Earth
    - (*d*) Dimensions
    - (*e*) Seasons
    - (*f*) Telescopic Features
  - (2) Venus ....Repeat same Analysis as of Mercury
  - (3) The Earth............ ....
    - (*a*) Dimensions
    - (*b*) Rotundity
    - (*c*) Apparent and Real Motion
    - (*d*) Diurnal Motion of Earth
      - (1) Diurnal Motion of Sun
      - (2) Unequal rate of Motion
      - (8) Paths of Stars
      - (4) Unequal Velocities of Stars
      - (5) Appearance of Stars, etc.
    - (*e*) Yearly Motion of Earth: its Consequences
      - (1) Change in Appearance of Heavens
      - (2) Yearly Path of Sun
      - (3) Moves N. & S.
      - (4) Change of Seasons, etc. 20 points under this topic
    - (*f*) Precession of Equinoxes
    - (*g*) Nutation
    - (*h*) Refraction and Aberration
    - (*i*) Parallax
    - — The Moon
      - (*a*) Motion
      - (*b*) Dimensions
      - (*c*) Librations
      - (*d*) L'g't & H't
      - (*e*) Atmosphere
      - (*f*) Lunarians
      - (*g*) Earth Shine
      - (*h*) Phases
      - (*i*) Harv'st M'n
      - (*j*) Wet Moon
      - (*k*) Nodes
      - (*l*) Occultations
      - (*m*) Seasons
      - (*n*) Telescopic Features
    - — Eclipses
    - — The Tides
  - (4) Mars ....Same Analysis as Mercury
  - (5) The Small Planets
  - (6) Jupiter.........Same Analysis as Mercury
  - (7) Saturn ....Same Analysis as Mercury
  - (8) Uranus.........Same Analysis as Mercury
  - (9) Neptune........Same Analysis as Mercury
- (III) Meteors and Shooting Stars
- (IV) Comets ....
- (V) The Zodiacal Light..........

(III)–(V): The subjects of the paragraphs may be inserted by the pupil, to complete these analyses, at the pleasure of the teacher

THE SOLAR SYSTEM

INTRODUCTION

The Solar System is mainly comprised within the limits of the zodiac. It consists of—

(1) The sun — the center.
(2) The major planets — Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune.
(3) The minor planets, of which about four hundred and fifty have been found.
(4) The satellites, or moons, more than twenty in number, which revolve around the different planets.
(5) Meteors and shooting stars.
(6) Numerous comets, which, by a second return, have now been found to move like the planets, in elliptic paths, and to revisit the sun periodically.
(7) The zodiacal light.

How we are to imagine the Solar System to Ourselves.—We are to think of it as suspended in space; being held up, not by any visible object, but in accordance with the law of universal gravitation discovered by Newton, whereby each planet attracts every other planet, and is in turn attracted by all.

First, the sun, a great central globe, so vast as to overcome the attraction of all the planets, and compel them to circle around him; next, the planets, each turning on its axis while it journeys around the sun in an elliptical orbit; then, accompanying these, the satellites, each revolving about its own planet; next, the comets, rushing across the planetary orbits at irregular intervals of time and space; and, finally, shooting stars and meteors darting hither and thither, interweaving all in apparently inextricable confusion.

To make the picture more wonderful still, every member is speeding with inconceivable velocity, and yet with such accuracy that the solar system is the most perfect timepiece known.

I. THE SUN

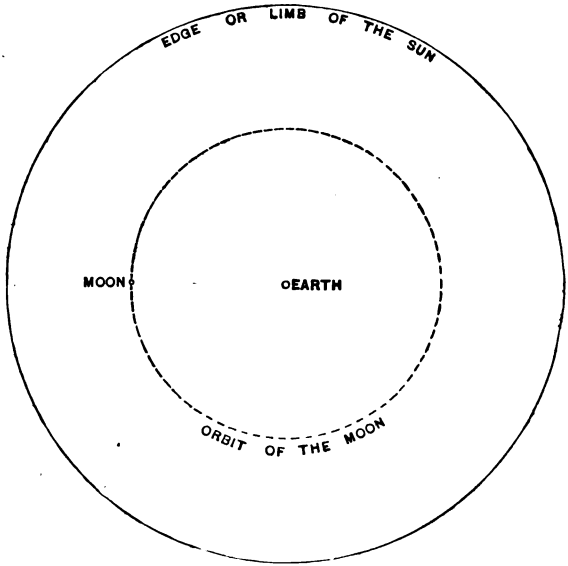
Sign, ⊙, a buckler with its boss

Distance. — The sun's average distance from the earth is nearly 93,000,000 miles. Since the earth's orbit is elliptical, and the sun is situated at one of its foci, the earth is 3,000,000 miles farther from the sun in aphelion than in perihelion. The sun's distance from the earth is determined, as we shall learn hereafter (see Celestial Measurements, page 291), by means of the solar parallax, and in other ways.

As we attempt to locate the heavenly bodies in space, we are startled by the enormous figures employed. The first number, 93,000,000 miles, is far beyond our grasp. Let us, however, try to comprehend it. If an infant were born with an arm long enough to reach the sun, and should touch that fiery globe, he would grow to manhood and to old age and finally die, before the sensation could traverse the nerve to his brain, and he feel the burn. If there were air to convey a sound from the sun to the earth, and a noise could be made loud enough to pass that distance, it would require over fourteen years for it to come to us. Suppose a railroad could be built to the sun. An express train, traveling day and night, at the rate of thirty miles an hour, would require 352 years to reach its destination. Ten generations would be born and would die; the young men would become gray-haired, and their great-grandchildren would forget the story of the beginning of that wonderful journey, and would read it in history, as we now read of Queen Elizabeth or of Shakespeare; the eleventh generation would see the solar station at the end of the route. Yet this enormous distance of 93,000,000 miles is used as the unit for expressing celestial distances,—as the foot rule for measuring space; and astronomers speak of so many times the sun's distance as we speak of so many feet or inches.

The Light of the Sun is about equal to that of 6000 wax candles at a distance of one foot from the eye. It would require 600,000 full moons to produce a day as brilliant as one of cloudless sunshine. According to Professor Langley, the sun is blue, and to the inhabitants of other worlds may shine as a bluer star than Vega. The light from different parts of the solar disk, however, varies in color; while that from the center has a decidedly blue tint, that from the edge is of a chocolate hue. This difference is probably owing to the fact that the latter passes through a greater thickness of the solar atmosphere, while our own atmosphere does its part in strangling the blue rays of the sunlight, the red rays filtering through with little loss.

Heat of the Sun.—The amount of heat we receive annually is sufficient to melt a layer of ice nearly 200 feet thick, extending over the whole earth. Yet the sunbeam is only $\frac{1}{46000}$ part as intense as it is at the surface of the sun. Moreover, the heat and light stream off into space equally in every direction. Of this vast flood, only $\frac{1}{2200000000}$ part reaches the earth. If the heat of the sun were produced by the burning of coal, it would



SIZE OF SUN COMPARED WITH MOON'S ORBIT

require a layer more than 20 feet in thickness, extending over its whole surface, to feed the flame a single hour. Were the sun a solid body of coal, it would burn up at this rate in less than 50 centuries. Sir John Herschel has said that if a solid cylinder of ice 45 miles in diameter and 200,000 miles long were plunged, end first, into the sun, it would melt in a second of time.

Of the sun's heat, Professor Todd writes in *Stars and Telescopes* (1899): 'Imagine that hemisphere of our globe turned toward the sun to be covered with horses, arranged as closely together as possible, no horse standing in the shadow of any other; then cover the opposite hemisphere with an equal number of horses: the solar energy intercepted by the earth is more than equivalent to the power of all these animals exerting themselves to the utmost and continuously.'

Apparent Size. — The sun appears to be a little over half a degree in diameter, so that 337 solar disks, laid side by side, would make a half circle of the celestial sphere. It seems a trifle larger to us in winter than in summer, as we are 3,000,000 miles nearer it. If we represent the luminous surface of the sun when at its average (mean) distance by 1000, the same surface will be represented when in aphelion (July) by 967, and when in perihelion (January) by 1034.

Dimensions. — Its *diameter* is 865,400 miles.[1] Let us try to understand this amount by comparison.

A mountain upon the surface of the sun, to bear the same proportion to the globe itself as the loftiest peak of the Himalayas does to the earth, would need to be about 600 miles high.

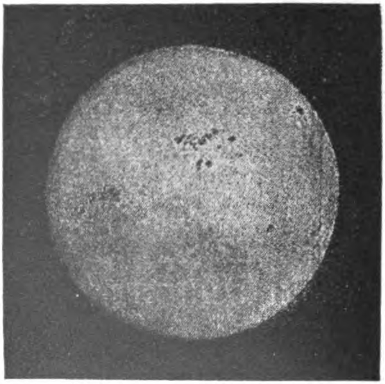
Again: Suppose the sun were hollow, and the earth, as in the diagram, placed at the center, not only would there be room for the moon to revolve in its regular orbit within the shell, but that would stretch off in every direction nearly 200,000 miles beyond.

Its *volume* is 1,300,000 times that of the earth;

[1] Pythagoras, whose theory of the universe was in so many respects very like the one we receive, believed the sun to be 44,000 miles from the earth, and seventy-five miles in diameter.

it would take 1,300,000 earths to make a globe the size of the sun. Its *mass* is 750 times that of all the planets and moons in the solar system, and 330,000 times that of the earth. Its *weight* may be expressed in tons, thus :—

1,980,000,000,000,000,000,000,000,000.[1]



THE SUN SEEN THROUGH A SMALL TELESCOPE

The *density* of the sun is only about one fourth that of the earth, or 1.4 that of water, so that the weight of a body transferred from the earth to the sun would not be increased in proportion to the comparative size of the two. On account also of the vast size of the sun, its surface is so far from its center that the attraction is largely diminished, since that decreases, we remember, as the square of the distance increases.

[1] This number is meaningless to our imagination, but yet it represents a force of attraction that holds our own earth and all the planets steadily in their places; while it fills the mind with an indescribable awe as we think of that Being who 'made the sun, and holds it in the very palm of His hand.'

However, a man weighing at the earth's equator 150 pounds, at the sun's equator would weigh about two tons, — a force of attraction that would instantly crush him. At the earth's equator, a stone falls 16 feet the first second; at the sun's equator, it would fall 444 feet.

Telescopic Appearance of the Sun: Sun Spots. — We may sometimes examine the sun with the naked eye at early morning or late in the afternoon, and at midday by using a smoked glass. The disk will appear distinct and circular, and with no spot to dim its brightness. If we use a telescope of moderate power, taking the precaution to shield the eye with a colored eyepiece, we shall find the sun sprinkled with irregular spots as in the opposite illustration.[1]

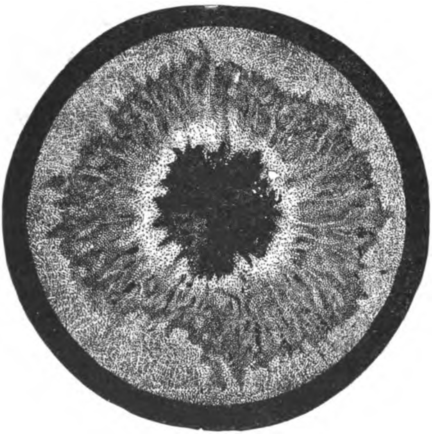
DISCOVERY OF THE SOLAR SPOTS. — The solar spots seem to have been noticed as early as A.D. 807, although the telescope was not invented until 1610, and Galileo is considered to have discovered them in the following year.[2]

NUMBER AND LOCATION. — Sometimes the sun's disk is clear. During a period of ten years, observations were made on 1982 days, on 372 of which there were

[1] The natural purity of the sun seems to have been formerly an article of faith among astronomers, and therefore on no account to be called in question. Scheiner, it is said, having reported to his superior that he had seen spots on the sun's face, was abruptly dismissed with these remarks: 'I have read Aristotle's writings from end to end many times, and I assure you I do not find anything in them similar to that which you mention. Go, my son, tranquilize yourself; be assured that what you take for spots are the faults of your glasses or your own eyes.'

[2] We read in the log of the good ship *Richard of Arundell*, on a voyage in 1590 to the coast of Guinea, that 'on the 7, at the going downe of the sunne, we saw a great black spot on the sunne; and the 8 day, both at rising and setting, we saw the like, which spot to me seeming was about the bignesse of a shilling, being in 5 degrees of latitude, and still there came a great billow out of the souther board.'

no spots seen. As many as two hundred spots have been noticed at one time. They are found mostly in two belts, one on each side of the sun's equator, within not less than 5° nor more than 30° of latitude. They seem to herd together, — the length of the straggling group being generally parallel to the equator.



SUN SPOT

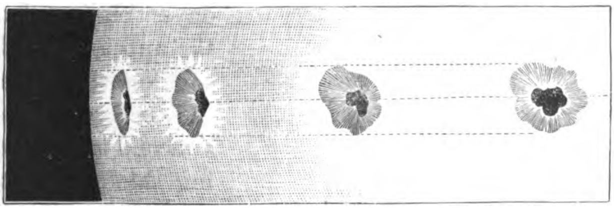
Size of the Spots. — It is not uncommon to find a spot with a surface greater than that of the earth. Schroeter measured one more than 29,000 miles in diameter. Sir John Herschel calculated that one which he saw was 50,000 miles in diameter. In 1843, one was seen which was 75,000 miles across, and was visible to the naked eye for an entire week.[1] On the day of the eclipse in 1858, a spot over 108,000 miles broad was distinctly seen, and attracted general attention in this country. In 1839, Captain Davis saw one which he computed was 180,000 miles long, and had an area of 24,000,000,000 square miles.

If these are deep openings in the luminous atmosphere of the sun, what an abyss must that be at 'the

[1] On the sun's surface 1″=450 miles. This spot, according to Schwabe, was 2′ 47″ across.

bottom of which our earth could lie like a bowlder in the crater of a volcano!'

SPOTS CONSIST OF DISTINCT PARTS.—From the picture on the opposite page, it will be seen that a spot generally consists of a dark portion called the *umbra*, and around that a grayish portion styled the *penumbra* (*pæne*, almost, and *umbra*, shadow). Sometimes, however, umbræ appear without a penumbra, and *vice versa*. The umbra itself has generally a dense black center, called the *nucleus*. Besides this, the umbra is sometimes divided by luminous bridges (page 58).

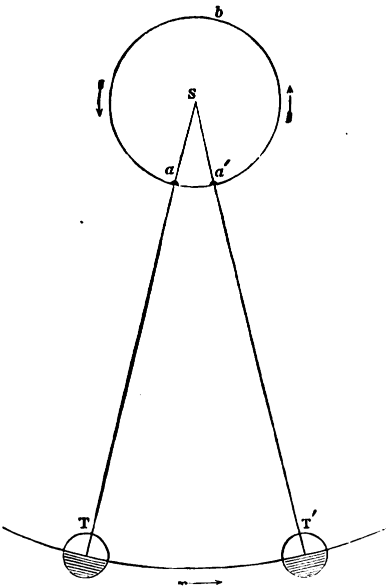


APPARENT CHANGE IN A SPOT AS IT CROSSES THE DISK

SPOTS ARE IN MOTION.—The spots change from day to day; but all have a common movement. About fourteen days are required for a spot to pass across the disk of the sun from the eastern side, or *limb*, to the western; in fourteen days it reappears, changed in form perhaps, but generally recognizable.

SPOTS APPARENTLY CHANGE THEIR SPEED AND FORM AS THEY PASS ACROSS THE DISK.—A spot is seen on the eastern limb; day by day it progresses, with a gradually increasing rapidity, until it reaches the center; it then slowly loses its rapidity, and finally disappears on the western limb. The diagram illustrates the apparent change in form. Suppose at first the spot is of an oval shape ; as it approaches the center it apparently widens and becomes circular. Having passed that point, it becomes more and more oval until it disappears.

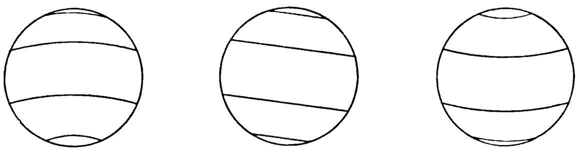
THIS CHANGE IN THE SPOTS PROVES THE SUN'S ROTATION ON ITS AXIS.—These changes can be accounted for only on the supposition that the sun rotates on its axis: indeed, they are the precise effects which the laws of perspective demand in that case. About twenty-seven days elapse from the appearance of a spot on the eastern limb before it is seen a second time. During this period the earth has gone forward in its orbit, so that the location of the observer is changed ; allowing for this, the sun's time of rotation at the equator is 25¼ days.



SYNODIC AND SIDEREAL REVOLUTIONS

Curiously enough, the equatorial regions move more rapidly, and complete a rotation in less time, than the rest of the sun. While a spot near the equator performs a rotation in twenty-five days, one situated halfway to either pole requires nearly twenty-eight days.

SYNODIC AND SIDEREAL REVOLUTIONS OF THE SPOTS. — We can easily understand why we make an allowance for the motion of the earth in its orbit. Suppose a solar spot at *a* (page 54), on a line passing from the center of the earth to the center of the sun. For the spot to pass around the sun and come into the same relative position again, requires about twenty-seven days. But, during this time, the earth has passed on from T to T′. The spot has not only traveled around to *a* again, but also beyond that to *a*′, or the distance from *a* to *a*′ more than an entire revolution. To do this requires about two days. A revolution from *a* around through *b* and on to *a*′ is called a *synodic*, and one from *a* around to *a* again is called a *sidereal*, revolution.



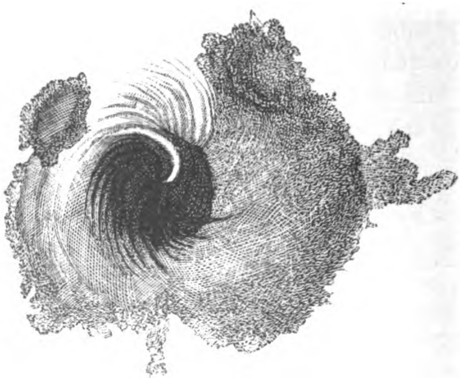
March *June* *September*

APPARENT PATHS OF SPOTS IN DIFFERENT MONTHS

SPOTS DO NOT ALWAYS MOVE IN STRAIGHT LINES. —Sometimes their path curves toward the north, and sometimes toward the south, as in the figure. This is explained on the supposition that the sun's axis is inclined to the ecliptic about 7°.

SPOTS HAVE A MOTION OF THEIR OWN.—Besides the motion already named as assigned to the sun's rotation, nearly every spot seems to have an individual motion. Some spots circle about in small elliptical paths, often quite regularly for weeks and even months. Immense cyclones occasionally pass over the surface with fearful rapidity, producing rotation and sudden changes in the spots. At other times, however, the spots seem 'to set sail and move across the disk of the sun like gondolas over a silver sea.'

SPOTS CHANGE THEIR REAL FORM.— Spots have been seen to break out and then disappear under the eye of the astronomer. Wollaston saw one that seemed to be shattered like a fragment of ice when it is thrown on a frozen surface, breaking into pieces, and sliding off in



SOLAR CYCLONE, MAY 5, 1857, ACCORDING TO SECCHI

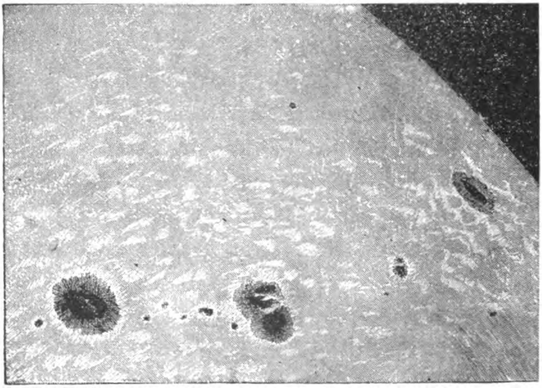
every direction. Sometimes one divides itself into several nuclei, while again several nuclei combine into a single nucleus. Occasionally a spot will remain for six or eight rotations, while rarely it will last scarcely half an hour. Sir W. Herschel relates that, when examining a spot through his telescope, he turned away for a moment, and when he looked back it was gone.

APPEARANCE OF THE SPOTS IS PERIODICAL. — It is a remarkable fact that the number of spots increases and diminishes through a regular interval of about

11.11 years. Also that they begin in relatively high solar latitudes, about 30° on both sides of the sun's equator, gradually reach their maximum in middle latitudes, and die out in low latitudes. This regular variation is called the 'law of zones,' but its cause has not been ascertained. The spot period is probably caused by the action of forces originating in the sun itself, and is closely connected with similar variations in the aurora borealis and magnetic earth currents which interfere with the operation of the telegraph. The regular increase and diminution in the number of the spots was discovered by Schwabe, of Prussia, who watched the sun so carefully that it is said for thirty years the sun never appeared above the horizon without being confronted by his imperturbable telescope. There was a maximum of solar spots in 1893–94, and a minimum in 1899. The next maximum is due in 1905, and the next minimum in 1910–11.

ARE THE SPOTS INFLUENCED BY THE PLANETS?—Some astronomers believe that the solar spots are especially sensitive to the approach of Mercury and Venus, on account of their nearness, and of Jupiter, because of its size; that the area of the spots exposed to view from the earth is uniformly greatest when any two of the larger planets come into line with the sun; and that when both Venus and Jupiter are on the side of the sun opposite to us, the spots are much larger than when Venus alone is in that position. Most authorities, however, deny planetary influence altogether.

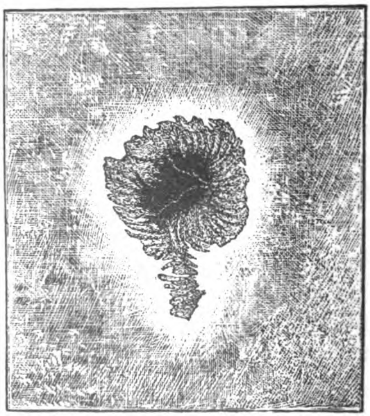
SPOTS DO NOT INFLUENCE FRUITFULNESS OF THE SEASON.—Herschel first advanced the idea that years of abundant spots would be years also of plentiful



PHOTOGRAPHIC VIEW OF SPOTS AND FACULÆ

harvests. This is not now generally believed. Whether the spots influence the weather is still a mooted question.

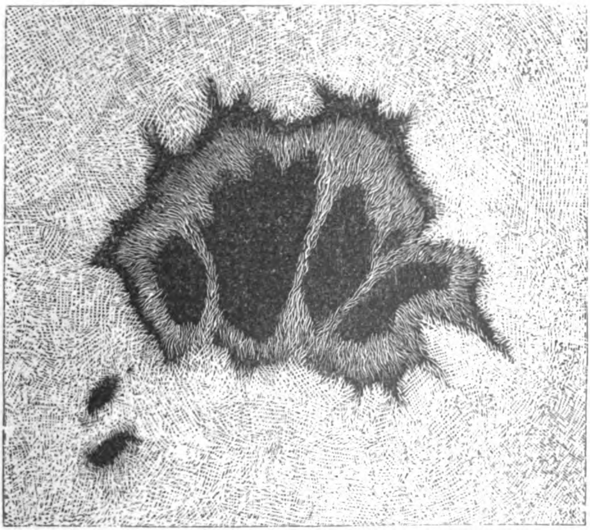
SPOTS ARE COOLER THAN THE SURROUNDING SURFACE. — It seems that the breaking out of a spot sensibly diminishes the temperature of that portion of the sun's disk. The faculæ (page 60) do not increase the temperature.



SPOT WITH BRIDGES ACROSS THE UMBRA

SPOTS ARE DEPRESSIONS. — Careful observations show that, in general, the 'floor,' so to speak, of the umbra is sunk from two to six thousand miles below the level of the luminous surface. Occasionally a spot is observed which is not a depression.

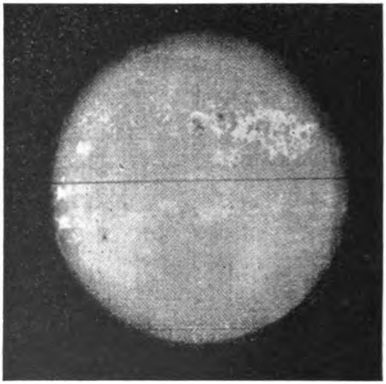
COMPARATIVE BRIGHTNESS OF SPOTS AND SUN.— If we represent the ordinary brightness of the sun by 1000, then that of the penumbra would be about 800, and that of the umbra, 540, according to Langley. There may be much light and heat radiated by a spot



SPOT SURROUNDED BY WILLOW-LEAF STRUCTURE

which seems black as compared with the sun; for we remember that even a calcium light, held between our eyes and the sun, appears as a black spot on the disk of that luminary.

APPEARANCE OF THE SUN'S SURFACE.—Even a telescope of moderate power will show that the surface of the sun has a peculiar *mottled* appearance not unlike that of an orange skin. But, under favorable circumstances and with a telescope of high power, the solar disk is seen to be covered with small, intensely bright bodies irregularly distributed. These are now known as *rice grains*. They are often apparently crowded together in luminous ridges, or streaks, termed *faculæ* (*facula*, a torch); while the rice grains themselves, according to Langley, are composed of *granules*. Minute as a granule seems, probably the smallest has a diameter of at least 100 miles. The faculæ visible with the telescope are most numerous near the edge, or limb of the sun; but by means of a complicated instrument called the *spectroheliograph*, they are recorded by photography in belts reaching across the sun's disk in zones similar to those in which the spots are seen (page 52).



PHOTOGRAPH SHOWING FACULÆ

Physical Constitution of the Sun.[1] — Of the constitution of the sun, and the cause of the solar spots, very little is definitely known.

WILSON'S THEORY supposed that the sun was composed of a solid, dark globe, surrounded by three atmospheres. The first, nearest the dark body of the sun, was thought to be a dense, cloudy covering, pos-

[1] For the views of various authorities on the constitution of the sun solar spots, etc., see Newcomb's *Astronomy* (3d edition), page 271.

Typical Sun Spot of December, 1873, showing the Filaments pointing to the Center sessing high reflecting power. The second was called the *photosphere*. It consisted of an incandescent gas, and was the seat of the light and heat of the sun, being the visible part of the sun. The third, or outer one, was transparent — very like our atmosphere.

EXPLAINING WILSON'S THEORY OF SOLAR SPOTS

According to this theory, the spots were explained in the following manner: they were simply openings in these atmospheres made by powerful upward currents. At the bottom of these chasms was seen the dark sun as a *nucleus* at the center, and around this the cloudy atmosphere — the *penumbra*. This explained a black spot with its penumbra. Sometimes the opening in the photosphere might be smaller than that in the inner or cloudy atmosphere; in that case there would be a black spot without a penumbra.

It was natural to suppose that when the heated gas of the photosphere, or second atmosphere, was violently rent asunder by an eruption or current from below, luminous ridges would be formed by the heaped-up gas on every side of the opening. This would account for the *faculæ* surrounding the sun spots. It was natural, also, to suppose that sometimes the cloudy atmosphere below would close up first over the dark surface of the sun, leaving only an opening through the photosphere, disclosing at the bottom a grayish surface of *penumbra*. As the sun revolving on its axis brought a spot nearer and nearer to the center, thus giving us a more direct view of the opening, we could see more and more of the dark body. Then as it passed by the center the nucleus would disappear, until finally we could see only the side of the fissure, the penumbra, which in its turn would vanish.

THE PRESENT THEORY, sometimes called after Kirchhoff, who laid its foundations, is deduced from the results of spectrum analysis, of which we shall speak hereafter. It is constantly being modified by new discoveries. But we may, in general, believe the sun to be a vast, fiery, gaseous body, surrounded by an atmosphere of substances volatilized by the intense heat. Among these we recognize familiar elements, as iron, copper, and many others.

The different portions of the sun are thought to be arranged thus: (1) The *nucleus*, probably gaseous.[1]

[1] The interior of the sun, although gaseous, must be powerfully condensed, because of the tremendous pressure of the massive exterior

(2) The *photosphere*, an envelope several thousand miles thick, which constitutes the visible part of the sun. (3) The *chromosphere*, composed of luminous gas, mostly hydrogen, and the seat of enormous *protuberances*, tongues of fire, which dart forth, sometimes at the rate of 150 miles a second, and to a distance of over 100,000 miles. (4) The *corona*,[1] an outer appendage of faint, pearly light, consisting of streamers reaching out often several hundred thousand miles. Of these solar constituents, the eye and the telescope ordinarily reveal only the photosphere; the rest are seen either during a total eclipse or by means of the spectroscope.

The outer portion of the sun radiates its heat and light, and, becoming cooler, sinks; the hotter matter in the interior then rises to take its place, and thus convection currents are established, as explained in physics. The cooler, descending currents are darker, and the hotter, ascending ones are lighter; this gives rise to the mottled look of the sun. At times, this occurs on a grand scale, when the heated, up-rushing masses form the faculæ, and the cooler, down-rushing ones produce the solar spots.

The Heat of the Sun is generally considered to be produced by condensation, whereby the size of the sun is constantly decreasing, and its potential energy thus

portions. High temperature, however, prevents the gas from liquefying. The rain storms on the sun, if such ever occur, consist of drops of molten iron, copper, zinc, etc., vaporized by the enormous heat; and often a tempest would drive before it this white-hot, metallic blast, with a speed of 100 miles a second.

[1] This is so called because, during a total eclipse, it forms around the moon a corona or glory, the most wonderful feature of this rare event. (See pages 145, 146.)

PLATE II

Various Forms of Solar Prominences.

converted into kinetic. The heat of the sun could be maintained by an annual contraction of 300 feet in its diameter, a decrease so insignificant as to be imperceptible with the best instruments. The dynamic theory accounts for the heat and the solar spots by assuming that there are vast numbers of meteors revolving around the sun; that these constantly rain down upon the surface of that luminary; and that their motion, thus stopped, is changed to heat, and feeds this great central fire. Were Mercury to strike the sun in this way, it would generate sufficient heat to compensate the loss by radiation for seven years. But this theory fails of acceptance because the existence of so much meteoric matter in the immediate neighborhood of the sun is improbable.

Doubtless, the solar heat is gradually diminishing, and will ultimately be exhausted. In time, the sun will cease to shine, as the earth did long since. Newcomb says that in 5,000,000 years, at the present rate, the sun will have shrunk to half its present size, and that it cannot sustain life on the earth more than 10,000,000 years longer. Of this we may be assured, there is enough to support life on our globe for millions of years yet to come.

II. THE PLANETS

(INTRODUCTION)

The Planets will be described in regular order, passing outward from the sun. In this journey, we shall examine each planet in turn, noticing its distance, size, length of year, duration of day and night, temperature, climate, number of moons, and other interesting facts, showing that we can know something of its world life in spite of its wonderful distance. We shall encounter the earth in our imaginary wanderings through space, and shall explain many celestial phenomena already partly familiar.

In all these worlds, we shall find traces of the same divine hand, molding and directing in conformity to one universal plan. We shall discover that the laws of light and heat are invariable, and that the force of gravity, which causes a stone to fall to the ground, acts similarly upon the most distant planet. Even the elements of which the planets are composed will be familiar to us, so that a book of science published here might, in some of its general features, answer on Mars or Jupiter.

Common Characteristics. — (1) The planets move in the same direction around the sun; their course, as viewed from the north side of the ecliptic, being contrary to the motion of the hands of a watch.

(2) They describe around the sun elliptical paths, not differing much from circles.

(3) Their paths are more or less inclined to the ecliptic, and each orbit intersects it in two points, — the nodes, — one half of the orbit lying north, and the other south of the earth's path.

(4) They are opaque bodies, and shine by reflecting the light received from the sun.

(5) They nearly all rotate upon their axes in the same direction as the earth, and hence have the alternation of day and night.

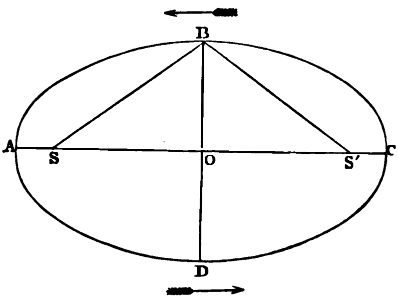
(6) Agreeably to the principles of gravitation, their velocity is greatest at that part of their orbit nearest

the sun, and least at that part most distant from it; in other words, they move quickest in *perihelion*, and slowest in *aphelion*.

Comparison of the Two Groups of the Major Planets. — Separating the major planets into two groups, if we take Mercury, Venus, the Earth, and Mars as belonging to the interior, and Jupiter, Saturn, Uranus, and Neptune to the exterior group, we shall find that they differ in the following respects: —

(1) The interior planets, with the exception of the Earth and Mars, are not attended by any satellite, while all the exterior planets have satellites.

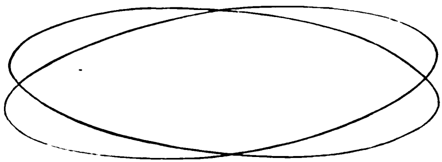
(2) The average density of the first group considerably exceeds that of the second, the approximate ratio being 5 : 1.



AN ELLIPSE

Properties of the Ellipse. — In the figure S and S′ are the *foci* of the ellipse; AC is the *major axis*; BD, the *minor*, or *conjugate axis*; O, the *center*; OA, the *semi-axis-major*, or mean distance; OB, the *semi-axis-minor*; the ratio of OS to OA is the *eccentricity*; the least distance, SA, is the *perihelion distance*; the greatest distance, SC, the *aphelion distance*.

Characteristics of a Planetary Orbit. — It will not be difficult to follow in the mind the additional characteristics of a planet's orbit. Take two hoops and bind them into an oval shape. Incline one slightly to the other, as shown below. Let the horizontal hoop represent the plane of the ecliptic. Imagine a planet following the inclined hoop, or ellipse; at a certain point it rises above the level of the ecliptic; this point is called the *ascending node*, and the opposite point of intersection is termed the *descending node*. A line connecting the two nodes is the *line of nodes*. The *longitude of the node* is its distance from the first point of Aries, measured eastward on the ecliptic.

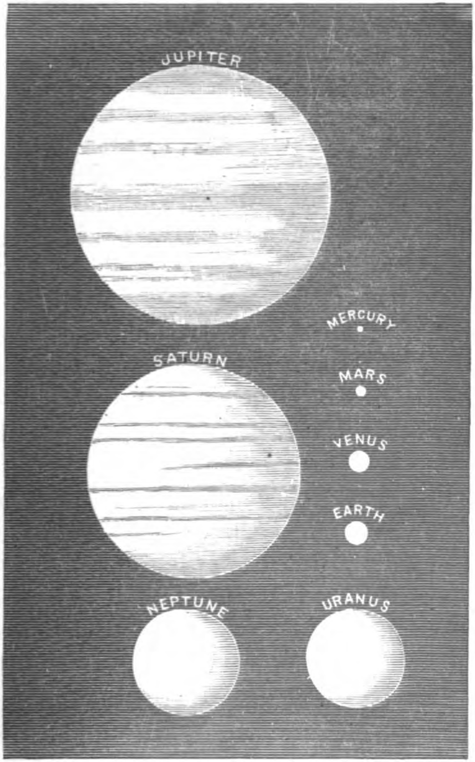


PLANETARY ORBIT INCLINED TO ECLIPTIC

Comparative Size of Planets. — The following scheme will assist in obtaining some notion of the magnitude of the planetary system. Choose a level field or common; on it place a globe two feet in diameter for the sun: Mercury will then be represented by a mustard seed, at a distance of 82 feet; Venus by a pea, at a distance of 142 feet; the Earth, also by a pea, at a distance of 215 feet; Mars by a small bicycle ball, at a distance of 327 feet; most of the minor planets by grains of sand, at distances varying from 500 to 600 feet. If space will permit, we may place a moderate-sized orange nearly a quarter of a mile distant from the starting point to represent Jupiter; a small orange two fifths of a mile for Saturn; a full-sized cherry three quarters of a mile distant for Uranus; and, lastly, a plum 1¼ miles off for Neptune, the most distant planet yet known. Extending this scheme, we should find that the aphelion distance of Encke's comet would be 880 feet; the aphelion distance of Donati's comet of 1858, six miles; and the nearest fixed star would be placed at about 8000 miles.

According to this scale, the daily motion of Mercury in its orbit would be 3 feet; of Venus, 2 feet; of the Earth, 1⅞ feet; of Mars, 1½ feet; of Jupiter, 10½ inches; of Saturn, 7½ inches; of Uranus, 5 inches; and of Neptune, 4 inches. Note how the orbital velocities of planets decrease as their distances from the sun increase.

Conjunction of Planets. — The grouping together of several planets within a limited area of the heavens is a rare event. The earliest record we have is the one by the Chinese (page 16), stating that a conjunction of



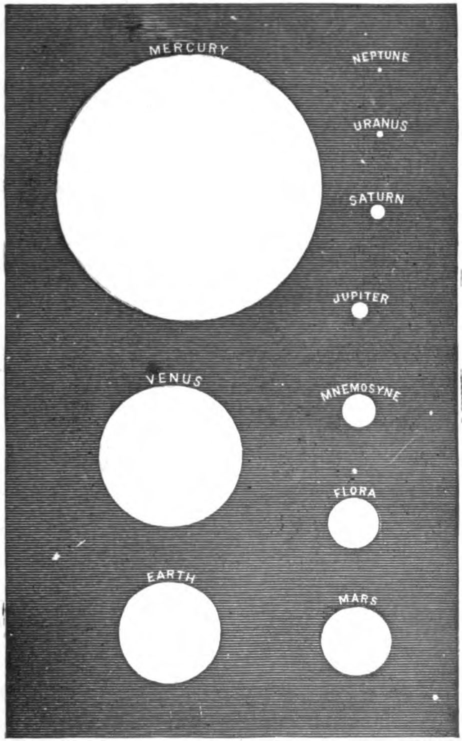
COMPARATIVE SIZE OF THE PLANETS

Mars, Jupiter, Saturn, and Mercury occurred in the reign of the Emperor Tchuen-hiu, February 28, B.C. 2446, between 10° and 18° of Pisces. There is a very general impression, however, that this conjunction was chronicled in their records at a later date, having been calculated backward. In 1725, Venus, Mercury, Jupiter, and Mars appeared in the same field of the telescope. In 1859, Venus and Jupiter came so near each other that they appeared to the naked eye as one object.

Are the Planets Inhabited? — This question is one which very naturally arises, when we think of the planets as worlds in some respects similar to our own. We can give no conclusive answer. Many think that the only object God can have in making a world is to form an abode for man. Our own earth seems to have been prepared, although perhaps not created, for this express purpose. Everywhere about us we find proofs of special forethought and adaptation. Coal and oil in the earth for fuel and light, forests for timber, metals in the mountains for machinery, rivers for navigation, and level plains for corn. The human body, the air, light, and heat are all fitted to one another with exquisite nicety.

When we turn to the planets, we do not know whether God has other races of intelligent beings who inhabit them, or has entirely different ends to attain. Of this, however, we are assured, that, if inhabited, the conditions on which life is supported vary much from those familiar to us. When we come to speak of the different planets, we shall see that they differ (1) in the light and heat received from the sun, from seven times our usual temperature to less than $\frac{1}{1000}$; (2) in the intensity of the force of gravity, from $2\frac{1}{2}$ times that of the earth to less than $\frac{1}{2}$; (3) in the constitution of the planet itself, from a density greater than that of the earth to about that of Michigan pine.

The temperature may drop through a scale of many hundred degrees in passing from Mercury to Neptune. Probably no human being could reside on the former, while we cannot conceive of any polar inhabitant who could endure the intense cold of the latter. At the



RELATIVE SIZE OF THE SUN AS SEEN FROM THE PLANETS

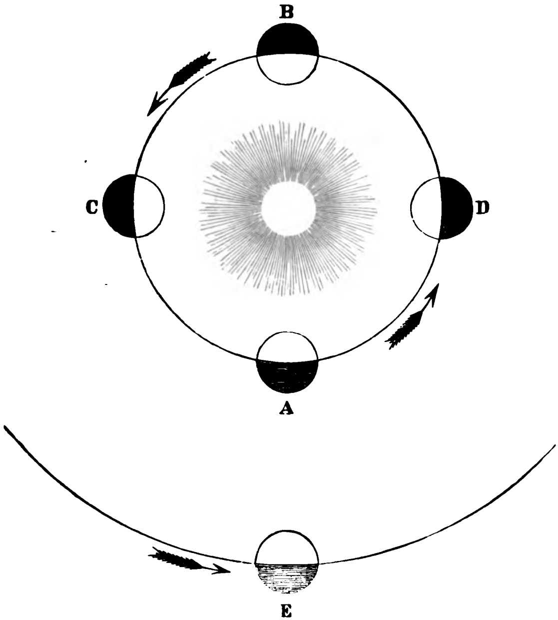
surface of the sun, one of our pounds would weigh nearly twenty-eight pounds; on our moon, the pound weight would become only about two ounces; while on Vesta, a small planet, a man could easily spring sixty feet in the air and sustain no shock in falling. Yet, while we speak of these apparent peculiarities, we do not know what modification of atmosphere may exist on Venus to temper the heat, or on Neptune to reduce the cold.

With all these diversities, we must, however, admit the power of an all-wise Creator to form beings adapted to the life and the land, however different from our own. The Power that prepared a world for us could as easily and perfectly prepare one for other races. May it not be that the same love of diversity that never makes two leaves after the same pattern, nor two pebbles of the same size, delights in worlds peopled by races as diverse? Astronomers conceive the universe to contain worlds in every possible stage of development, from the primary, gaseous nebula, to a worn-out, dead globe, like the moon. At a certain brief period in its entire existence, each world is doubtless adapted to support life. Millions may now be in that condition; others may be approaching, while others have passed it.

While, then, we cannot affirm that the planets are or are not inhabited, analogy would lead us to think that they are, and that the most distant star that shines in the arch of heaven may give light and heat to living beings under the care and government of Him who enlivens the densest forest with the hum of insects, and populates even a drop of water with teeming millions of animalcules.

Divisions of the Planets. — The planets are divided into two classes: (1) *Inferior*, or those whose orbits are within that of the earth — viz., Mercury, Venus; (2) *Superior*, or those whose orbits are beyond that of the earth — viz., Mars, the small planets, Jupiter, Saturn, Uranus, Neptune.

Motions of a Planet as seen from the Sun. — Could we stand at the sun and watch the movements of the planets, they would all be seen revolving with different velocities in the order of the zodiacal signs. But to us,



CONJUNCTIONS OF INFERIOR PLANET

standing on one of the planets, itself in motion, the effect is changed. To an observer at the sun all the motions would be real, while to us many are only apparent. The position of a planet, as seen from the center of the sun, is called its *heliocentric place;* as seen from the center of the earth, its *geocentric place.* When

Venus is between the earth and the sun, an observer at the sun would see it in the opposite part of the heavens from that in which it appears as viewed from the earth.

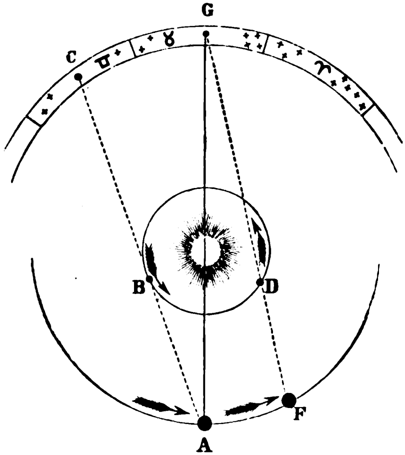
Motions of an Inferior Planet. — An inferior planet is never seen by us in any part of the sky opposite to the sun. It cannot recede from him as much as 90°, or $\frac{1}{4}$ the circumference, since it moves in an orbit entirely inclosed by the orbit of the earth. Twice in every revolution it is in conjunction (☌) with the sun, — an *inferior conjunction* (A, page 73) when it comes between the earth (E) and the sun, and a *superior conjunction* (B) when the sun lies between it and the earth.

When the planet attains its greatest apparent distance east or west from the sun, it is said to be at its *greatest elongation*.

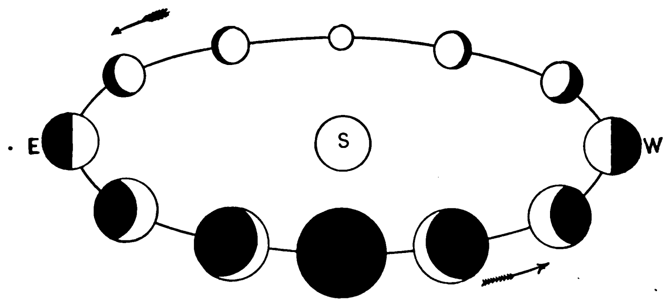
When passing from B to A it is east of the sun, and from A to B it is west of the sun. When east of the sun, it sets later than the sun, and hence is *evening star:* when west of the sun, it rises earlier than the sun, and hence is *morning star*. An inferior planet is never visible when in *superior* conjunction, as its light is then lost in the greater brilliancy of the sun. When in *inferior* conjunction, it sometimes passes directly between the earth and the sun, and appears to us as a round, black spot, very slowly moving across his disk. This is called a *transit*.

Retrograde Motion of an Inferior Planet. — Suppose the earth at A in the following figure, and the planet at B. Now, while the earth is passing to F, the planet will pass to D, — the arc AF being shorter than BD, because the nearer a planet is to the sun, the greater is its velocity. While the planet is at B, we locate it at C in the zodiac, in Gemini; but at D, it appears to us to be at G, in Taurus. So that the planet has retrograded through an entire sign in the zodiac, while its true course has all the time been forward in the order of the signs; and to an observer at the sun, such would have been its apparent motion as well. Beyond D, it will for a short time seem to be stationary.

PHASES OF AN INFERIOR PLANET. — An inferior planet presents all the phases of the moon. At superior conjunction, the whole illumined disk is turned toward us, but the planet is lost in the sun's rays. A little before or after superior conjunction, an inferior planet may be seen with a telescope; but a part of the light side is turned away from us, and so the planet appears *gibbous*, like the moon between the first quarter and full. At greatest elongation, the planet shows us only one half its illumined disk; this decreases, becoming more and more crescent toward inferior conjunction, at which time the unillumined side is toward us. In the following figure are shown these changing phases, and corresponding variations in apparent size.



RETROGRADE MOTION OF INFERIOR PLANET

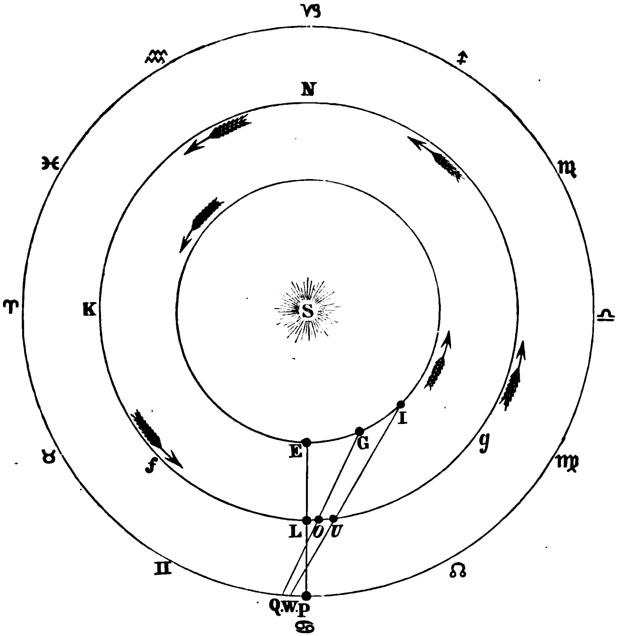


PHASES OF AN INFERIOR PLANET

Motions of a Superior Planet.—The superior planet moves in an orbit which lies entirely outside that of the earth. When the earth is at E, in the next diagram, the planet at L is said to be in *opposition* to the sun (☍). It is then at its greatest apparent distance from him—180°. The planet is on the meridian at midnight, while the sun is on the corresponding meridian on the opposite side of the earth; or the planet may be rising, when the sun is just setting. When the planet is at N, it is in *conjunction*, and being lost in the sun's rays is invisible to us. When 90° east or west of the sun, the planet is said to be in *quadrature* (□).

RETROGRADE MOTION OF A SUPERIOR PLANET.—Suppose the earth to be at E and the planet at L, and that we move on to G while the planet passes on to O—the distance EG being longer than LO, the reverse of what takes place in the movements of the inferior planets; at E, we should locate the planet at P in the zodiac, in the sign Cancer; but at G, we should see it at Q, in the sign Gemini, it having apparently retrograded on the ecliptic the distance PQ, while it was all the time really moving in the direct order of the signs.

Now, suppose the earth passes on to I and the planet to U; we should then see it at the point W, further on in the zodiac than Q, which indicates direct motion again; and at some point near Q the planet must have appeared without motion.



RETROGRADE MOTION OF A SUPERIOR PLANET

After this, it will continue in direct motion until the earth has completed a large portion of her orbit, as we can easily see by imagining various positions of the earth and planet, and then drawing lines as we have just done, noticing whether they indicate direct or retrograde motion. The greater the distance of a planet, the less it will retrograde, as we can perceive by drawing another orbit outside the one represented in the cut, and making the same suppositions concerning it as those already explained.

Sidereal and Synodic Revolution.—The interval of time required by a planet to perform a revolution round the sun from one fixed star back to it again, is the length of its *sidereal* revolution (*sidus*, Latin for a star).

(*a*) The interval of time between two similar conjunctions of an inferior planet is the length of its *synodic* revolution. Were the earth at rest, there would be no difference between a sidereal and a synodic revolution, and the planet would come into conjunction twice in each revolution. Since, however, the earth is in motion, it follows that, after the planet has completed its sidereal revolution, it must overtake the earth before they can both come again into the same position with regard to the sun. The faster a planet moves, the sooner it can do this. Mercury, traveling at a greater speed and on an inner orbit, accomplishes it much more quickly than Venus. The synodic period of an inferior planet always exceeds the sidereal.

(*b*) The interval between two successive conjunctions or oppositions of a superior planet is the length of its *synodic* revolution. Since the earth moves so much faster than any superior planet, it follows that, after it has completed a sidereal revolution, it must overtake the planet before they can again come into the same position with regard to the sun. The slower the planet, the sooner this can be done. Uranus, making a sidereal revolution in eighty-four years, can be overtaken more quickly than Mars, which makes one in less than two years. It consequently requires over a second revolution for the earth to catch up with Mars, only $\frac{1}{11}$

of a second one to overtake Jupiter, and but little over $\frac{1}{100}$ of a second one to overtake Uranus.

Planets as Evening and Morning Stars. — The inferior planets are evening stars from superior to inferior conjunction; and the superior planets, from opposition to conjunction. During the other part of their revolutions, they are morning stars.

Mercury is evening star about 2 months.
Venus is evening star about 9½ months.
Mars is evening star about 13 months.
Jupiter is evening star about 6½ months.
Saturn is evening star about 6¼ months.
Uranus is evening star about 6 months.

I. MERCURY

The fleetest of the gods. Sign ☿, his wand

Description. — Mercury is nearest to the sun of any of the definitely known planets; for the supposed discoveries of intramercurian planets made by Watson and Swift during the total eclipse of 1878 have not been verified. When the sky is very clear, we may sometimes see Mercury, just after sunset, as a bright, sparkling star, near the western horizon. Its elongation increases evening by evening, but never exceeds 28°. This distance at greatest elongation varies much, owing to the eccentricity of Mercury's orbit. If we watch closely, we shall find that the planet again approaches the sun and becomes lost in his rays. Some days afterward, just before sunrise, we can see the same planet in the east, rising higher each morning, until its greatest elongation nearly equals that which it before attained in the west. Thus the planet appears slowly but steadily to oscillate like a pendulum, to and fro, from one side of the sun to the other. The ancients, deceived by this puzzling movement, at first failed to discover the identity of the two stars, and called the morning star Apollo, the god of day, and the evening star Mercury, the god of thieves, who walk to and fro in the night time, seeking plunder.[1]

On account of the nearness of Mercury to the sun, it is difficult to detect.[2] It is said that Copernicus, an old man of seventy, lamented in his last moments that, much as he had tried, he had never been able to see it. In our latitude and climate, we can generally find it easily if we watch for it at the time of greatest elongation, as commonly given in the almanac.

Motion in Space.—Mercury revolves around the sun at a mean distance of about 36,000,000 miles. Its orbit is the most eccentric of any among the eight principal planets; so that, although when in perihelion it approaches to within about 28,000,000 miles, in aphelion it speeds away 15,000,000 miles further, or to the distance of over 43,000,000 miles. Being so near the sun, its motion in its orbit is correspondingly rapid,—viz., thirty miles a second, a velocity that would enable us to cross the Atlantic Ocean in two minutes.

[1] The Greeks gave to Mercury the additional name of 'The Sparkling One.' The astrologists looked upon it as the malignant planet. The chemists, because of its extreme swiftness, applied the name to quicksilver. The most ancient account that we have of this planet is given by Ptolemy, in his *Almagest;* he states its location on the 15th of November, B.C. 265. The Chinese also state that on June 9, A.D. 118, it was near the Beehive, a cluster of stars in Cancer. According to the best calculations, it was at that date within less than 1° of that group.

[2] An old English writer by the name of Goad, in the seventeenth century, humorously termed this planet 'A squinting lacquey of the sun, who seldom shows his head in these parts, as if he were in debt.'

The Mercurian year comprises only about eighty-eight days, or nearly three of our months. Mercury was formerly thought to rotate upon its axis in about the same time as the earth, so that the length of the Mercurian day would be nearly the same as that of the terrestrial one. But recent observations appear to show that it turns round on its axis only once while going completely round the sun. The Mercurian day, therefore, may be said to be infinite in duration, on about half of the planet's surface; and it is perpetually night on the other half, though the boundaries between the two hemispheres are not fixed, on account of Mercury's libration in longitude, similar to that of the moon (page 129).

Though Mercury thus completes a sidereal revolution around the sun in eighty-eight days, yet to pass from one inferior or superior conjunction to the next (a synodic revolution) requires 116 days. The reason of this is that when Mercury comes around again to the point of its last conjunction, the earth has gone forward, and it requires twenty-eight days for the planet to overtake us.

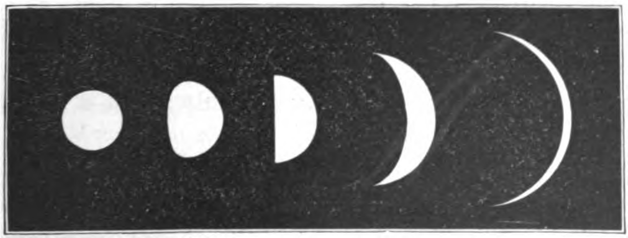
The Distance from the Earth varies still more than the distance from the sun. At inferior conjunction, Mercury is between the earth and the sun, and its distance from us is the *difference* between the distances of the earth and of the planet from the sun; at superior conjunction, it is the *sum* of these distances. Its apparent diameter in these different positions varies inversely in the same proportion as the distance, or nearly three to one. The greatest and least distances vary as either planet happens to be in aphelion or perihelion. If at inferior conjunction Mercury is in aphelion and the earth in perihelion, its distance from us is only 91,500,000 − 43,000,000 = 48,500,000 miles. If at superior conjunction Mercury is in aphelion and the earth in aphelion also, its distance from us is 94,500,000 + 43,000,000 = 137,500,000 miles.

Dimensions. — Mercury is about 3000 miles in *diameter.* Its *volume* is about $\frac{1}{20}$ that of the earth; *i.e.* it would require twenty globes as large as Mercury to make one the size of the earth. Its density is nearly equal to that of the earth, its *mass* is about $\frac{1}{20}$ that of the earth, and a stone let drop upon its surface would fall nearly $5\frac{1}{2}$ feet the first second. A pound weight removed to Mercury would weigh only about $5\frac{1}{2}$ ounces, if tested with a spring balance.

Seasons. — As Mercury's axis is not much if at all inclined from a perpendicular to its orbit plane, there is no distinction of zones marked as with us. The sunward hemisphere is most torrid at its pole, where the sun is perpetually near the zenith. The farther one journeys from this pole, which is always on the planet's equator, the less torrid and the more temperate is the solar heat. On the opposite hemisphere of the planet is continual night, and a climate whose peculiarities are difficult to ascertain, because of the probable absence of atmosphere on Mercury. Along the meridian girdle, which libration carries at one time into sunlight, and again out of it, there must be an alternation of temperatures, somewhat as in our temperate zones, though in much shorter periods.

An inhabitant of Mercury, if able to journey from one part of the planet to another, must be accustomed to sudden and violent vicissitudes of temperature. At one spot on the equator, the sun not only pours down its vertical rays, but, on account of Mercury's elliptical orbit, when in perihelion the planet approaches so near the sun that the heat and light are ten times as great as ours, while in aphelion it recedes so as to reduce the amount to four and a half times. The average heat is about seven times that of the earth,—a temperature sufficient to turn water into steam, and even to melt zinc.

The sun, apparently three times as broad as it seems to us, must be a magnificent spectacle, and illumine every object with insufferable brilliancy. The evening sky is, however, not known to be lighted by any moon.



PHASES AND RELATIVE APPARENT SIZE OF MERCURY

Telescopic Features.—Through the telescope, Mercury presents all the phases of the moon, from a slender crescent to gibbous, after which its light is lost in that of the sun. These phases prove that Mercury is spherical, and shines by the light reflected from the sun. Being an inferior planet, we never see it when perfectly full; nor when nearest the earth, as then its dark side is turned toward us.

The older observers depicted the surface of Mercury as mottled by extensive and faintly marked patches. The most modern observations reveal a multitude of narrow lines intersecting each other obliquely, much like the crosshatching on a wood engraving.

II. VENUS

The Queen of Beauty. Sign ♀, a looking-glass

Description. — Venus, the next in order to Mercury, is the most brilliant of the planets. When visible before sunrise, she was called by the ancients Phosphorus, Lucifer, or the Morning Star; and when she shone in the evening after sunset, Hesperus, Vesper, or the Evening Star.

She presents the same appearances as Mercury. Owing, however, to the larger size of her orbit, her greatest apparent oscillations are nearly 48° east and west of the sun; distances which, although about 20° more than those of Mercury, vary only about 3°, owing to the slight eccentricity of Venus's orbit. Venus is therefore seen much earlier in the morning than Mercury, and much later at night. Like the planet Mercury, Venus is morning star from inferior to superior conjunction, and evening star from superior to inferior conjunction.

When Venus is most brilliant she is bright enough to cast a shadow at night. If, in addition, at this time of greatest brilliancy, Venus is near her highest north declination, she may be seen with the naked eye in full daylight.[1]

Motion in Space. — Venus has an orbit the most

[1] Arago relates that Bonaparte, upon repairing to the Luxembourg when the Directory was about to give him a *fête*, was much surprised at seeing the multitude paying more attention to the heavens above the palace than to him or his brilliant staff. Upon inquiry, he learned that these curious persons were observing with astonishment a star which they supposed to be that of the Conqueror of Italy. Bonaparte himself was not indifferent when his piercing eye caught the clear luster of Venus smiling upon him at midday.

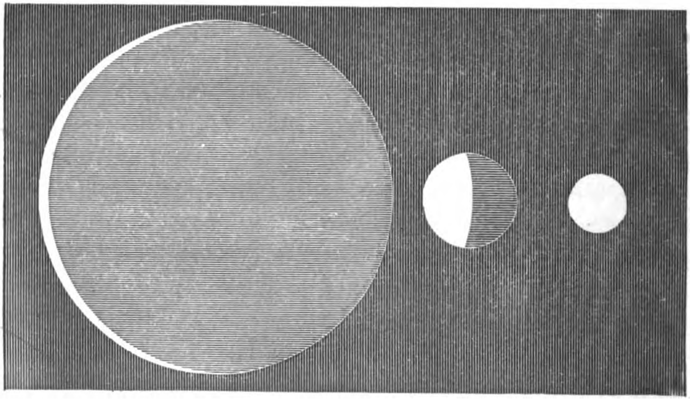
nearly circular of any of the principal planets. Her mean distance from the sun is about 67,000,000 miles, which varies at aphelion and perihelion 1,000,000 miles,—a contrast to Mercury, which varies 15,000,000 miles.

Venus makes a complete revolution around the sun in about 225 days, at the mean rate of twenty-two miles a second; hence her year is equal to about seven and one half of our months. This is a *sidereal* revolution, as it would appear to an observer at the sun; a *synodic* revolution requires 584 days.

Mercury, we remember, catches up with the earth in twenty-eight days after it reaches the point where it left the earth at the last inferior conjunction. But it takes Venus nearly two and a half revolutions to overtake the earth and come into the same conjunction again. This comes from the fact that she has a longer orbit than Mercury, and moves only about one sixth faster than the earth, while Mercury travels nearly twice as fast as our planet. Venus rotates upon her axis once while making one complete revolution round the sun. On practically one half her surface, therefore, it is perpetual day, and on the other half continual night.

Distance from the Earth.—Like that of Mercury, the distance of Venus from the earth, when in inferior conjunction, is the difference between the distances of the two planets from the sun; when in superior conjunction, the sum of these distances. When nearest to us, Venus is only about 25,000,000 miles away.

The following figure represents her apparent dimensions at the least, intermediate, and greatest distances from us. The variation is nearly as the numbers 60, 16, and 10. It would be natural to think that the planet is brightest when nearest, and thus largest; but we should remember that then the bright side is toward the sun, and the unillumined side toward us. Indeed, at the period of greatest brilliancy, only about *one fourth* of her illuminated hemisphere is visible. At this time, however, some observers have seen the entire contour of the planet.



GREATEST, INTERMEDIATE, AND LEAST APPARENT SIZE OF VENUS, AND HER PHASES

To find the time of greatest brilliance, take the date of inferior conjunction and add five weeks to it, or subtract the same interval from it. Venus is then nearly 40° either east or west of the sun, and her phase is about the same as that of the moon when five days old. Venus next attains her greatest brilliancy at eastern elongation on the 1st of June, 1900; and about that time she may for several days be seen high up in the sky in full daylight, near the meridian, about three o'clock P.M.

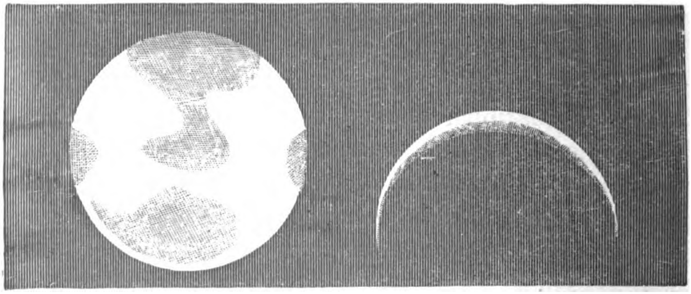
Dimensions.—Venus is about 7600 miles in *diameter.* The *volume* and *density* of the planet are each about nine tenths that of the earth. A stone let fall upon her surface would fall thirteen feet in the first second; a pound weight removed to her equator would weigh about thirteen ounces.

Seasons.—The seasons of Venus resemble those of Mercury. The heat and light are double that of the earth, while the circular form of her orbit gives practically no effect of libration. The presence of an atmosphere, together with the perpendicularity of her axis to the plane of her orbit, produces a softening of the harsh climatic lines on the perpetually sunward hemisphere. The opposite half of the globe, being in continual shadow, is quite possibly a glacial hemisphere; a view sustained by the fact that, although never illumined by direct sunlight, it has often been glimpsed by many observers, as if phosphorescent —perhaps a diffused gleam from ice and snow.

Telescopic Features.—Venus, being an inferior planet, presents, like Mercury, all the phases of the moon. This was discovered by Galileo, and was among the first achievements of his telescope. It had been argued against the Copernican system that, if it were true, Venus should wax and wane like the moon. Indeed, Copernicus himself boldly declared that, if means of seeing the planets more distinctly were ever invented, Venus would be found to present such phases. Galileo, with his telescope, proved this fact, and thus vindicated the Copernican theory.

Venus undoubtedly has a dense but cloudless atmosphere. This was suggested by the fact that at the transits of Venus over the sun in 1761, 1769, 1874, and 1882, a faint ring of light surrounded the black disk of the planet. The evidence of an atmosphere rests also upon the peculiar appearance attending her slender crescent shape: when very near to inferior conjunction, it is extended to an almost complete ring; whereas, if Venus had no atmosphere, the crescent would be semicircular merely.

The luminous horns of the crescent do not end abruptly; on the contrary, their light diminishes gradually. This diminution can be explained by a twilight



CRESCENT AND SPOTS OF VENUS AS DRAWN BY THE EARLIER OBSERVERS

caused by an atmosphere which diffuses the rays of light into regions of the planet where the sun is already set. Thus on Venus, as on the earth, the evenings are lighted by twilight, and the mornings by dawn.

Markings. — Venus is not known to have any moon. The planet's markings seen by the most modern observers are very difficult to recognize, and not yet fully confirmed. They are confined, of course, to the sunward hemisphere, and rudely resemble the hub and spokes of a wheel. Like those on Mercury, they are thought to have a natural origin, and are perhaps due to corrugations caused by shrinkage.

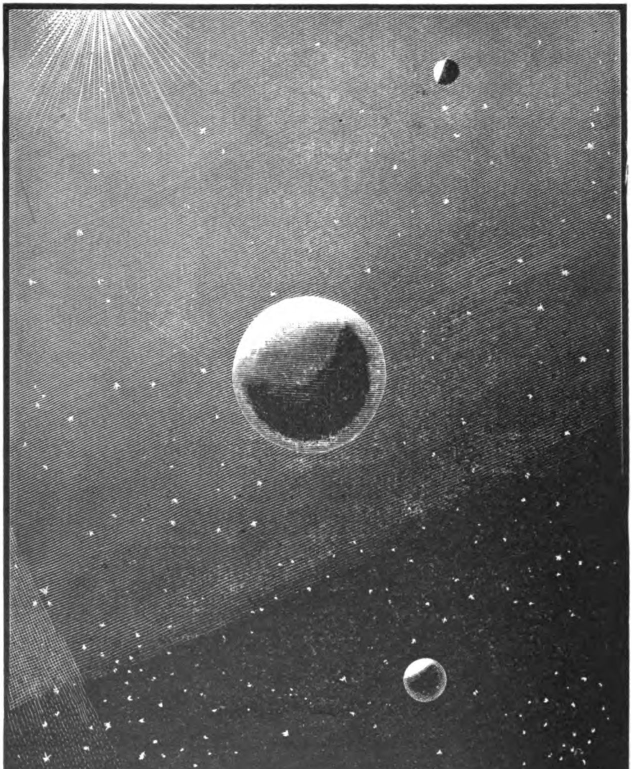
III. THE EARTH

Sign, ⊕, a circle with Equator and Meridian

THE EARTH is the next planet we meet in passing outward from the sun. To the beginner, it seems strange enough to class our world among the heavenly bodies. *They* are brilliant, while *it* is dark and opaque; they appear light and airy, while it is solid and firm; we see in it no motion, while they are constantly changing their position; they seem mere points in the sky, while it is vast and extended.

Yet, at the very beginning, we are to consider the earth as a planet shining brightly in the heavens, and appearing to other worlds as a planet does to us. We are to learn that it is in motion, traversing its orbit with inconceivable velocity; that it is not fixed, but hangs in space, held by an invisible power of gravitation which it cannot evade; that it is small and insignificant beside the mighty globes that so gently shine upon us in the far-off sky; that, in fact, it is only one atom in a universe of worlds, some of them firm and solid, and a few, perhaps, equally fitted to be the abode of life. Were the sun's attractive force upon the earth replaced by the largest steel telegraph wires, it would require nine wires for each square inch of the sunward side of our globe, to hold the earth in her orbit.

Dimensions.—The earth is not 'round like a ball,' but flattened at the poles. Its form is nearly that of an oblate spheroid. Its polar diameter is about 7899½ miles, and its equatorial about 7926½. The compression is, therefore, 27 miles. (See table in Appendix.) If we represent the earth by a sphere 30 inches in diameter, the polar diameter would be one tenth of an inch too



THE EARTH, THE MOON, AND VENUS IN SPACE

long. The circumference of the earth is nearly 25,000 miles. Its density is about $5\frac{1}{2}$ times that of water. Its weight is 6,000,000,000,000,000,000,000 tons.

The inequalities of the earth's surface, arising from valleys, mountains, etc., have been likened to the roughness on the rind of an orange. On a globe sixteen inches in diameter, the land, to be in proportion, should be represented by the thinnest writing paper, the hills by very fine grains of sand, and elevated ranges by thick drawing paper. To represent the deepest wells or mines, a scratch should be made that would be invisible except with a glass.

The Rotundity of the Earth is proved in various ways: (1) By the fact that vessels have sailed around the earth;[1] (2) when a ship is coming into port, we see her masts and funnels first; (3) the shadow of the earth on the moon is circular; (4) the polar star seems higher in the heavens as we pass north; and (5) the horizon expands as we ascend an eminence.[2] If we climb to the top of a hill, we can see further than when on the plain at its foot. Our eye-

[1] It is curious, in connection with this well-known fact, to recall the arguments urged by the Spanish philosophers against the reasoning of Columbus, when he assured them that he could arrive at Asia just as certainly by sailing west as east. 'How,' they asked, 'can the earth be round? If it were, then on the opposite side the rain would fall upward, trees would grow with their branches down, and everything would be topsy-turvy. Every object on its surface would certainly fall off, and if a ship by sailing west should get around there, it would never be able to climb up the side of the earth and get back again. How can a ship sail uphill?'

[2] 'The history of aëronautic adventure affords a curious illustration of this same principle. The late Mr. Sadler, the celebrated aëronaut, ascended on one occasion in a balloon from Dublin, and was wafted across the Irish Channel, when, on his approach to the Welsh coast, the balloon descended nearly to the surface of the sea. By this time the sun was set, and the shades of evening began to close in. He threw out nearly all his ballast, and suddenly sprang upward to a great height, and by so doing brought his horizon to *dip* below the sun, producing the whole phenomenon of a western sunrise. Subsequently descending in Wales, he of course witnessed a second sunset on the same evening.'

sight is not improved; it is only because ordinarily the curvature of the earth shuts off the view of distant objects, but when we ascend to a higher point, we can see further over the side of the earth. The curvature is eight inches for one mile, $2^2 \times 8$ in. = 32 inches for two miles, $3^2 \times 8$ in. for three miles, etc. Objects of these respective heights would be just hidden at these distances.

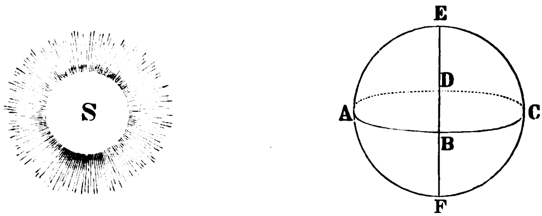
Apparent and Real Motion. — In endeavoring to understand the varying appearances of the heavenly bodies, it is well to remember how in daily life we transfer motion. On the cars, when in rapid movement, we seem to sit still and see the fences and trees glide by us. On a bridge, when we are at rest, we watch the undulations of the water, until at last we come to think that it is stationary and we are sweeping upstream.

'In the cabin of a large vessel going smoothly before the wind on still water, or drawn along a canal, not the smallest indication acquaints us with the "way it is making." We read, sit, walk, as if we were on land. If we throw a ball into the air, it falls back into our hand; if we drop it, it alights at our feet. Insects buzz around us as in the free air, and smoke ascends in the same manner as it would do in an apartment on shore. If, indeed, we come on deck, the case is in some respects different; the air, not being carried along with us, drifts away smoke and other light bodies, such as feathers cast upon it, apparently in the opposite direction to that of the ship's progress; but in reality they remain at rest, and we leave them behind in the air. And what is the earth itself but the good ship we are sailing in through the universe, bound round the sun; and as we sit here in one of the berths, we are unconscious of there being any "way" at all upon the vessel. On deck, too, out in the open air, it's all the same so long as we keep our eyes on the ship; but immediately we look over the sides — and the horizon is but the gunwale of our vessel — we see the blue tide of the great ocean around us go drifting by the ship, and sparkling with its million stars as the waters of the sea itself sparkle at night between the tropics.'

Diurnal Rotation of the Earth upon its Axis. — The earth, in constantly turning from west to east, elevates our horizon above the stars on the west, and depresses it below the stars on the east. As the horizon appears to us to be stationary, we assign the motion to the stars, thinking those on the west, which it passes over and hides, to have sunk below it, or *set;* and imagining those on the east, below which it has dropped, to have moved above it, or *risen.* So, also, the eastern horizon is depressed below the sun, and we call it *sunrise;* the western horizon is elevated above the sun, and we call it *sunset.*

We thus see that the diurnal movement of the sun by day and the stars by night is an optical illusion, — that here as elsewhere we simply transfer motion. This seems easy enough for us to understand; but it was the 'stone of stumbling' to ancient astronomers for thousands of years. Copernicus himself, it is said, first thought of the true solution while riding on a vessel and noticing how he insensibly transferred the movement of the ship to the objects on the shore. How much grander the beautiful simplicity of this system than the cumbersome complexity of the old Ptolemaic belief!

Diurnal Motion of the Sun. — The explanation just given illustrates the apparent motion of the sun, and the cause of day and night. Suppose S (page 94) to be the sun. The earth, turning upon its axis EF from west to east, has only half its surface illuminated at one time by the sun. To a person at D, the sun is in the horizon, and day commences, that luminary seeming to rise higher and higher, with an apparent westerly motion, as the observer is carried forward easterly by the earth's diurnal rotation to A, where he has the sun on his meridian, and it is consequently noon. The sun then begins to decline in the sky until the spectator arrives at B, where it sets, or is again in the horizon on the west side, and night begins. He moves on to C, which marks his position at midnight, the sun being then on the meridian of places on the opposite part of the earth, and he is brought round again to D, the point of sunrise, when another day commences.



APPARENT DAILY MOTION OF THE SUN

UNEQUAL RATE OF DIURNAL MOTION.—Different points upon the surface of the earth revolve with different velocities. At the poles the speed of rotation is nothing, while at the equator it is greatest, or over 1000 miles an hour. At Quito the circle of latitude is much longer than the one at the mouth of the St. Lawrence, and the velocities vary in the same proportion. The former place moves at the rate of about 1038 miles an hour; the latter, 682 miles. At the latitude of 41°, the speed is about 780 miles an hour. We do not perceive this wonderful velocity with which we are speeding, because the atmosphere moves with us.[1]

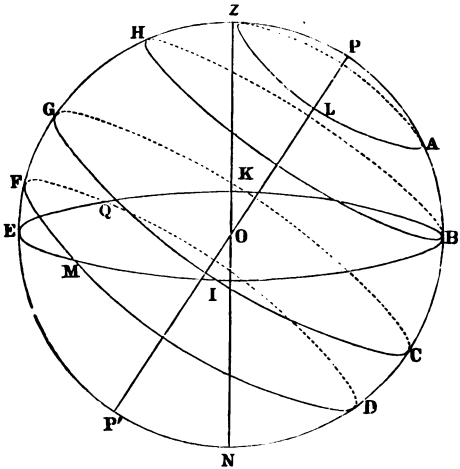
[1] 'An ingenious inventor once suggested that we should utilize the earth's rotation as the most simple and economical, as well as rapid mode of locomotion that could be conceived. This was to be accomplished by ris-

Were the earth suddenly to stop its rotation, the terrible shock would, without doubt, destroy the entire race of man. On the other hand, were the rate of rotation to increase, the length of the day would be proportionally shortened, and the weight of all bodies decreased by the centrifugal force thus produced. If the rotary movement should become swift enough to reduce the day to eighty-four minutes, the force of gravity would be overcome, and, at the equator, all bodies would be without weight; if the speed were still further increased, loose bodies would fly off from the earth like water from a swiftly turned grindstone, while we should be compelled constantly to hold on to avoid sharing the same fate.[1] But against such a catastrophe we are assured by the immutability of God's laws. He is 'the same yesterday, to-day, and forever.'

ing in a balloon to a height inaccessible to aerial currents. The balloon, remaining immovable in this calm region, would simply await the moment when the earth, rotating underneath, should present the place of destination to the eyes of travelers, who would then descend. A well-regulated watch and an exact knowledge of longitude would thus render traveling possible from east to west, all voyages north or south being interdicted. This suggestion has only one fault; it supposes that the atmospheric strata do not revolve with the earth. Upon that hypothesis, since we rotate (at London) with the velocity of 333 yards in a second, there would result a wind in the contrary direction ten times more violent than the most terrible hurricane. Is not the absence of such a state of things a convincing proof of the participation of the atmospheric envelope in the general movement?'—GUILLEMIN.

[1] Laplace concluded in 1799 that the inequalities of the earth's rotation were too insignificant for measurement. But, more recently, Delaunay has shown from the moon's acceleration that a minute change, caused by the friction of the sea and atmosphere upon the earth's surface, has taken place, producing a very slight variation in the length of the day. The acceleration of the moon in its path is, however, only seven feet a century, or less than an inch per annum, and the time of the earth's rotation has, according to Sir Robert Ball, increased but $\frac{125}{100000}$ of a second in 2400 years.

UNEQUAL DIURNAL PATHS OF THE STARS.—In the following figure, let O represent our position on the earth's surface; EZB, our meridian; EIBK, our horizon; P and P′, the north and south poles of the heavens; Z, the zenith; N, the nadir; and GICK, the celestial equator. Now PB, it will be seen, is the elevation of the north pole above the horizon, or the latitude of the place.



ILLUSTRATING ARCS OF DIURNAL MOTION

Suppose we should see a star at A, on the meridian below the pole. The earth revolves in the direction GIC; the star will therefore move along AL to Z, when it is on the meridian above the pole. It continues its course along the dotted line around to A again, when it is on the meridian below the pole, having made a complete circuit around the pole, but not having descended below our horizon.

A star rising at B would just touch the horizon; one at I would move on the celestial equator, and would be above the horizon as long a time as it is below,—twelve hours in each case; a star rising at M would pass through a short arc above the south horizon and set again at Q.

UNEQUAL DIURNAL VELOCITIES OF THE STARS.—The stars appear to us to be set in a concave shell which revolves daily about the earth. As different parts of the earth *really* rotate with different velocities, so the stars *appear* to revolve at different rates of speed. Those near the pole, having a small orbit, revolve very slowly, while those near the celestial equator move at the greatest speed.

APPEARANCE OF THE STARS AT DIFFERENT PLACES ON THE EARTH.—Were we placed at the north pole, Polaris (page 227) would be almost directly overhead, and the stars would seem to pass around us in circles parallel to the horizon, and increasing in diameter from the upper to the lower ones. Were we placed at the equator, the pole star would be at the horizon, and the stars would move in circles perpendicular to the horizon, and decreasing in diameter north and south from those in the zenith, while we could see constantly one half of the path of each star. Were we placed in the southern hemisphere, the circumpolar stars would revolve about the south pole, and the others in circles resembling the star paths in our sky; and, as in our sky, this motion would be from east to west. Were we placed at the south pole, the appearance would be the same as at the north pole, except that no bright star is there to mark the direction of the earth's axis.

Motion of the Earth in Space about the Sun.—The earth revolves in an elliptical path about the sun at a mean distance of 93,000,000 miles.

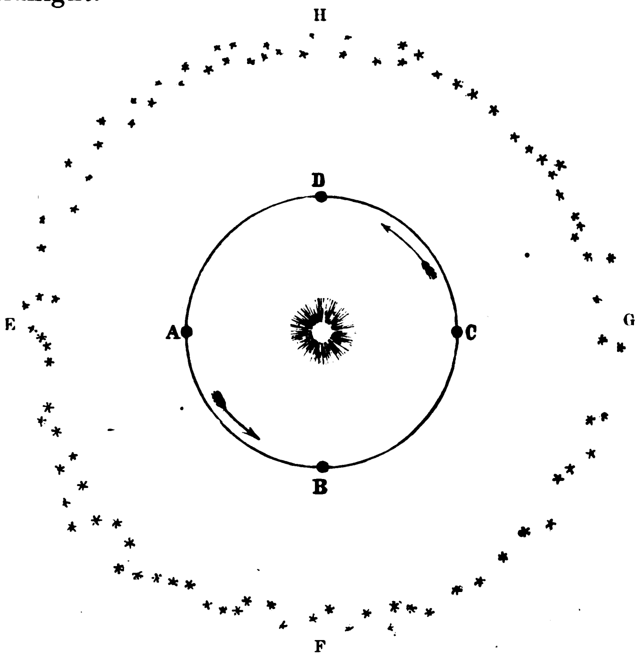
The eccentricity of this path is much greater than that of the orbit of Venus, but is now slowly diminishing from century to century. The orbit would, therefore, finally become circular, were it not that, after the lapse of some thousands of years, the eccentricity will begin to increase again, and will thus vary through all time within definite limits. The earth's path around the sun is nearly 600,000,000 miles long, and the earth pursues its wonderful journey at the rate of over eighteen miles a second.

This revolution of the earth about the sun gives rise to various phenomena, of which we shall now speak.

(1) CHANGE IN THE APPEARANCE OF THE HEAVENS IN DIFFERENT MONTHS. — In the figure opposite suppose ABCD to be the orbit of the earth, and EFGH the sphere of the fixed stars, surrounding the sun in every direction. When our globe is at A, the stars about E are on the meridian at midnight. Being seen from the earth in the quarter opposite to the sun, they are favorably placed for observation. The stars at G, on the contrary, will be invisible, for the sun intervenes between them and the earth: they are on the meridian of the spectator about the same time as the sun, and are hidden in his rays.

In three months, the earth has passed over one fourth of its orbit, and has arrived at B. Stars about F now appear on the meridian at midnight; those at E, which previously occupied their places, have descended toward the west; while those about G are just coming into sight in the east.

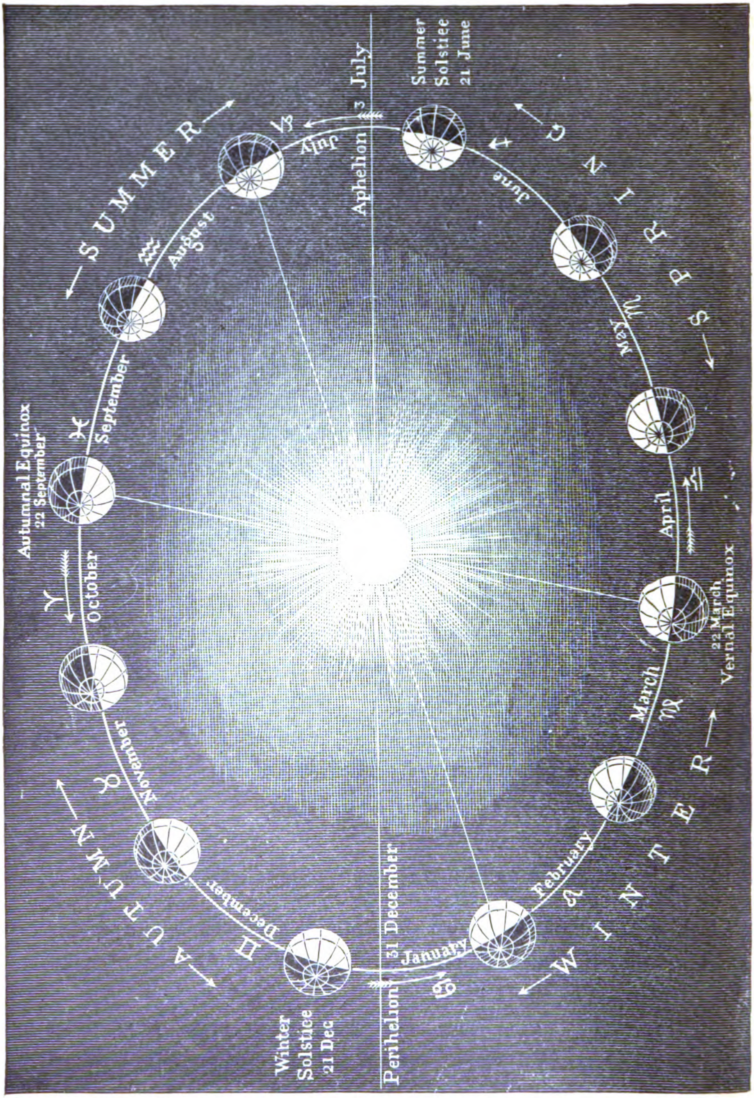
In three months more, the earth is situated at C, and stars about G shine in the midnight sky, those at F having, in their turn, vanished in the west; stars at E are on the meridian at noon, and consequently hidden in daylight; and those about H are just making their appearance in the east. One revolution of the earth will bring the same stars again on the meridian at midnight.



APPEARANCE OF THE HEAVENS IN DIFFERENT SEASONS

Thus the earth's motion round the sun as a center explains the varied aspect of the heavens in summer and winter skies.

(2) YEARLY PATH OF THE SUN THROUGH THE HEAVENS. — We have spoken of the diurnal motion of the sun. We shall now speak of its *second* apparent motion, its yearly path among the stars, — along the



The Orbit of the Earth as seen by an Observer in the Northern Heavens. (See note, page 101) ecliptic. This movement of the sun among the fixed stars is not so apparent to us as his daily motion, because his superior light blots out the stars. If we look at the opposite figure, we can see how the motion of the earth in its orbit is transferred to the sun, and causes him to appear to travel in a fixed path through the heavens. When the earth is in any part of its orbit, the sun seems to us to be in the point directly opposite. For example, when the earth is in Libra (♎)[1]—autumnal equinox—the sun is in Aries (♈)—vernal equinox; when the sun enters the next sign, Taurus (♉), the earth has passed on to Scorpio (♏). Thus, as the earth moves through her orbit, the sun seems to pass along the opposite side of the ecliptic, making the circuit of the heavens in a year, and returning, at the end of that time, to the same place among the stars. The ecliptic crosses the celestial equator at two points, called the *equinoxes*. (See page 37.)

(3) Apparent Movement of the Sun, North and South. — Having now spoken of the apparent *diurnal* and *annual* motions of the sun, there yet remains

[1] When we say 'the earth is in Libra,' we mean that a spectator placed at the sun would see the earth in that part of the heavens which is occupied by the sign Libra, while a spectator on the earth would see the sun, at the same time, in that part of the heavens which is occupied by the sign Aries. Just so, on June 21st, the earth enters Capricorn, and the sun, Cancer. It is customary, however, having reference solely to the sun's place, to locate the vernal equinox in Aries, and the autumnal equinox in Libra; the summer solstice in Cancer, and the winter solstice in Capricorn. In the figure the terms summer solstice, autumnal equinox, etc., refer to the season upon the earth, and to the location of the sun in the ecliptic, but are not the names of those points in the earth's orbit. The zodiacal signs are inserted for convenience of illustration, to show where the earth would be located by a solar spectator; the pupil should remember, however, that the signs belong to the ecliptic, — which is the projection of the plane of the earth's orbit upon the celestial sphere, — and not to the earth's path.

a *third* motion. In summer, at midday, the sun is high in the heavens; in winter, he is low, near the southern horizon. In summer, he is a long time above the horizon; in winter, a short time. In summer, he rises and sets north of the east and west points; in winter, south of the east and west points. This subject is so intimately connected with the next, that we shall understand it best when taken in connection with that topic.

(4) CHANGE OF THE SEASONS. VARIATION IN LENGTH OF DAY AND NIGHT.—By studying the last figure and imagining the various positions of the earth in its orbit, let us try to understand the following points:—

(I) *Obliquity of the ecliptic.*—The axis of the earth is inclined 23½° from a perpendicular to its orbit. This angle is called the obliquity of the ecliptic.

(II) *Parallelism of the axis.*—In all parts of the orbit, the axis of the earth is parallel to itself, and points almost exactly toward the North Star (page 227).

Nature reveals to us nothing more permanent than the axis of rotation in anything that is rapidly turned. It is its rotation that keeps a boy's hoop from falling. For the same reason, a quoit retains its direction when whirled, and stays in the same plane at whatever angle it may be thrown. A man slating a roof wishes to throw a slate to the ground; he whirls it perpendicularly, and it will strike on the edge without breaking. So long as a top spins there is no danger of its falling, since its tendency to keep its axis of rotation parallel is greater than the attraction of the earth. This wonderful law would lead us to think that the axis of the earth points steadily in the same direction, even if we did not know it from direct observation.

(III) *The rays of the sun strike the various portions of the earth, when in any position, at different angles.* — When the earth is in Libra, and also when in Aries, the sun's rays strike vertically at the equator, but more and more obliquely in the northern and southern hemispheres, as the distance from the equator increases, until at the poles they strike almost horizontally.

This varying inclination of the rays to the earth's surface produces a corresponding variation in the intensity of the sun's heat and light at different places, and accounts for the difference between the torrid and polar regions.

(IV) *As the earth changes its position the angle at which the rays strike any portion is varied.* — Consider the earth when it is in Capricornus (♑) and the sun in Cancer (♋). He is now overhead at noon, at all places 23½° *north* of the equator. His rays strike less obliquely in the northern hemisphere than when the earth was in Libra. Let six months elapse; the earth is now in Cancer, and the sun in Capricornus; and he is overhead at noon, at all places 23½° *south* of the equator. His rays strike less obliquely in the southern hemisphere than before, but in the northern hemisphere more obliquely. These six months have changed the direction of the sun's rays on every part of the earth's surface. This accounts, in part, for the difference in temperature between summer and winter. The long nights and short days of winter, and the short nights and long days of summer, are also important factors in producing this difference of temperature.

(V) *Equinoxes.* — At the equinoxes, one half of each hemisphere is illuminated: hence the name *Equinox* (*æquus*, equal; and *nox*, night). At these points of the orbit the days and nights are equal over the entire earth, each being twelve hours in length.

(VI) *Northern and southern hemispheres unequally illuminated.* — While one half of the earth is constantly illuminated, the proportion of the northern or the southern hemisphere that is in daylight or darkness varies at all times, except at the equinoxes. When more than half of a hemisphere is in the light, its days are longer than the nights, and *vice versa*.

(VII) *The seasons and the comparative length of the days and nights in the south temperate zone, at any time, are the reverse of those in the north temperate zone, except at the equinoxes, when the days and nights are of equal length.*

(VIII) *The Summer Solstice.* — At the time of the summer solstice, which occurs about the 21st of June, the sun is overhead at noon, at all places 23½° north of the equator; and if his vertical rays could leave a golden line on the surface of the earth as it rotates, they would mark the Tropic of Cancer. The sun is at its furthest northern declination; he ascends the highest he is ever seen above our horizon, and rises and sets farthest north of the east and west points. He seems now to stand still in his northern and southern course, and hence the name *Solstice* (*sol*, the sun; *sto*, I stand). The days in the north temperate zone are longer than the nights. It is our summer, and the 21st of June is the longest day of the year. In the south temperate zone it is winter, and the shortest day of the year. The great circle that separates day from night extends 23½° beyond the north pole, and the small circle that marks the limit of *continual* day is the parallel of 66½° north latitude — the Arctic Circle. It is noon of the long six-months north polar day. The Antarctic Circle now marks the limit of continual night, and at the south pole it is midnight of the long six-months polar night (page 121).

(IX) *The Autumnal Equinox.* — The earth crosses the aphelion point early in July. It is then at its furthest distance from the sun, which each day rises and sets a trifle further toward the south, passing through a lower circuit in the heavens. At the time of the autumnal equinox, about the 21st of September, he is on the equinoctial; and if his vertical rays could leave a line of golden light, they would mark on the earth the circle of the equator. It is autumn in the north temperate zone and spring in the south temperate zone. The days and nights are equal over the whole earth, the sun rising at 6 A.M. and setting at 6 P.M., exactly in the east and the west, where the equinoctial intersects the horizon.

(X) *The Winter Solstice.* — The sun after passing the equinoctial — 'crossing the line' — sinks lower toward the southern horizon each day. At the time of the winter solstice, about the 21st of December, the sun is directly overhead 23½° south of the equator, and if his vertical rays could leave a line of golden light, they would mark on the earth's surface the Tropic of Capricorn. He is at his furthest southern declination, and rises and sets farthest south of the east and west points. It is our winter, and the 21st of December is the shortest day in the year. In the south temperate zone it is summer, and the longest day in the year.

The great circle that separates day from night extends $23\frac{1}{2}°$ beyond the south pole, and the Antarctic Circle marks the limit of continual day. At the south pole it is the noon of the long six-months polar day. In the Arctic regions the reverse is true; the rays fall $23\frac{1}{2}°$ short of the north pole, where it is the midnight of the long six-months polar night. Here again the sun appears to stand still a day or two before retracing his course, and this time is therefore called the Winter Solstice.

(XI) *The Vernal Equinox.* — The earth reaches its *perihelion* about the 31st of December. It is then nearest the sun, which rises and sets each day further and further north, and climbs up higher in the heavens at midday. Our days gradually increase in length, and our nights shorten in the same proportion. About the 21st of March the sun reaches the equinoctial, at the vernal equinox. He is overhead at the equator, and the days and nights are again equal. It is our spring, but in the south temperate zone it is autumn.

(XII) *Yearly path finished.* — As the earth moves on in its orbit through the spring and the summer months, the sun continues his northerly course, ascending at noon each day higher in the heavens, and his rays becoming less and less oblique. About the 21st of June, he again reaches his furthest northern declination, and is at the summer solstice.

We have thus traced the yearly path, and noticed the course of the changing seasons, with the length of the days and nights. The same series has been repeated through the ages of the past, and will be through the future till time shall be no more.

(XIII) *Distance of the earth from the sun varies.*—We notice, from what we have just seen, that we are nearer the sun in winter than in summer by 3,000,000 miles. The obliqueness with which the rays strike the north temperate zone at that time prevents our receiving any special benefit from this favorable position of the earth.

(XIV) *Southern summer.*—The inhabitants of the south temperate zone have their summer while the earth is in perihelion, and the sun's rays are about $\frac{1}{30}$ warmer than when in aphelion, our summer time. This will perhaps partly account for the extreme heat of their season.[1] The southern winters, for a similar reason, are colder; and this makes the average yearly temperature about the same as ours.

(XV) *Extremes of heat and cold not at the solstices.*—We do not have our greatest heat at the time of the summer solstice, nor our greatest cold at the winter solstice. After the 21st of June, our part of the earth, already warmed by the genial spring days, continues to receive more heat from the sun by day than it radiates by night: thus its temperature still increases. On the other hand, after the 21st of December, our latitudes continue to become colder, because they lose more heat during the night than is received during the day.

(XVI) *Summer longer than winter.*—As the sun is not in the center of the earth's orbit, but at one of its foci, the earth, from the time of the vernal to that of the autumnal equinox, passes through more than one

[1] Captain Sturt, in speaking of the extreme heat of Australia, says that matches accidentally dropped on the ground were ignited. An official report states that in South Australia, January, 1882, the heat in the sun was 180°—only 32° below the boiling point.

half of its orbit. Our summer is, therefore, longer than our winter. The difference is enhanced by the variation in the earth's velocity at aphelion and at perihelion.

(XVII) *Varying velocity of the earth in its orbit.*—From the time of passing perihelion (about December 31st) until the earth passes its aphelion, the solar attraction tends to check its speed; thence until the time of passing perihelion again, the attraction is partly in the direction of the earth's motion, and so increases its velocity.

(XVIII) *Curious appearance of the sun at the north pole.*—To a person standing at the north pole the sun appears to sweep horizontally around the sky every twenty-four hours, without any perceptible variation in its distance from the horizon. It is, however, slowly rising, until, about the 21st of June, it is 23½° high, a little more than one fourth of the distance from the horizon to the zenith. This is the highest point it ever reaches. From this altitude it slowly descends, its track being represented by a spiral or screw with a very fine thread; and in the course of three months it worms its way down to the horizon, which it reaches about the 21st of September. On this day it slowly sweeps around the sky with its face half hidden below the icy sea. It still continues to descend, and after it has entirely disappeared it is still so near the horizon that it carries a bright twilight around the heavens in its daily circuit. As the sun sinks lower and lower, this twilight grows gradually fainter, till it fades away. About December 21st, the sun is 23½° below the horizon, and this is the midnight of the dark polar winter. From this date, the sun begins to ascend, and after a time it is heralded by a faint dawn, which circles slowly around the horizon, completing its circuit every twenty-four hours. This dawn grows gradually brighter, and about the 21st of March the peaks of ice are gilded with the first level rays of the six-months day. The bringer of this long day continues to wind his spiral way upward, till he reaches his highest place about the 21st of June, and his annual course is completed.

(XIX) *Results, if the axis of the earth were perpendicular to the ecliptic.*—The sun would then always appear to move along the equinoctial. He would rise and set every day at the same points on the horizon, and pass through the same circle in the heavens, while the days and nights would everywhere be equal the year round. There would be near the equator a fierce torrid heat, while north and south the climate would change into temperate spring, and, lastly, into the rigors of a perpetual winter.

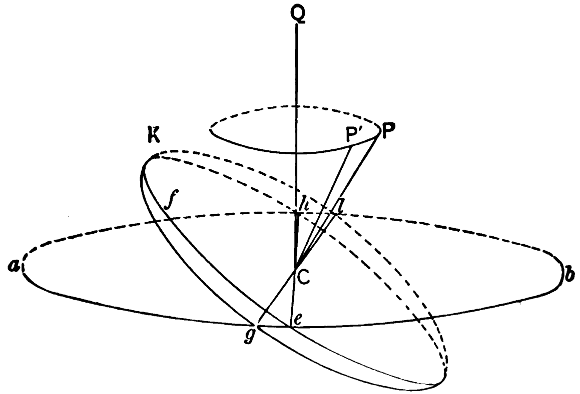
(XX) *Results, if the equator of the earth were perpendicular to the ecliptic.*—Were this the case, to a spectator at the equator, as the sun leaves the vernal equinox, he would each day pass through a smaller circle, farther north, until at the summer solstice he would reach the north pole, when he would halt for a time, and then slowly return in an inverse manner. Then, during the next half year, he would similarly approach to and return from the south pole.

In our own latitude, the sun would make his diurnal evolutions as described, his rays shining past the earth's north pole further and further, until we were included in the region of continual day. He would seem to wind in a spiral course up to the celestial north pole, and then return in a descending curve to the equator and beyond to the south pole of the heavens. In our winter we should be included for a corresponding length of time in the region of continual night.

Precession of the Equinoxes.—We have spoken of the equinoxes as if they were stationary. Over two thousand years ago, Hipparchus (page 18) found that they are slowly falling back westward along the ecliptic. Modern astronomers fix the rate at about $50\frac{1}{4}''$ of space annually. If we mark either point in the ecliptic where the days and nights are equal over the earth — at which time the plane of the earth's equator passes exactly through the center of the sun — we shall find the sun comes back to that position the next year, about 20 m. 23 s. of time earlier. This remarkable effect is called *Precession of the Equinoxes*, because the position of the equinoxes in any year precedes that which they occupied the year before. Since the circle of the ecliptic is divided into 360°, it follows that the time occupied by the equinoctial points in making a complete revolution at the rate of $50\frac{1}{4}''$ a year is about 25,800 years.

RESULTS OF THE PRECESSION OF THE EQUINOXES.— In the last figure we saw that the plane of the earth's equator is inclined to that of the ecliptic. In order that the plane of the terrestrial equator should pass through the sun's center $50\frac{1}{4}''$ farther west each year, it is necessary that the plane itself should slightly change its place. The axis of the earth is always perpendicular to this plane, hence it follows that the axis is not rigorously parallel to itself. It varies in direction, so that the celestial north pole very slowly describes upon the starry vault a small circle twice $23\frac{1}{2}°$ in diameter.

To illustrate this, let us suppose that, after a series of years, the position of the earth's equator has changed from *efh* to *g*K*l* (see diagram). The inclination of the axis of the earth, CP, to CQ, a perpendicular to the ecliptic plane, remains unchanged; but as it must turn with the equator, its position is moved from CP to CP′, and the pole of the earth slowly traces the portion of a circle, PP′. The direction of this motion, viewed from the north, is the same as that of the hands of a watch, or the reverse of the revolution of the earth. In the Appendix is a description of a simple apparatus for illustrating this subject. The position of the north pole in the heavens is gradually, though very slowly, changing. It is now distant from the north polar star about $1\frac{1}{4}°$. It will continue to approach Polaris until they are less than half a degree apart. In 12,000 years, Vega will be our polar star: 4500 years ago the



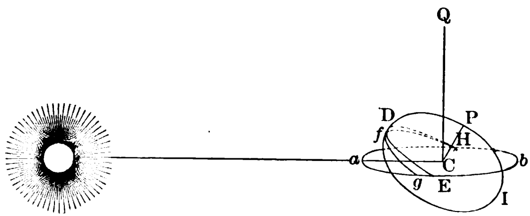
Change of Earth's Equator and Axis by Precession

polar star was the bright star Thuban in the constellation Draco (page 227).

As the right ascensions of stars are reckoned eastward from the vernal equinox along the equinoctial, the precession of the equinoxes increases the R. A. of equatorial stars $50\frac{1}{4}''$ a year. On this account accurate star maps should be accompanied by the date of their calculation, that they may be corrected to correspond with this annual variation.

The constellations of the zodiac (page 40) are fixed in the heavens, while the signs are simply abstract divisions which move with the equinoxes. When the constellations were named, the sun was in both the sign and the constellation Aries, at the time of the vernal equinox; but since then the equinoxes have retrograded nearly a whole sign, so that now, while the vernal equinox is in the sign Aries, this sign corresponds to the constellation Pisces, which is therefore the first constellation in the zodiac (figure on page 221).

CAUSES OF THE PRECESSION OF THE EQUINOXES.—Before commencing the explanation of this phenomenon, it is necessary to impress upon the mind a few facts. (1) The earth is not a perfect sphere, but is



INFLUENCE OF THE SUN ON A MOUNTAIN NEAR THE EQUATOR

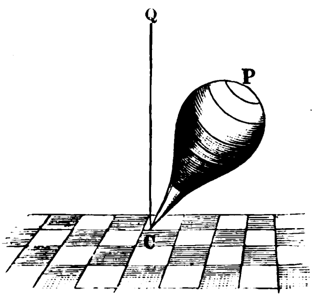
swollen at the equator. It is like a sphere covered with padding, increasing in thickness from the poles to the equator; this gives it a slightly turniplike shape. (2) The attraction of the sun is greater, the nearer a body is to it. (3) The attraction is not for the earth as a mass, but for each particle separately.

In the figure, the position of the earth at the time of the winter solstice is represented. P is the north pole, *ab*, the plane of the ecliptic; C, the center of the earth; CQ, a line perpendicular to the ecliptic; the angle QCP, the obliquity of the ecliptic. In this position, the equatorial protuberance of which we have spoken — the ring of matter about the equator — is not turned exactly toward the sun, but is elevated above it. Now the attraction of the sun pulls the part D more strongly than the center; the tendency of this is to bring D down to *a*, and to lift I toward *b*. The attraction for C is greater than for I, so it tends to draw C away from I; and, as at the same time D tends toward *a*, to pull I up toward *b*. The effect of this, one would think, would be to change the inclination of the axis CP toward CQ, and make it more nearly perpendicular to the ecliptic. This would be the result if the earth were not rotating upon its axis.

Let us consider the case of a mountain near the equator. This, if the sun did not act upon it, would pass through the curve HDE in the course of a semirotation of the earth. But it is nearer the sun than is the center C; the attraction therefore tends to pull the mountain downward and tilt the earth over, as we have just described; so the mountain will pass through the curve H*fg*, and instead of crossing the ecliptic at E, will cross at *g*, a little sooner than it otherwise would. The same influence, though in a less degree, obtains on the opposite side of the earth. The mountain passes around the earth in a curve nearer to *b*, and crosses the ecliptic a little earlier.

The same reasoning will apply to each mountain and to all the protuberant mass near the equatorial regions. The final effect is slightly to turn the earth's equator so that its plane intersects the ecliptic sooner than it would, were it not for this attraction. At the summer solstice, the same tilting motion is produced. At the equinoxes, the plane of the earth's equator passes through the center of the sun, and therefore there is no tendency to change of position. As the axis CP must move with the equator, it slowly revolves, keeping its inclination unchanged, around CQ, the perpendicular to the ecliptic, describing, in about 25,800 years, a small circle 47° in diameter.

PRECESSION ILLUSTRATED BY THE SPINNING OF A TOP. — This motion of the earth's axis is singularly illustrated in the spinning of a top, and the more so because the forces are of an opposite character to those which act on the earth, and thus produce an opposite effect. We have seen that, if the earth had no rotation, the sun's attraction on the equatorial protuberance would bring CP nearer to CQ; but that, in consequence of this rotation, the effect really produced is that CP, the earth's axis, slowly *revolves around* Q, the pole of the ecliptic, in a direction *opposite* to that of rotation.

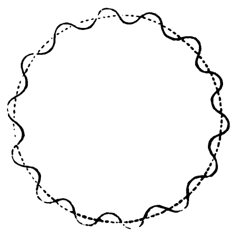


REELING OF A TOP

In the illustration let CP be the axis of a spinning top, and CQ a vertical line. The direct tendency of the earth's attraction is to bring CP *further from* CQ (or to make the top fall), and if the top were not spinning, this would be the result; but, in consequence of the rotary motion, the inclination does not sensibly alter (until the spinning is retarded by friction), and so CP slowly revolves around CQ in the *same direction* as that of rotation.

Nutation (*nutatio*, Latin for nodding). — We have noticed the sun as producing precession; the moon has, however, treble his influence; for although her mass is but $\frac{1}{27000000}$ part that of the sun, yet she is 400 times nearer and her effect correspondingly greater.[1] The moon's orbit does not lie in the plane of the ecliptic, but is inclined to it. Now the sun attracts the moon, and disturbs its path, as he would that of the mountain we have supposed, and the effect is the same. The intersections of the moon's orbit with the ecliptic travel backward, completing a revolution in about 18 years.

During half of this time, the moon's orbit is inclined to the ecliptic in the same way as the earth's equator; during the other half, it is inclined in the opposite way. In the former state, the moon's attractive tendency to tilt the earth is very small, and the precession is slow; in the latter, the tendency is great, and precession goes on rapidly. The consequence of this is that the pole of the earth is irregularly shifted, so that the celestial pole travels in a slightly curved line, giving it a kind of 'nodding' motion, as shown in the diagram, greatly exaggerated. The obliquity of the ecliptic, which we consider 23½°, is the *mean* of the various obliquities corresponding to different points in the irregularly curved line. If the obliquity were constant, the pole would travel along the dotted circle, whose center is the north pole of the ecliptic, and whose diameter is twice the obliquity.



Curved Path of the North Pole in the Heavens

Secular Change in the Obliquity of the Ecliptic. — Although it is sufficiently near for all general purposes to consider the obliquity of the ecliptic

[1] See the differential effect of sun and moon (page 153).

invariable, yet this is not strictly the case. It is subject to a small but appreciable variation of about 46″ a century. This is caused by a slow change of the position of the earth's orbit, due to the attraction of the planets. The present effect of this movement is gradually to diminish the inclination of the earth's equator to the ecliptic (the obliquity of the ecliptic). This will continue for a long time, when the angle will as gradually increase; the extreme limit of change being only $1\frac{1}{3}°$. The orbit of the earth thus vibrates backward and forward, each oscillation requiring a period of 10,000 years.

In its effect upon the obliquity of the ecliptic, this change is so intimately blended with that caused by precession and nutation, that they are separable only in theory; in fact, they all combine to produce the waving motion we have already described. As a consequence of the variation in the obliquity of the ecliptic, the sun does not now come so far north nor decline so far south as formerly; while the positions of all the terrestrial circles — the Tropic of Cancer, of Capricorn, etc. — are constantly but slowly changing. As another result, some stars which were once just south of the ecliptic are now north of it, and others that were just north are now a little further north; thus the latitude of most stars is very gradually changing.

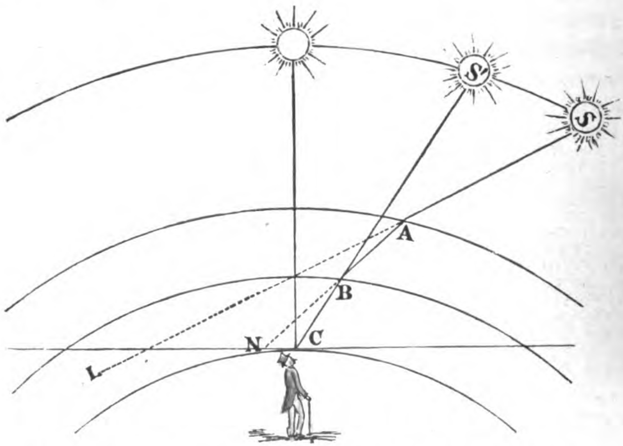
Change in the Major Axis (Line of Apsides) of the Earth's Orbit. — Besides all the changes in the position of the earth in its orbit due to precession, etc., the orbit itself (and hence the line connecting the aphelion and perihelion points of the orbit) is slowly revolving in its own plane. This causes a variation in the length of the seasons at different periods of time.

In the year B.C. 3958, according to Chambers, the earth was in perihelion at the time of the autumnal equinox, so that the summer and autumn seasons were of equal length, but shorter than the winter and spring seasons, which were also equal. In the year A.D. 1267 the earth was in perihelion at the time of the winter solstice, December 21st, instead of December 31st, as now; the spring quarter was therefore equal to the summer one, and the autumn quarter to the winter one, the former being the longer. In the year A.D. 6493 the earth will be in perihelion at the time of the vernal equinox; summer will then be equal to autumn, and winter to spring, the former seasons being the longer. In the year A.D. 11,719 the earth will be in perihelion at the time of the summer solstice; finally, in A.D. 16,945, the cycle will be completed, and the autumnal equinox will again coincide with the earth's perihelion.

Permanence in the Midst of Change. — We thus see that the orbit of the earth is constantly modifying its elliptical shape, while it slowly oscillates northward and southward; that the earth's axis steadily turns its long index finger over a dial that marks 25,800 years; that the earth, accurately poised in space, gently nods and bows to the attraction of the sun, moon, and planets.[1] Thus changes are taking place that would ultimately reverse the order of nature, if they were to continue without limit. But each of these variations has its bounds, beyond which it cannot pass. The promise made to man is that, 'while the earth remaineth, seedtime and harvest, and cold and heat, and summer and winter, and day and night shall not cease.' The modern discoveries of astronomy prove conclusively that the seasons are to be permanent; that the Creator, amid all these transitions, has ordained the means of carrying out His promise through all time.

[1] These oscillations extend throughout the whole planetary system, the periods varying from 50,000 to 2,000,000 years. 'Great clocks of eternity, which beat ages as ours beat seconds.' — NEWCOMB'S *Astronomy*, page 95.

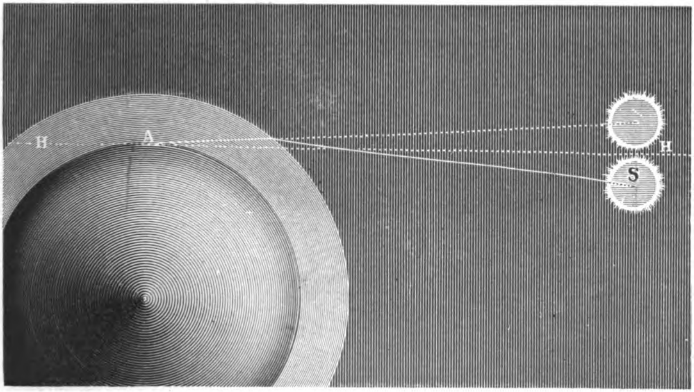
Refraction. — The atmosphere extends above the earth perhaps 100 miles. Near the surface of our globe it is dense, while in the upper regions it is exceedingly rare. The rays of light from the heavenly bodies passing through these different layers are turned downward toward a perpendicular more and more as the density increases. According to a well-known law of optics, if the ray of light from a star were bent in fifty directions



REFRACTION SEEMS TO ELEVATE THE CELESTIAL BODIES

before entering the eye, the star would nevertheless appear to be in the line of the one nearest the eye. The effect of this is that the apparent place of a heavenly body is higher than the true place. The sun at S in the diagram would send a direct ray to L were it not for the atmosphere. Instead the ray is refracted downward at A, and would then enter the eye at N; passing, however, through a layer of different density at B, it is again bent, and meets the eye of the observer at C. He sees the sun, not in the direction of the curved line CBAS, but in that of the straight line CBS′.

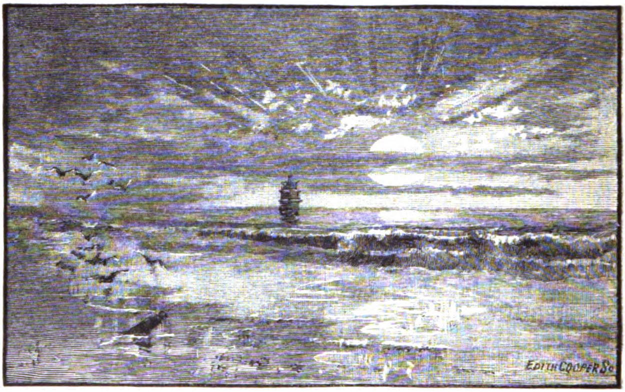
The amount of refraction varies with the temperature and other conditions of the atmosphere. It is zero for a body in the zenith, and increases gradually toward the horizon (as the thickness of the intervening atmosphere increases), where it is sometimes as much as 35′.



REFRACTION MAKES THE SUN VISIBLE ABOVE THE HORIZON WHEN REALLY BELOW IT

CHANGE OF PLACE AND APPEARANCE OF THE SUN AND THE MOON.—The sun may be really below the horizon, and yet seem to be above it. For example, on April 20, 1837, the moon was eclipsed before the sun had set. The mean diameter of both the sun and the moon being about half a degree, it follows that when we see the lower edge of either of these luminaries apparently just touching the horizon, as at H on the right in the above illustration, in reality the whole disk is *below* it, as at S, and would be hidden were it not for refraction. Consequently the day is materially lengthened.

The sun and the moon often appear *flattened* when near the horizon. The rays from the lower edge pass through a denser layer of the atmosphere, and are therefore refracted more than those from the upper edge: the effect of this is to make the vertical diameter appear less than the horizontal, and so to distort the figure of the disk into an oval shape.



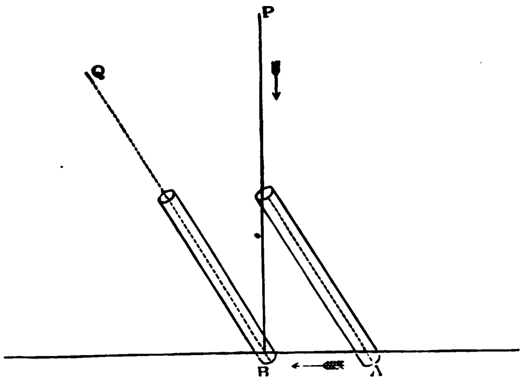
DEFORMATION OF THE SUN BY REFRACTION NEAR THE HORIZON

The dim and hazy appearance of the heavenly bodies when near the horizon is caused not only by the rays of light having to pass a greater distance through the atmosphere, but also by their traversing the denser part. The intensity of the solar light is so greatly diminished by going through the lower strata, that often we are enabled to look upon the sun without being dazzled by its brilliant beams.

TWILIGHT. — The glow of light after sunset and before sunrise, which we term twilight, is caused by refraction and reflection of the sun's rays by the atmosphere. For a time after the sun has really set, his refracted rays continue to reach us; but when these have ceased he still illuminates the clouds and upper strata of the air, just as he may be seen shining on the summits of lofty mountains long after he has disappeared from the view of inhabitants of the plains below. The air and clouds thus illuminated reflect back a part of the light to the earth. As the sun sinks lower, less light reaches us, until reflection ceases and night ensues. The same thing occurs before sunrise, only in reverse order.

Twilight is usually reckoned to last until the depression of the sun below the horizon amounts to 18°; the duration of twilight, however, varies with the latitude, seasons, and condition of the atmosphere. When the sun's path is very oblique to the horizon, a longer time is required for the sun to descend or ascend the requisite vertical distance of 18° from the horizon; and a shorter time when his path is more nearly perpendicular. In the latitude of New York, twilight lasts from $1\frac{1}{2}$ to 2 hours, the shortest twilight being in winter, and the longest in summer. Strictly speaking, in the latitude of Greenwich there is no true night for a month before and after the summer solstice, but constant twilight from sunset to sunrise. The sun is then overhead near the Tropic of Cancer, and does not descend so much as 18° below the horizon during the entire night. At the equator the length of the twilight is about $1\frac{1}{4}$ hours, and remains almost constant the entire year. The twilight is longest toward the poles, where the night of six months is shortened by an evening twilight of about fifty days and a morning one of equal length.

Diffused Light. — The diffused light of day is produced in the same manner as twilight. The atmosphere reflects and scatters the sunlight in every direction. Were it not for this, no object out of direct sunshine would be visible to us; every shadow of a passing cloud would be pitchy darkness; the stars would be visible all day; no window would admit light except as the sun shone directly through it, and



Illustrating Aberration of Light

one would require a lantern to go about the house at noon. The blue light reflected to our eyes from the atmosphere above us, or, more correctly, from the vapor in the air, produces the optical illusion we call the sky.

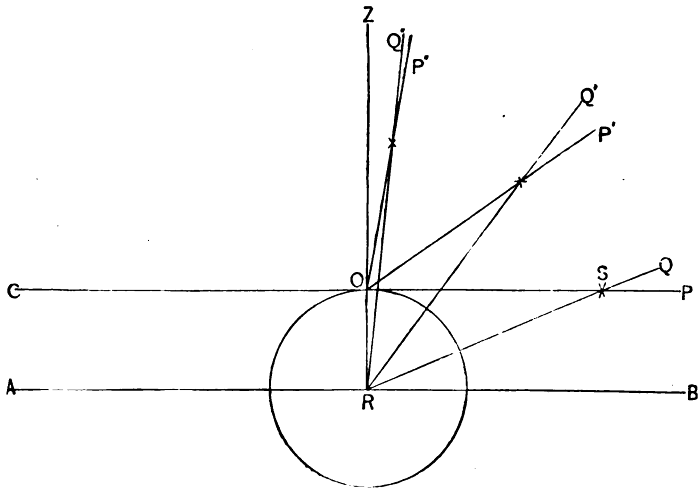
Aberration of Light. — We have seen that the places of the heavenly bodies are apparently changed by refraction. Besides this, there is another change due to the motion of light combined with the motion of the earth in its orbit. For example: the mean distance of the earth from the sun is about 93,000,000 miles, and since light travels a little over 186,000 miles in a second, it follows that the time occupied by a ray of light in reaching us from the sun is about $8\frac{1}{3}$ minutes (8 m. 18 s.); so that, in fact, (1) we do not see the sun as it is but as it was $8\frac{1}{3}$ minutes ago. And since, during this time, the earth has moved about $20\frac{1}{2}''$ in its orbit, (2) we do not see that luminary in the exact place it occupies at the time of observation.

ILLUSTRATION.—Suppose a ball let fall from P (page 122), above the horizontal line AB, and a tube of which A is the lower extremity placed to receive it. If the tube were fixed, the ball would strike it on the lower side; but suppose the tube were carried forward in the direction AB, with a velocity properly adjusted at every instant to that of the ball, while *preserving its inclination* to the horizon, so that when the ball, in its natural descent, reached B, the tube would have been carried into the position BQ. It is evident that the ball throughout its whole descent would then be found in the tube; and a spectator referring to the tube the motion of the ball, and carried along with the former, unconscious of its motion, would think that the ball had been moving in an inclined direction and had come from Q.

A very common illustration may be seen almost any rainy day. Choose a time when the air is quiet, and the drops large. Then if you stand still, you will see that the drops fall vertically; but if you walk forward, you will see the drops fall as if they were meeting you. If, however, you walk backward, you will observe that the drops fall as if they were coming from behind you. We thus see that the drops have an apparent as well as a real motion.

THE GENERAL EFFECT OF ABERRATION is to cause each star apparently to describe in the course of a year a minute ellipse, the central point of which is the place the star would actually occupy were our globe at rest.

Parallax *is the difference in direction of an object as seen from two different places.* For a simple illustration, hold your finger before you in front of the window.



PARALLAX AT DIFFERENT ALTITUDES

Upon looking at it with the left eye only, you will locate your finger at some point on the window; on looking with the right eye only, you will locate it at an entirely different point. Use your eyes alternately and quickly, and you will be astonished to see how your finger will seem to change its place. Now, the difference in the direction of your finger as seen from the two eyes is its parallax.

In astronomical calculations, the position of a body as seen from the earth's surface is called its *apparent* place, while that in which it would be seen from the center of the earth is called its *true* place. Thus, in the diagram, a body is seen by the observer at O in the direction OP; if it could be viewed from the center R, its direction would be in the line RQ. It is therefore seen from O at a point in the heavens *below* its position in reference to R. From looking at the cut, we can see (1) that the parallax of a body near the horizon is greatest, while it decreases gradually until it disappears altogether at the zenith, since an observer at O, as well as one at R, would see the body Z directly overhead; and (2) that the nearer a body is to the earth, the greater its parallax becomes.

It has been agreed by astronomers, for the sake of uniformity, to correct all observations so as to refer them to their true places as seen from the center of the earth. Tables of parallax are constructed for this purpose. The question of parallax is also of great importance, because as soon as the parallax of a body is accurately known, its distance and diameter can be determined. (See Celestial Measurements, page 287.)

HORIZONTAL PARALLAX is the parallax of a body when at the horizon. It is, in fact, *the earth's semidiameter as seen from the body.* In the figure just given, the parallax of the body S is the angle OSR, which is measured by the line OR — the semidiameter of the earth. The *sun's horizontal parallax* is the angle subtended (measured) by the earth's semidiameter as seen from that luminary. As the moon is nearest the earth, its horizontal parallax is greater than that of any other heavenly body.

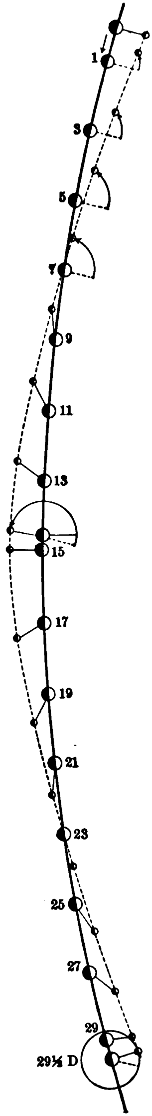
ANNUAL PARALLAX. — The fixed stars are so distant from the earth that they exhibit no change of place when seen from different parts of the earth. The lines OS and RS are so long that they are apparently parallel. Therefore, instead of taking the earth's semidiameter, or 4000 miles, as the measuring unit, astronomers observe the position of the fixed stars at opposite points in the earth's orbit. This gives a change in place of 186,000,000 miles. One half the variation of position which the stars undergo as viewed from these remote points is called their *annual parallax*.

THE MOON

New Moon, ●. First Quarter, ☽. Full Moon, ○. Last Quarter, ☾.

Motion in Space. — The orbit of the moon, considering the earth as fixed, is an ellipse of which our planet occupies one of the foci. Her distance from the earth, therefore, varies incessantly, but only in a slight degree relatively to the whole distance, because the ellipse differs only a little from a true circle. At perigee (*peri*, near; *gē*, the earth), she is 26,000 miles nearer than in apogee (*apo*, from; *gē*, the earth): the mean distance is about 239,000 miles. To reach the moon would require a chain of thirty globes equal in size to the earth. An ordinary express train would take about a year to accomplish the journey.

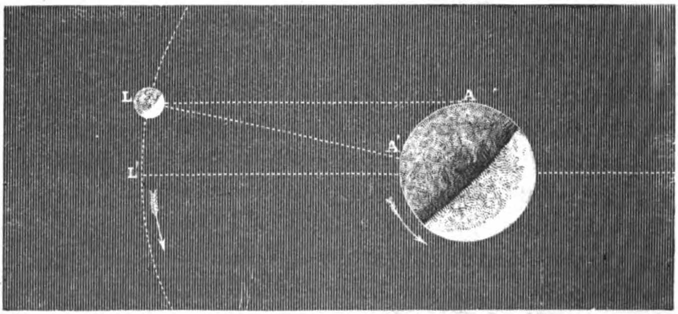
The moon completes her revolution (*sidereal*) around the earth in about 27⅓ days; but as the earth is constantly passing on in its orbit around the sun, it requires over two days longer before the moon comes into the same position with respect to the sun and the earth, thus completing a *synodic* revolution, or lunar month (29½ days).



THE REAL PATH OF THE MOON is the result of her own motion and the onward movement of the earth. The two combined produce a wavelike curve that crosses the earth's path twice each month; this is always concave toward the sun, owing to the small diameter of the moon's orbit compared with the earth's orbit, and to the relatively slow rate of revolution of the moon round the earth. In the figure the earth's path is represented by the heavy curve, which is practically a circular arc, and the moon's path by the dotted line. If the earth stood still, the moon would travel round it in an orbit represented by a small, almost circular ellipse. But because of the earth's rapid forward movement, the moon's real path is a curve which is concave on its sunward side. As the moon constantly keeps the same side turned toward us, it follows that she must rotate on her axis once each lunar month.

Dimensions. — The moon's diameter is about 2160 miles. To equal the earth would require fifty globes the size of the moon. The apparent diameter varies with the distance; the mean is, however, about half a degree, nearly the same as that of the sun. The moon always appears slightly larger than she really is, on account of her brightness. This is the effect of what is termed in optics *irradiation.*[1] For the same reason it is often noticed that the crescent moon seems to be part of a larger circle than the rest of the moon. The moon appears larger on the horizon than when high in the sky. This, however, is a mere illusion.[2] For it is easily seen that the moon at L, in the horizon of A, is almost 4000 miles farther from the observer than when the observer has been carried on to A′ and the moon is in the zenith.

Besides these general variations in size, the moon varies in apparent size to different observers. In a



THE DISTANCE OF THE MOON AT THE HORIZON AND AT THE ZENITH

large party or class a comparison of her apparent magnitude may cause much amusement. The estimates range from a small saucer to a wash tub.

Librations (*librans*, swinging). — Though the moon presents, in general, the same hemisphere to us, there

[1] To illustrate this principle, cut two circular pieces of the same size, one of black and the other of white paper. The white circle, when held in a bright light, will appear much larger than the black one.

[2] At the horizon we compare her with various terrestrial objects which lie between her and us, while aloft we have no association to guide us in judging of her distance, and we are led to underrate her size. If we look at her, when near the horizon, through a very small roll of paper, or the hands held tube-wise, this illusion will vanish.

are three causes which enable us to see, in all, about $\frac{3}{5}$ of her entire surface.

(1) The axis of the moon is inclined a little from a perpendicular to her orbit, as also her orbit is inclined somewhat to the earth's orbit; so, when her north pole leans alternately toward and from the earth, we see sometimes past her north and sometimes past her south pole. This effect is called her *libration in latitude.*

(2) The moon's rotation on her axis is always performed in the same time, while her movement along her orbit is variable; hence we occasionally see a little further around her eastern or western limb (outer edge) than at other times. This is *libration in longitude.*

(3) The size of the earth is so much greater than that of the moon, that an observer, by the rotation of the earth, or by going north or south, can see further around the moon's edge.

Light and Heat. — If the whole sky were covered with full moons, they would scarcely make daylight, since the brilliancy of the moon does not exceed $\frac{1}{600,000}$ that of the sun. That portion of the moon's surface which is directly exposed to the sun is thought to be highly heated; probably to the degree of boiling water in those regions where the sun is at or near the lunar zenith. During the lunar night, the temperature must fall nearly to that of space itself, or about 200° below zero, Fahrenheit.

Whether or not the moon radiates any heat to the earth was long a mooted question. The best authorities, at present, estimate the average heat received from the moon at about $\frac{1}{180000}$ that we receive from the sun. It is absurd to suppose that this slight amount of heat can have any appreciable effect upon the weather.

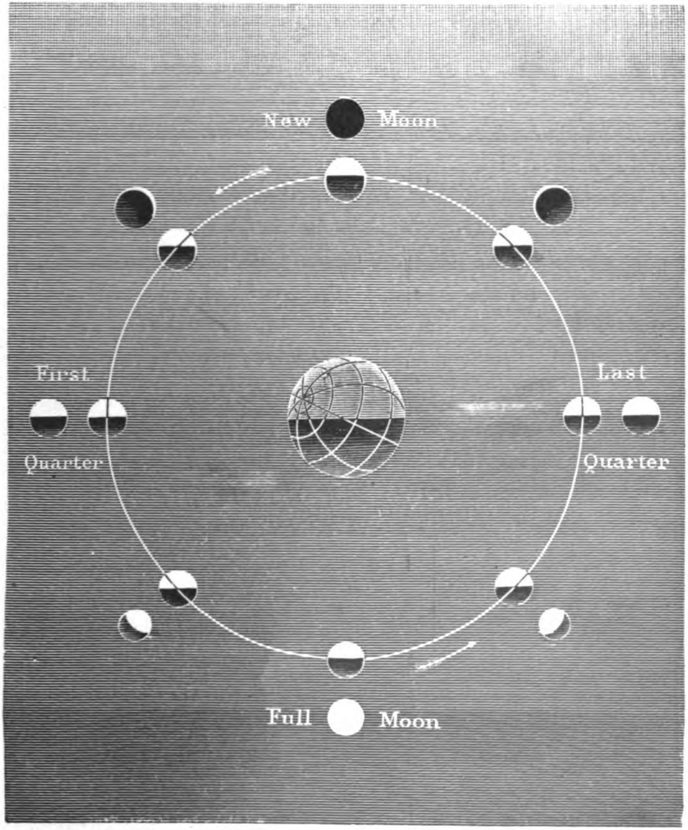
Atmosphere of the Moon.—The existence of an atmosphere upon our satellite is at present an open question. If there be any, it must be extremely rarefied, perhaps as much so as that in the vacuum obtained in the receiver of our best air pumps. Certainly there is no lunar atmosphere sufficient to produce a barometric pressure as great as $\frac{1}{750}$ of that at the earth's surface.

Appearance of the Earth to Lunarians.—If there be any lunar inhabitants on the side toward us, the earth must present to them all the phases which their world exhibits to us, only in a reverse order. When we have a new moon, they have a *full earth*, a bright, full-orbed moon with fourteen times as much apparent surface as ours. The lunar inhabitants upon the side opposite to us of course never see our earth, unless they take a journey to the regions whence it is visible, to behold this wonderful spectacle. Those living near the limbs of the disk might, however, on account of the *librations*, get occasional glimpses of it near their horizon.

The Earth Shine.—For a few days before and after new moon, we may distinguish the outline of the unillumined portion of the moon. In England, it is popularly known as 'the old moon in the new moon's arms.' This reflection of the earth's rays must serve to keep the lunar nights quite light, even in *new earth*.

Phases of the Moon.—The phases of the moon show conclusively that it is a dark body, which shines by reflecting the light it receives from the sun. Let us compare its various appearances with the positions indicated in the next figure.

(1) We see the moon as a delicate crescent in the west just after sunset, as she emerges from the sun's



PHASES OF THE MOON: INNER AS SEEN FROM THE NORTHERN HEAVENS; OUTER AS SEEN FROM THE EARTH

rays at conjunction. She soon sets below the horizon. Half of the surface is illumined, but only a slender edge with the horns turned from the sun is visible to us. Each night the crescent broadens, the moon recedes about 13° further from the sun, and sets correspondingly later, until at quadrature half of the hemisphere turned toward us is illumined, and the moon is said to be in her *first quarter.*

(2) The moon, continuing her eastern progress round the earth, becomes *gibbous* in form (*gibbous* meaning more than a half and less than the whole of a circle), and, about the fifteenth day from new moon, she reaches the point in the heavens directly opposite to that which the sun occupies. She is then in *opposition*, the whole of the side turned toward us is illumined, and we have a *full moon.* She is on the meridian at midnight, and so rises in the east as the sun sets in the west, and *vice versa.*

(3) The moon, passing on in her orbit from opposition, presents phases reversed from those between first quarter and full. The proportion of illumined surface visible to us gradually decreases; she becomes *gibbous* again; rises nearly an hour later each evening, and in the morning lingers high in the western sky after sunrise. She again comes into quadrature, and is in her *third quarter.*

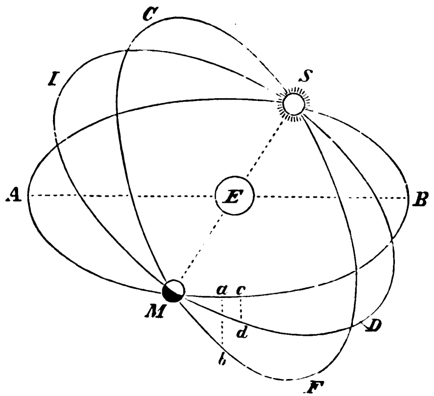
(4) From the third quarter, the moon decreases to the crescent form again; as, however, the bright side constantly faces the sun, the horns are pointed toward the west. She is now seen as a bright crescent in the eastern sky just before sunrise. At last, the illumined side is completely invisible from the earth, and the moon herself, coming into conjunction with the sun, is lost in his rays. To accomplish this journey through her orbit from new moon to new moon again, requires 29½ days — a *lunar month.*

MOON RUNS HIGH OR LOW. — Doubtless, all have noticed that, in the long nights of winter, the full moon is high in the heavens, and continues a long time above the horizon ; while in midsummer she is low, and remains a much shorter time above the horizon. This is a wise plan of the Creator, which is seen yet more clearly in the Arctic and Antarctic regions. At the poles, the moon, during the long summer day of six months, is above the horizon only in her first and fourth quarters, when her light is least ; but during the tedious winter night of equal length, she is continually above the horizon for her second and third quarters. Thus, in polar regions, the moon is never full by day, but is full every month in the night.

We can easily understand these phenomena when we remember that the new-moon is in the same quarter with, and the full moon is in the opposite quarter from, the sun. When, therefore, the sun sinks low in the southern sky the full moon rises high, and when the sun rises high the full moon sinks low.

Harvest Moon. — While the moon rises, on the average, 50 minutes later each night, the exact time varies in our middle latitudes from less than half an hour to a full hour and a quarter. Near the time of the autumnal equinox the moon, at her full, rises about sunset for a number of nights in succession. This produces a series of brilliant moonlight evenings. It is the time of harvest in England, and hence has there received the name of the Harvest Moon. In the following month (October), the same occurrence takes place ; it is then termed the Hunter's Moon.

The cause of this phenomenon lies in the fact that the moon's path is variously inclined to the horizon at different seasons of the year.[1] When, at the time of rising, the full moon is near the point in the celestial sphere called the vernal equinox (September and October), the angle her orbit makes with the horizon is least, and when she is near the point called autumnal equinox it is greatest. In the former case, the moon, by moving eastward each day about 13°, will be but little farther below the eastern horizon than at its previous rising; and so for several successive evenings will rise at about the same hour. In the latter, she will descend much further each day and thus will rise much later each night. At latitude 40°, the least possible variation in the hour of rising is 20 minutes; — the greatest is 1 hour and 20 minutes.



EXPLAINING THE HARVEST MOON

In the above figure, let S represent the sun; E, the earth; M, the moon; CF, the moon's path around the earth when the autumnal equinox is in the eastern horizon; ID, when the vernal equinox is in the eastern horizon; AMBS, the horizon; and $Md = Mb = 13°$, the distance the moon moves each day. When passing along the path CF, the moon sinks below the

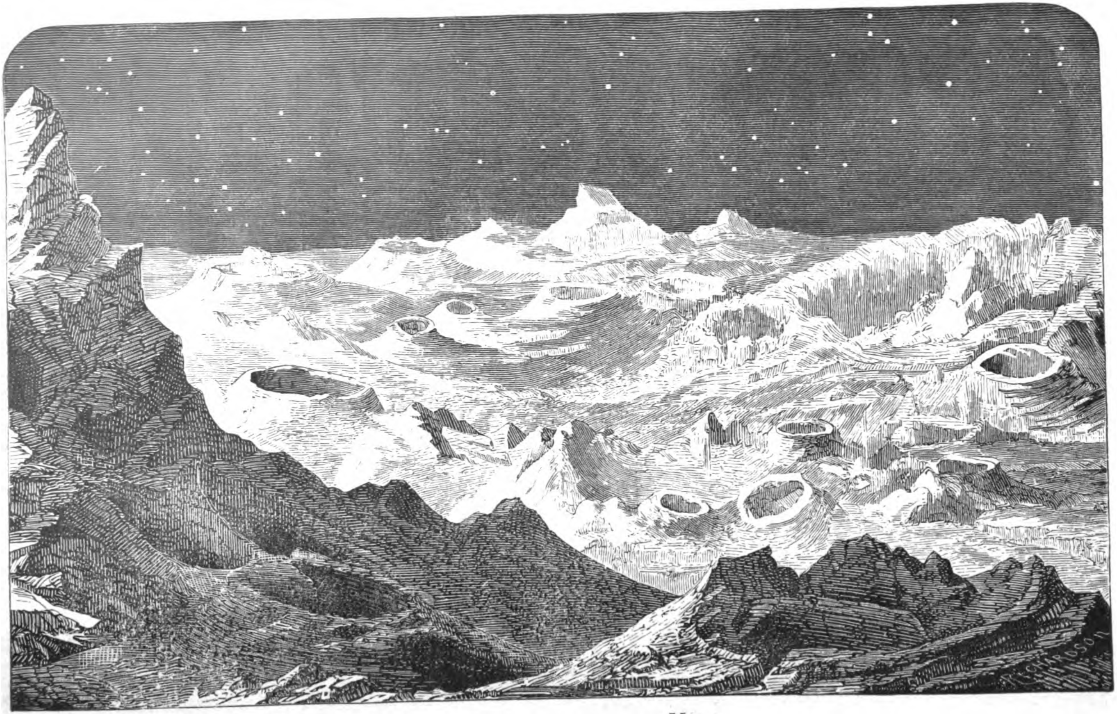
[1] Besides this reason, we should remember that the motion of the moon is slowest at apogee and fastest at perigee. (See note, page 319.)

horizon the distance *ab*; but when moving along the path ID, only the distance *cd*. It is obvious that before the moon can rise in the former case, the horizon must be depressed the distance *ab*, and in the latter only *cd*; and the moon will rise each evening correspondingly later in the one and earlier in the other.

Dry Moon and Wet Moon.—At new moon, when the line of the cusps lies nearly perpendicular to the horizon, the moon is popularly called a *wet moon*, and when it is almost horizontal, the moon is termed a *dry moon*. The cause of this change in the crescent is astronomical, and not meteorological. The direction of the form of the crescent has therefore no connection with the weather. A little reflection will show us that the horns, or cusps, of the new moon must point from the sun. As the ecliptic (from which the moon's path varies but slightly) is differently inclined to the horizon at various times of the year, this will give the crescent a different position with reference to the horizon (page 38).

Nodes.—The orbit of the moon is inclined to the ecliptic about 5°, the points where her path crosses it being termed *nodes*. The ascending node (☊) is the place where the moon crosses in coming above the ecliptic, or toward the North Star; the descending node (☋) is where it passes below the ecliptic. The imaginary line connecting these two points is called the 'line of the moon's nodes.'

Occultations.—The moon, in the course of her monthly journey round the earth, frequently passes in front of the stars, and occasionally the planets, which disappear on the eastern side of her disk and reappear on the western. This is termed an *occultation*, and is of



IDEAL LANDSCAPE ON THE MOON

practical use in determining the difference of longitude between various places on the earth when not connected by telegraph or cable lines.

Lunar Seasons; Day and Night, etc. — As the moon's axis is nearly perpendicular to her orbit, she cannot have any change of seasons. During nearly fifteen of our days, the sun pours down his rays unmitigated by any atmosphere to temper them; and the lunar rocks, as already mentioned, probably rise above the temperature of boiling water. To this long day succeeds a night of equal length and more than polar cold.

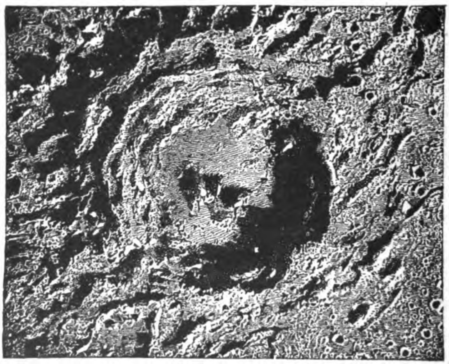
How strange the lunar phenomena would be to us! The disk of the sun is continually surrounded by the wonderful radiance of the corona. The sky is black and overspread with stars even at midday. There is no twilight, for the sun bursts instantly into day, and, after a fortnight's glare, as suddenly gives place to night; no air to conduct sound; no clouds; no winds; no rainbow; no blue sky; no gorgeous tinting of the heavens at sunrise and sunset; no delicate shading; no soft blending of colors, but only sharp outlines of sun and shade.[1]

The nights of the visible hemisphere must be brilliantly illuminated by the earth, whose phases 'serve well as a clock — a dial all but fixed in the same

[1] The moon appears to be a fossil world, an ancient cinder, a ruined habitation perpetuated only to admonish the earth of her own impending fate, and to teach her occupants that another home must be provided, which frost and decay can never invade. Doubtless the moon was once the seat of all the varied and intense activities that now characterize the surface of our earth. At one time its physical condition was like that of the parent earth from which it had just been separated; but, being smaller, it cooled faster, and its geologic periods were correspondingly shorter. Its life age was perhaps reached while the earth was yet glowing. — Consult Winchell's *Geology of the Stars*.

part of the heavens, like an immense lamp, behind which the stars slowly defile along the black sky.'

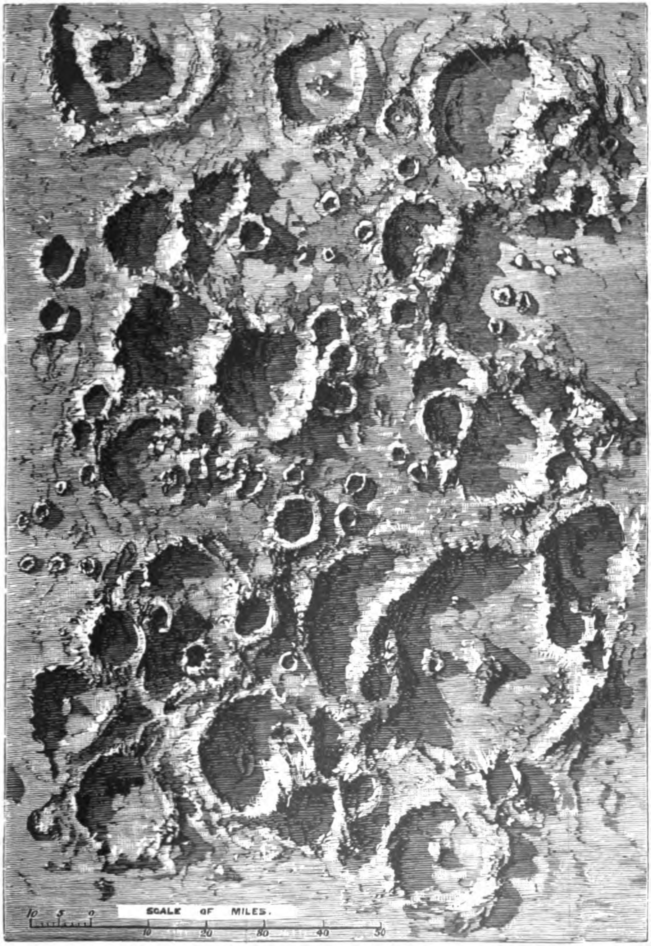
Telescopic Features. — Even with the naked eye, we see on the moon's surface bright spots (the summits of lofty mountains, gilded by the first rays of the sun), and darker portions — low plains yet lying in comparative shadow. The telescope reveals to us a region torn and shattered by fearful volcanic action, though now practically extinct. Everywhere the crust is pierced



LUNAR CRATER COPERNICUS

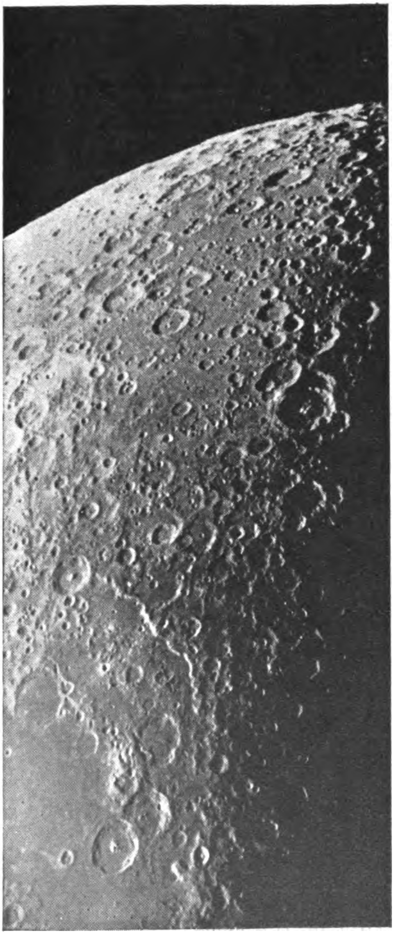
by craters, whose irregular edges and rents testify to the convulsions our satellite has undergone.

MOUNTAINS. — The heights of more than 1000 of the lunar mountains have been measured, some of which exceed 25,000 feet. When the sun's rays strike one of these mountains very obliquely, the shadow is as distinctly perceived as that of an upright staff when placed in the sunlight. Some of the elevations are isolated peaks that shoot up from the center of circular plains; a few others are mountain ranges extending



TELESCOPIC VIEW OF THE MOON

hundreds of miles. Most of the lunar heights have received names of men distinguished in science. Thus we find Plato, Aristarchus, Copernicus,[1] Kepler, and Newton, associated, however, with the Apennines, Carpathians, etc.



PHOTOGRAPH OF PART OF THE MOON

GRAY PLAINS, OR SEAS. — These are analogous to our prairies. They were formerly supposed to be sheets of water, but they exhibit the uneven appearance of a plain, instead of the regular curve of a sea. The former names have been retained, and we find on lunar maps *Mare Tranquillitatis* (Sea of Tranquillity), *Mare Serenitatis* (Sea of Serenity), etc.

RILLS, LUMINOUS RAYS. — The luminous rays are long,

[1] This is one of the grandest of the lunar craters. It is situated on the tip of the nose of the 'Man in the Moon.' Its diameter is forty-six miles, and its encircling rampart rises 12,000 feet above the interior plateau, in the midst of which stands a group of cones, one of them 2400 feet in height.

bright surface streaks best seen at full moon, but mysterious as to their meaning, irregular in outline and extent, and radiating in every direction from Tycho, Kepler, and other mountains. The rills and clefts are sunken and have sloping sides, and were at first thought to be ancient river beds. Their nature is not yet well made out; perhaps they are cracks in the moon's crust.

CRATERS constitute the most curious feature of the lunar landscape. They are mostly of volcanic origin, and usually consist of a cuplike basin, with frequently one or more conical elevations in the center. Some of the craters have a diameter of over 100 miles, and are great walled plains, sunk so far behind huge ramparts that the lofty wall surrounding an observer at the center would be beyond his horizon. The origin of these is probably not volcanic. Other craters are deep and narrow, — as Newton, which is said to be about four miles in depth, — so that neither earth nor sun is ever visible from a great part of the bottom. The appearance of these craters is strikingly shown in the accompanying view (page 139) of the region to the southeast of Tycho.

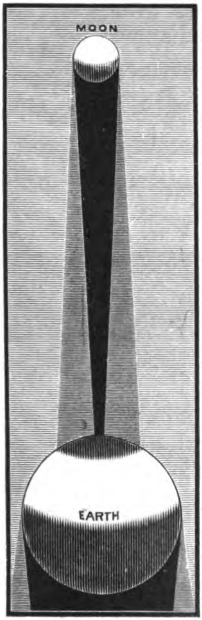
Recently photography has rendered a vast assistance to astronomers in depicting the surface of the moon. Maps of its rugged surface which formerly took months and even years to perfect are now replaced and improved upon by photographic exposures of only two or three seconds. Many photographic atlases have been published containing hundreds of views of the surface of our satellite, showing prominent craters in all stages of phase illumination by the sun. The best are those recently issued by the Prague and Paris Observatories.

ECLIPSES

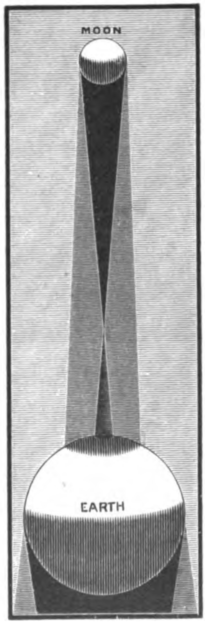
Eclipse of the Sun. — If the moon should pass through either node at or near the time of conjunction, or *new moon*, she would necessarily come between the earth and the sun, for the three bodies would then be in the same straight line. This would cause an eclipse of the sun. If the moon's orbit were in the same plane as the ecliptic, an eclipse of the sun would occur at every new moon; but as the orbit is inclined, it can occur only at or near a node.

Eclipse may be Partial, Total, or Annular. — In the first figure we see where the dark shadow (*umbra*) of the moon falls on the earth and obscures the entire body of the sun. To persons within that region, there is a *total eclipse;* the breadth of this space is not great, averaging less than one hundred miles. Beyond this umbra, there is a lighter shadow, *penumbra* (*pæne*, almost; *umbra*, a shadow), where only a portion of the sun's disk is obscured. Within this region, there is a *partial eclipse.* To persons in our country north of the umbra, the eclipse passes over the lower limb of the sun; to those south of the umbra, it passes over the upper limb. When the eclipse occurs almost exactly at the node, it is said to be *central.* If the eclipse takes place when the moon is at apogee, her apparent diameter is less than that of the sun; as a consequence, her disk does not cover the disk of the sun, and the visible portions of that luminary appear in the form of a ring (*annulus*); hence there is an *annular eclipse* in all those places comprised within the limits of the cone of shadow prolonged to the earth, as in the second figure.

GENERAL FACTS CONCERNING A SOLAR ECLIPSE. — The following data may guide in understanding the circumstances of solar eclipses: —



THEORY OF A TOTAL ECLIPSE OF THE SUN



THEORY OF AN ANNULAR ECLIPSE OF THE SUN

(1) The moon must be new.

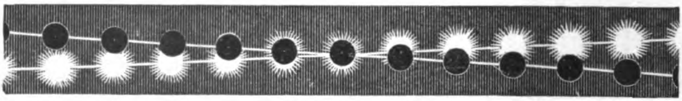
(2) She must be at or near a node, as shown in the next illustration.

(3) When her distance from the earth is less than the length of her shadow, the eclipse will be total or partial.

(4) When her distance is greater than the length of her shadow, the eclipse will be annular or partial.

(5) There can be no eclipse at those places where the sun himself is invisible, that is, where it is night.

(6) An eclipse is not visible over the whole illumined side of the earth. As the moon's diameter is less than that of the earth, her cone of shadow is too small to enshroud our entire globe, and the region in which it is total never exceeds 170 miles in breadth. As, however, the earth is constantly rotating on its axis during the duration of an eclipse, the shadow may travel over a large surface, several thousand miles in length.



SOLAR ECLIPTIC LIMIT (18° EACH WAY FROM THE NODE)

(7) If the moon's shadow falls upon the earth when she is nearing her ascending node, it will sweep across the south polar regions; if when nearing her descending node, it will graze the earth near the north pole. In general, the nearer a node a conjunction occurs, the nearer the equatorial regions the shadow will strike.

(8) At the equator, the longest possible duration of a total solar eclipse is about eight minutes; of an annular, twelve minutes. One reason of the greater length of the latter is that then the moon is in apogee, where she always moves slower than in perigee. The duration of total obscuration is greatest when the moon is in perigee and the earth in aphelion; for then the apparent size of the moon is greatest, and that of the sun is least.

(9) There cannot be more than five nor less than two solar eclipses a year. A total or an annular eclipse, in its recurrence at any place, is exceedingly rare. Since A.D. 1140 there has been (according to Halley) only one total eclipse visible at London (in 1715).

(10) A solar eclipse begins on the western limb or edge of the sun, and passes off on the eastern.

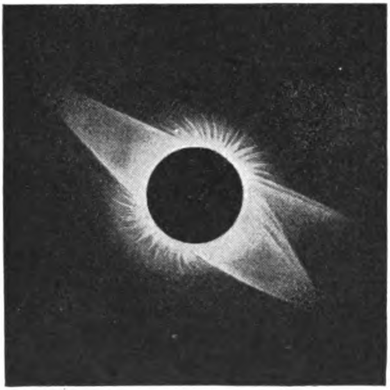
(11) The disk of the sun is divided into twelve digits, and the amount of the eclipse is estimated by the number of digits which the moon covers. Thus an eclipse of six digits is one in which half the diameter of the disk is concealed.

Following are the total eclipses of the sun visible in the United States for half a century : —

1869, August 7,	Iowa to North Carolina.
1878, July 29,	Wyoming to Texas.
1880, January 11,	California.
1889, January 1,	California and Nevada.
1900, May 28,	New Orleans to Norfolk.
1918, June 8,	Vancouver to Georgia.

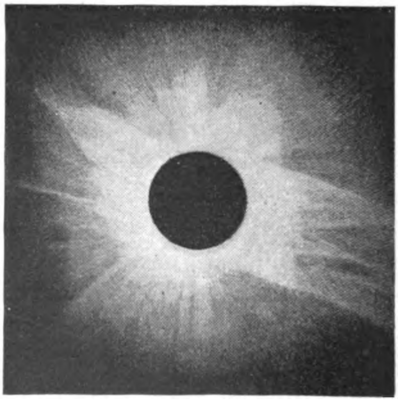
On May 18, 1901, a total eclipse of very long duration, exceeding six minutes, will be visible in Sumatra ; and on June 20, 1955, the longest eclipse on record, nearly eight minutes, and total in Luzon, at or very near Manila.

CURIOUS PHENOMENA attend a total eclipse. Around the sun is always seen a beautiful corona, or halo of light, somewhat resembling that which painters give to the head of the Virgin Mary. When the spots on the sun are most numerous, as in 1882 and 1893, the corona is very brilliant, and pretty evenly developed all around the sun ; but when the spots are fewest, as in 1878 and 1889, the polar corona is but feebly developed, while the equatorial corona extends in broad bands outward from the sun, many millions of miles in length. Steady flames of a rose-red color appear at irregular intervals around the disk of the moon. When only the slenderest crescent of the sun is visible, it seems to resolve itself into bright spots interspersed with dark spaces, having the appearance of a string of glittering beads (Baily's Beads).



Corona of 1878

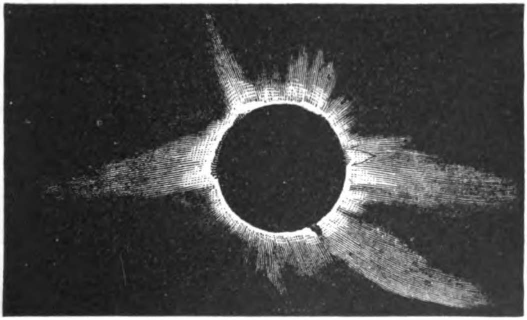
The attendant circumstances of a total eclipse are of a peculiarly impressive character. The darkness is so dense that a few of the brighter stars and planets are seen, birds cease their songs and fly to their nests, flowers close, and the face of nature assumes an unearthly, cadaverous hue, while a sudden fall of temperature causes the air to feel damp, and the grass to be wet as if from excessive dew. Orange, yellow, and copper tints give objects a strange



Corona of 1889

appearance. 'Men look at each other, and behold, as it were, corpses.'

The ancients regarded a total eclipse with feelings of indescribable terror, as an indication of the anger of an offended deity, or the presage of some impending calamity.[1] Even now, when the causes are fully under-

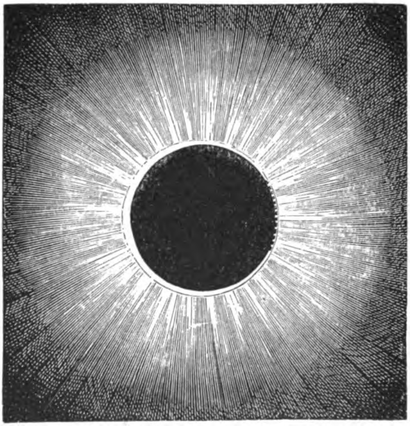


CORONA OF 1896

[1] William of Malmesbury thus connects the eclipse of August 2, 1133, with Henry I, who left England on that day, never to return alive: 'The elements manifested their sorrows at this great man's last departure. For the sun on that day, at the 6th hour, shrouded his glorious face, as the poets say, in hideous darkness, agitating the hearts of men by an eclipse: and on the 6th day of the week, early in the morning, there was so great an earthquake that the ground appeared suddenly to sink down; an horrid noise being first heard beneath the surface.'

The same writer speaking of the total eclipse of March 20, 1140, says: 'During this year, in Lent, on the 13th of the kalends of April, at the 9th hour of the 4th day of the week, there was an eclipse, throughout England, as I have heard. With us, indeed, and with all our neighbours, the obscuration of the Sun also was so remarkable, that persons sitting at table, as it then happened almost everywhere, for it was Lent, at first feared that Chaos was come again: afterwards learning the cause, they went out and beheld the stars around the Sun. It was thought and said by many, not untruly, that the king (Stephen) would not continue a year in the government.'

Columbus made use of an approaching eclipse of the moon, which took place March 1, 1504, to relieve his fleet, then in great distress from want of stood, and the time of the eclipse can be predicted accurately to the nearest second, the change from broad daylight to almost instantaneous gloom is overwhelming, and inspires with awe even the most careless observer. (See note, page 320.)



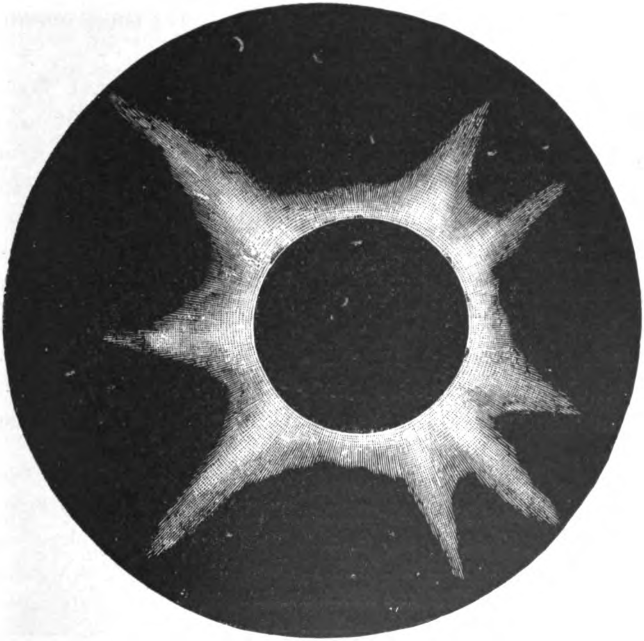
ANNULAR ECLIPSE, SHOWING BAILY'S BEADS

The Saros.—The nodes of the moon's orbit are constantly moving backward on the ecliptic, toward the west. They complete a revolution around the ecliptic in about $18\frac{1}{2}$ years. Now the moon makes 223 synodic revolutions in 18 years and 10 days; and

supplies. As a punishment to the islanders of Jamaica, who refused to assist him, he threatened to deprive them of the light of the moon. At first they were indifferent to his threats, but 'when the eclipse actually commenced, the barbarians vied with each other in the production of the necessary supplies for the Spanish fleet.'

Among the Hindus a singular custom is said to exist. When, during a solar eclipse, the black disk of our satellite begins slowly to advance over the sun, the natives believe that some terrific monster is gradually devouring it. Thereupon they beat gongs, and rend the air with screams of terror and shouts of vengeance. For a time their frantic efforts seem futile and the eclipse still progresses. At length, however, the increasing uproar reaches the voracious monster; he appears to pause, and then, like a fish rejecting a nearly swallowed bait, gradually disgorges the fiery mouthful. When the sun is quite clear of the great dragon's mouth, a shout of joy is raised, and the poor natives disperse, delighted to think that they have so successfully relieved their deity from his impending peril.

the sun makes 19 revolutions with regard to the lunar node in about the same time. Hence, after the lapse of that period, sun, moon, and nodes will be in nearly the same relative position as at the beginning. If, then, we reckon 18 years and 10 days from any eclipse, we shall find the time of its repetition.



Corona of 1871

This period was discovered, it is said, by the Chaldeans. By this means the ancients were enabled to predict eclipses, but it is too inaccurate for the exact purposes of modern astronomers.

Metonic Cycle.—The Metonic Cycle (sometimes confounded with the Saros) was not used for foretelling eclipses, but for ascertaining the *age of the moon* at a given period. It consists of 19 tropical years,[1] during which time there are 235 new moons; so that, at the end of this period, the new moons will recur at seasons of the year corresponding to those of the preceding cycle. Therefore, by registering the exact days of any cycle at which the new and full moons occur, such a calendar shows on what days these events will happen in succeeding cycles.

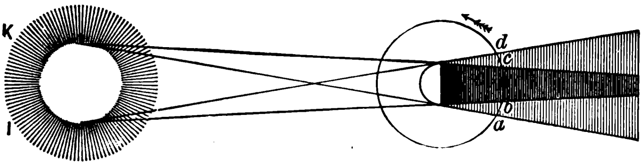
Since the appointment of games, feasts, and fasts has been made very extensively, both in ancient and modern times, according to new or full moons, such a calendar becomes very convenient for finding the day on which the required new or full moon takes place. Thus, if a festival were decreed to be held in any given year on the day of the first full moon after the vernal equinox: find what year it is of the Metonic Cycle, then refer to the corresponding year of any preceding cycle, and the day will be the same. The *Golden Number*, a term still used in our almanacs, denotes the year of the Metonic Cycle.

For 1898 the Golden Number is 18
For 1899 the Golden Number is 19
For 1900 the Golden Number is 1
For 1901 the Golden Number is 2
For 1919 the Golden Number is 1

An Eclipse of the Moon is caused by the passing of the moon into the shadow of the earth, and hence it can take place only at full moon — *opposition*. As the moon's orbit is inclined to the ecliptic, her path is

[1] A tropical year is the interval between two successive returns of the sun to the vernal equinox.

partly north and partly south of the earth's shadow; thus an eclipse of the moon can take place only at or near one of the nodes. In the diagram below the earth's *umbra* is represented by the dark space at the right of the earth, and included between the lines KC and Ib; outside of this is the *penumbra*, where the earth cuts off the light of only a portion of the sun. The moon, going round our globe in the direction of the arrow, enters the *penumbra* of the earth at *a*,—this is termed her *first contact with the penumbra;* next she encounters the dark shadow of the earth at *b*,—this is called the *first contact with the umbra;* she then emerges from the umbra at *c*,—*second contact with the umbra;* finally, she touches the outer edge of the penumbra at *d*,—*the second contact with the penumbra.* Since the earth is so much larger than the moon, a lunar eclipse can never be *annular;* as, however, the eclipse may occur a little above or below the node, the moon may only partly enter the earth's shadow, either on its upper or lower limb. From the first to the last contact with the penumbra, five hours and a half may elapse.



TOTAL ECLIPSE OF THE MOON

Total eclipses of the moon are rarer events than those of the sun, since the lunar ecliptic limit is only about 12°; yet they are more frequently seen at any given place (1) because every lunar eclipse is visible over the entire unillumined hemisphere of the earth, and also (2) because by the diurnal rotation during the long duration of the eclipse, large additional areas may be brought within sight of it. So it will happen that while the inhabitants of one district witness the eclipse throughout its continuance, those of other regions see merely its beginning, and others only its termination.

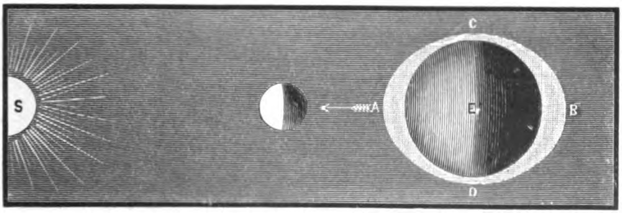
Usually the moon does not completely disappear even in total eclipses. The cause of this probably lies in the refraction of the solar rays in traversing the lower strata of the earth's atmosphere; the blue tints are absorbed, and our moon reflects only the copper hues of sunset. The amount of refraction and the color depend upon the state of the air at the time. Lunar eclipses are useful in investigations of the absorption and radiation of solar heat by the moon's surface. Also, if the eclipse is total, the times of disappearance and reappearance of small stars as the moon passes in front of them (called *occultations*) can be observed with great precision; and such observations assist the astronomer in correcting our knowledge of the figure, size, and distance of the moon.

THE TIDES

Description.—Twice a day, at intervals of about twelve hours and twenty-five minutes, the water begins to set in from the ocean, beating the pebbles and the foot of the rocky shore, often dashing its spray high in air. For about six hours it climbs far up on the beach, flooding the low lands and transforming creeks into deep rivers. The instant of *high water* or *flood* *tide* being reached, the water begins to descend, and the *ebb tide* succeeds the *flow*. The water, however, falls somewhat slower than it rises.

The Tides are caused by a great wave which, raised because of the moon's attraction, follows her in her course around the earth.[1] The sun, also, aids somewhat in producing this effect; but as the moon is 400 times nearer the earth, her influence is far greater.[2]

As the waters are in part free to yield to the attraction of the moon, she draws them away from C and D and they become heaped up at A. The earth, being nearer the moon than the waters on the opposite side,



SPRING TIDES

[1] Sir Robert Ball, formerly Royal Astronomer of Ireland, has shown that once the moon was nearer the earth than now; the day and the month were equal, each three hours long. At 40,000 miles distance, the moon was a greater tide producer by 216 times. As the moon receded from the earth, both revolved more slowly. At the present time, 27 earth rotations equal one moon rotation. This has remained, and will remain, sensibly true, for thousands of years. But the friction of the tides will in the far future lengthen the day to equal 57 of our present days,—a condition that will then last for ages.

[2] The whole attraction of the moon is only $\frac{1}{150}$ that of the sun; yet her influence in producing the tides and precession is greater, because that depends not upon the *entire* attraction either exerts, but upon the *difference* between their attractions upon the earth's center and upon the earth's nearest surface. For the moon, on account of her nearness, the relation of the distance of these points is treble that in the case of the sun, and hence her greater effect.

is more strongly attracted, and so being drawn away from them, they are left heaped up at B. As the result, high water is produced at A by the water being pulled from the earth, and at B by the earth being pulled from the water.

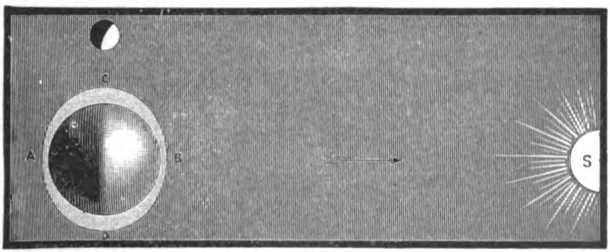
The influence of the moon requires a little time to produce its full effect; hence high water does not occur at any place when the moon is on the meridian, but a few hours after. As the moon rises about fifty minutes later each day, there is a corresponding difference in the time of high water. While, however, the lunar tide-wave thus lags about fifty minutes every day, the solar tide occurs uniformly at the same time. They therefore steadily separate from each other. At one time, they coincide, and high water is the sum of the lunar and solar tides; at other times, low water of the solar tide and high water of the lunar tide occur simultaneously, and high water is then the difference between the lunar and solar tides.[1]

CAUSES THAT MODIFY THE TIDES. — At new and at full moon (the *syzygies*) the sun acts with the moon (figure on page 153) in elevating the waters; this produces the highest, or *spring tide* as in the last figure. In quadrature (next figure), the sun tends to diminish the height of the water: this is called *neap tide*. When the moon is in perigee, her attraction is stronger; hence the flood tide is higher, and the ebb tide is lower than at other times. A similar law applies to the sun. The height of the tide also varies with the declination of the sun and the moon, — the highest or equinoctial

[1] We should bear in mind that, in accordance with the laws of wave motion, the tide in the open sea does not consist of a progressive movement of the water itself, but only of the form of the wave.

tides taking place at the equinoxes, if, when the sun is over the equator, the moon also happens to be very near it: the lowest occur at the solstices. The force and the direction of the winds, the shape of the coast, and the depth of the sea greatly complicate the explanation of local tides.

HEIGHT OF THE TIDE AT DIFFERENT PLACES.—In the open sea, the tide is hardly noticeable, the water sometimes rising not higher than a foot; but where the wave breaks on the shore, or is forced up into bays or narrow channels, it is very conspicuous. The difference between ebb and flood neap tide at New York is over three feet, and that of spring tide over five feet; while at Boston it is nearly double this amount. A headland jutting out into the ocean will diminish the tide; as, for instance, off Cape Florida, where the average height is only one and a half feet. The tide wave ascends the Hudson River at about the same speed as the steamboats; at Albany it reaches a height of a little over two feet. A deep bay opening up into the land like a funnel will converge the wave, as at the head of the Bay of Fundy, where it sweeps up with great rapidity, in places in a series of *bores*, and reaches an



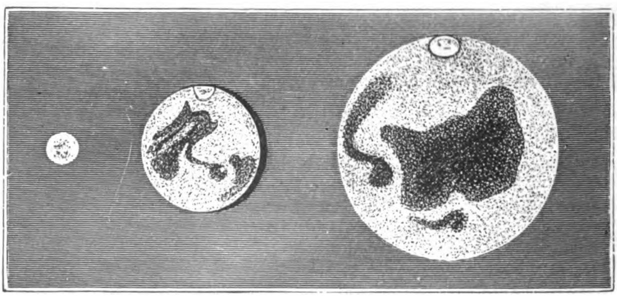
NEAP TIDES

extreme height of about sixty feet. The tide sets up against the current of rivers, and often entirely changes their character; for example, the Avon at Bristol is a shallow ditch, but at flood tide it becomes a deep channel, navigable by the largest ships.

IV. MARS

The god of war. Sign, ♂, shield and spear

Description. — Passing outward in our survey of the solar system, we next meet with Mars. This is the first of the *superior* planets, and the one most like the earth. It appears to the naked eye as a bright red star, rarely scintillating unless near the horizon, and shining with a steady light, which distinguishes



Relative Size of Mars at Greatest, Mean, and Least Distances

it from the fixed stars. At conjunction its apparent diameter is only about 4″; but once in about two years it comes into opposition with the sun, when its diameter may increase to 30″. At intervals of nearly fifteen years, this occurs when the planet is very near perihelion and the earth very near aphelion. Mars then shines with a brilliancy rivaling that of Jupiter himself. Its ruddy appearance has led to its being celebrated among all nations. The Jews called it 'blazing,' and it bore in other languages a similar name. The next very favorable opposition will occur in 1907.

Motion in Space. — Mars revolves around the sun at a mean distance of about 141,500,000 miles. Its orbit is sufficiently flattened to bring it at perihelion 26,000,000 miles nearer that luminary than when in aphelion. Its motion varies in different portions of its orbit, but the average velocity is about fifteen miles a second. The Martian day is 41 minutes longer than ours, and the year contains about 668 Martian days, equal to 687 terrestrial days (nearly two years).

Distance from Earth. — When in opposition, the distance of Mars is (like that of all the superior planets) the difference between the distance of the planet and that of the earth from the sun; at conjunction it is the sum of these distances. If the orbits were circular, and lying in the same plane, these distances would be the same at every revolution. The elliptical figure of the orbit, however, occasions much variation. Thus, if Mars, at opposition, be very near perihelion while the earth is very near aphelion, it is distant from us only about 34,000,000 miles.

Dimensions. — The diameter of Mars is nearly 4200 miles. Its volume is about $\frac{1}{7}$ and its density $\frac{4}{5}$ that of the earth. A stone let fall on its surface would fall six feet the first second. It is somewhat flattened at the poles, and bulges at the equator, like our globe. The ellipticity of the disk is $\frac{1}{200}$.

Seasons. — The light and heat of the sun at Mars are less than half that which we enjoy. Its axis is inclined about 27° from a perpendicular to its orbit, therefore its zones and seasons do not differ materially from our own. Since, however, its year is equal to nearly two of our years, the seasons are lengthened in proportion.

There must be a considerable difference between the temperatures of its northern and southern hemispheres, as the former has its summer when 26,000,000 miles further from the sun than the latter; an increased length of 76 days may, however, be sufficient compensation. It has an atmosphere somewhat similar to our own, in which clouds are sometimes seen.

Mars has two moons, discovered in August, 1877, by Professor Hall of the Naval Observatory, Washington. The outer one revolves about the planet in 30 hours 18 minutes, at a distance from its surface of about 12,500 miles; and the inner one in 7 hours 39 minutes, at a distance of 3760 miles (less than that of remote cities on our own continent). The inner moon moves so much faster than the rotation of Mars that to an inhabitant of that planet the moon would seem to rise in the west and set in the east, passing through all the phases of our moon during a single night. The moons have been named Deimos and Phobos, or Dread and Terror — the sons of Mars. The diameter of these little globes is probably less than 15 miles. Our earth and its moon present in the Martian sky a beautiful pair of planets, constantly remaining in close proximity to each other, and exhibiting all the phases which Mercury and Venus present to us.

Telescopic Features. — Under the telescope, Mars exhibits gibbous phases. Its surface is covered with reddish spots, which are believed to be continents.

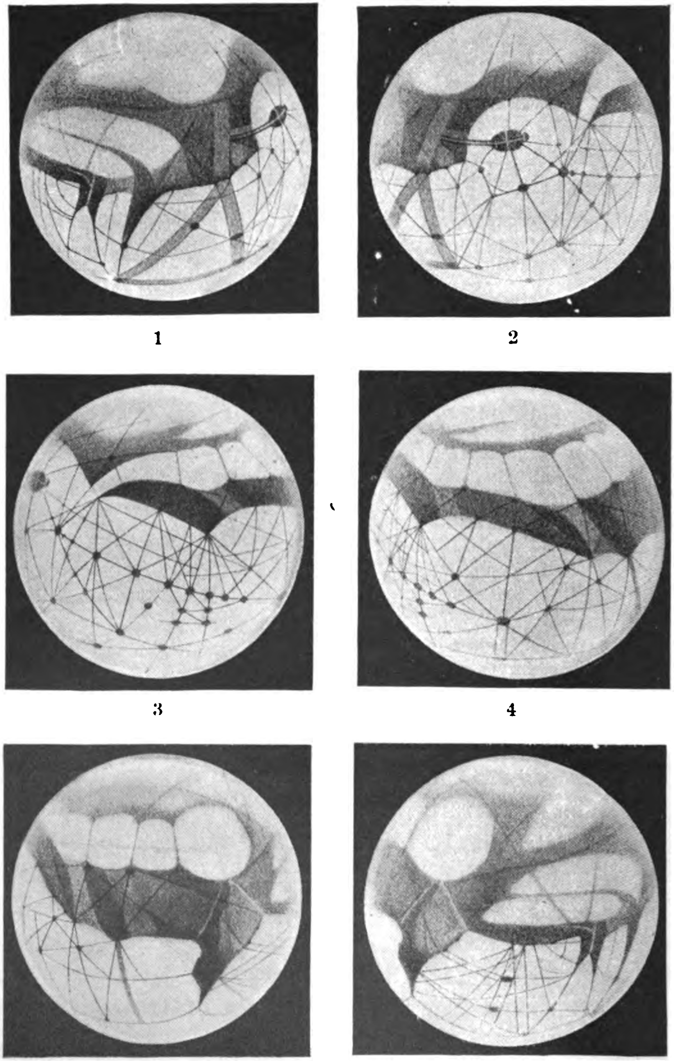
Other portions, of a dark green or bluish tint, are considered bodies of water. If this view is accepted, then the proportion of land to water on the earth is reversed in Mars. '*Here* every continent is an island; *there* every sea is a lake: but these, like our own continents, are chiefly confined to one hemisphere. So that the habitable area of the two globes may not differ so much as the size of the planets.'

EARLY TELESCOPIC VIEW OF MARS

The ruddy color is thought to be due to an ochery tinge in the soil, combined with peculiarities of the atmosphere and clouds. There are constant changes going on in the brightness of certain parts of the disk, owing possibly to the variation of the clouds of vapor in the atmosphere. No mountains have yet been discovered, and the elevations above the general level are probably slight.

In the vicinity of the poles are brilliant white spots, which are generally considered to be masses of snow. The 'snow zones' apparently melt and recede with the return of summer in each hemisphere, and increase on the approach of winter. In Martian southern midsummer of 1894 the south polar cap entirely disappeared, for the first time ever observed. We can thus from the earth watch the changes of the seasons on the surface of a neighboring planet.

So carefully has the surface of this planet been studied, that a globe of Mars has been prepared which



1 2

3 4

5 6

MAP OF THE GLOBE OF MARS ACCORDING TO RECENT OBSERVERS is in some respects more perfect than any globe of the earth yet prepared. The different light-colored and darkish areas have been named after distinguished astronomers. Schiaparelli, the Italian astronomer, was the first to discover a number of singular darkish, narrow lines, now known as 'canals.' They seem to radiate from the darkish areas, and if artificial are probably due to vegetation, as they are not seen in the planet's winter, gradually become visible with the approach of spring, and are best seen in each hemisphere when it is enjoying the full tide of summer. Then they are often seen double, a phenomenon called gemination, and not yet satisfactorily accounted for. At the intersections of the canals are circular spots formerly called 'lakes,' but now 'oases.' As the season advances, they too are often seen double. Lowell has added many new canals and oases.

V. THE SMALL PLANETS

Discovery. — Beyond Mars there is a wide interval not known to be filled until the beginning of the nineteenth century. The bold, imaginative Kepler conjectured that there was a planet in this space. This supposition was corroborated by the discovery of what has since been known as

Bode's Law. — Take the numbers 0, 3, 6, 12, 24, 48, 96, 192, each of which, after the second, is double the preceding one. If we add 4 to each of these numbers, we form a new series : —

4, 7, 10, 16, 28, 52, 100, 196.

At the time this law was discovered, these numbers represented very nearly the proportionate distances from the sun of the planets then known, taking the earth's distance as 10, except that there was a blank opposite 28. This naturally led to inquiry, and a systematic effort to solve the mystery.

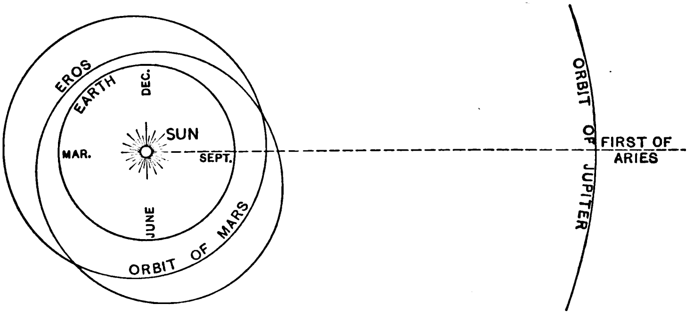
On the 1st of January, 1801, — the first day of the nineteenth century, — Piazzi discovered the small planet Ceres, at almost the exact distance necessary to fill the gap in Bode's series. The announcement of other new planets soon followed, until now there are known about 450, with a probability of hundreds more being found. Indeed, Leverrier has calculated that there may be perhaps 150,000 in all.

Description. — For the most part these minor worlds, or 'pocket planets,' as Herschel styled them, are diminutive indeed; but Ceres and Vesta shine at times as stars of the 6th magnitude, and can then be seen with the naked eye. Ceres is the largest, being nearly 500 miles in diameter; Pallas is 300, and Vesta nearly 250 miles in diameter. An average diameter of about 25 miles expresses the dimensions of the small planets so far discovered. Several of these little worlds have been found but to be lost again. The mere labor of tracing the movements of so many tiny globes is so tedious and exhausting that no nation except Germany performs any appreciable part of it. Those recently discovered are so small that it is difficult to decide which is the smallest. A good bicyclist could easily make the tour of one in a day; a prairie farmer would need to preempt a whole such world for a cornfield. 'A man placed on one of these tiny globes could leap sixty feet high, and, in his descent, would sustain no greater shock than he does on the earth from jumping or leaping a yard.' These planets revolve around the sun in regular orbits, comprising a zone about 260,000,000 miles in width. Their paths are variously inclined to the ecliptic; the inclination of Massalia's orbit (20) is only 41′, while that of Pallas's (2) rises to nearly 35°.

Origin. — A conjecture now abandoned concerning the origin of these bodies was that they are the fragments of a large planet shivered to pieces in remote antiquity by some terrible catastrophe. 'One fact seems above all others to confirm the idea of an intimate relation between these planets. It is this: if their orbits consisted of solid rings, they would be found so entangled that it would be possible, by taking up any one at random, to lift all the rest.' The more probable view is given under the 'Nebular Hypothesis' (page 267).

NAMES AND SIGNS. — Ceres, the first discovered, received a symbol like a sickle, as the goddess Ceres was supposed to preside over harvests. Pallas, the second, named from the goddess of wisdom and scientific warfare, obtained a sign like the head of a spear. Of late, simple parentheses inclosing the number in the order of discovery have been adopted; thus (1) represents Ceres, (331) is the sign of Etheridgea, and so on.

THE NEAREST PLANET. — This was discovered by the aid of photography, by Witt of Berlin, in August, 1898. It is No. 433 of the group, and he has named it Eros, from the god of love. It is perhaps the most important of all the small planets, because its mean distance from the sun (135,000,000 miles) is even less than that of Mars (141,500,000); and the orbit of Eros is so eccentric that when it happens to be at perihelion and in opposition about the same time, its distance from the earth is only about 13,000,000 miles. This occurred last in 1893–1894, and will happen again in 1924, when it will almost be visible to the naked eye. Probably it would take 100 planets the size of Eros placed side by



ORBITS OF EROS, MARS, AND EARTH

side to reach across the moon. As the cut shows, the most favorable oppositions of Eros can take place only in the months of January and February.

VI. JUPITER

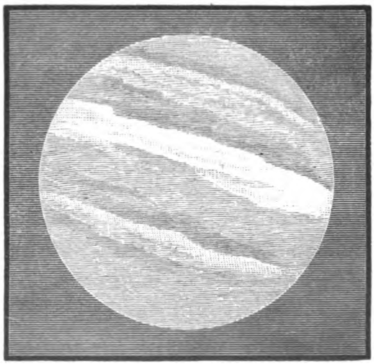
The king of the gods. Sign ♃, a hieroglyphic representation of an eagle, 'the bird of Jove'

Description. — From the smallest members of the planetary system we now pass to the largest planet — the colossal Jupiter. Its peculiar splendor and brilliancy distinguish it from the fixed stars, and vie even with the luster of Venus. It is one of the five planets discovered in primitive ages.[1]

Motion in Space. — Jupiter revolves round the sun at a mean distance of about 483,000,000 miles; at perihelion the distance is about 23,500,000 miles less than

[1] In those early times, Jupiter was supposed to be the cause of storm and tempest. Pliny thought that lightning owed its origin to this planet. A mediæval almanac of 1368, foretelling the harmless condition of Jupiter for a certain month, says, 'Jubit es hote and moyste and does weel til al thynges and noyes nothing.'

this, and at aphelion the same amount more than the mean distance. His movement among the fixed stars is slow and majestic, comporting well with his vast dimensions and the dignity conferred by five attendant moons. He advances through the zodiac at the rate of one sign yearly; so that if we locate the planet now, a year hence we shall find it equally advanced eastward in the next sign. Yet slowly as he seems to travel through the heavens, he is bowling along through space at the enormous speed of nearly 500 miles a minute. The Jovian day is equal to only about ten of our hours, while the year is lengthened to about twelve of our years, comprising nearly 10,500 of his days.



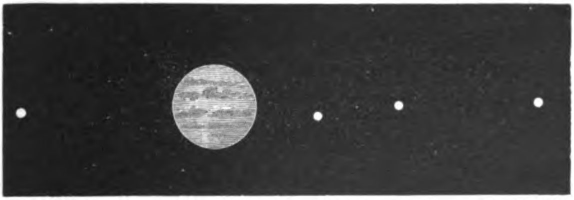
TELESCOPIC VIEW OF JUPITER

Distance from Earth. — Once in thirteen months Jupiter is in *opposition*, and his distance from the earth is measured by the difference of the distances of the two bodies from the sun. At the expiration of half this time he is in *conjunction*, and his distance from us is measured by the sum of these distances.

Dimensions. — The diameter of this planet is nearly 90,000 miles. Its volume is 1400 times that of the earth, and much exceeds that of all the other planets combined. If brought to the distance of the moon, this immense globe would fill more than 1500 times the apparent area of the full moon's disk. Its density is only one quarter that of the earth ; moreover, its rapid rotation upon its axis, whereby a particle on the equator revolves with a velocity of 473 miles a minute against the earth's 17 miles a minute, must produce a powerful centrifugal force which materially diminishes the weight of objects near its equator. Consequently a stone, if let fall on Jupiter's equator, would pass through only about 42 feet the first second. As a result of this rapid rotation, the planet is one of the most flattened of any in the solar system, the equatorial diameter exceeding the polar by 5000 miles.

Seasons. — As the axis of Jupiter is but slightly inclined from a perpendicular to the plane of its orbit, there is little difference in the length of his days and nights, which are each of about five hours' duration. At the exact poles, the sun is visible for nearly six years, and then remains set for the same length of time. The seasons are but slightly varied. Summer reigns near the equator, while the temperate regions enjoy perpetual spring. The light and heat of the sun are only $\frac{1}{27}$ of what we receive ; yet peculiarities of atmosphere may compensate for this difference. The evening sky on Jupiter must be magnificent ; besides the glittering stars which adorn our heavens, five moons, waxing and waning, each with its diverse phase, illuminate his night. All the starry exhibition sweeps through the sky in five hours.

Telescopic Features. — JUPITER'S MOONS. — Through the telescope Jupiter presents a beautiful Copernican system in miniature. Four large moons, and one very small one discovered in 1892, accompany him in his twelve-yearly revolutions. From hour to hour the positions of the large ones may be seen to vary, even in a small telescope; and they seem to oscillate from one side of the planet to the other. At one time, there will be two on each side, and again three on one side, while the remaining moon is left alone. They are also frequently found to disappear, one, two, or even three at a time, and, more rarely, all four at once. There are well-authenticated instances on record of their having been seen by the naked eye. Among others, the following singular case is mentioned. Wrangel, the celebrated Russian traveler, states that, when in Siberia, he once met a hunter, who said, pointing to Jupiter, 'I have just seen that star swallow a small one and



Jupiter and Satellites

then vomit it up again.' But it required the Lick telescope of 36 inches diameter and Professor Barnard's keen eye to discover the fifth moon, and it has never yet been seen with any glass of less than half that diameter.

The principal moons are called by the ordinal numbers, reckoning outward from the planet. With an ordinary glass, there is nothing to distinguish them from small stars. The IIIrd, being the largest and brightest, will generally be identified the most easily. The Ist satellite would appear to an inhabitant of the planet a little larger than our moon to us; the IInd and IIIrd, about half as large.

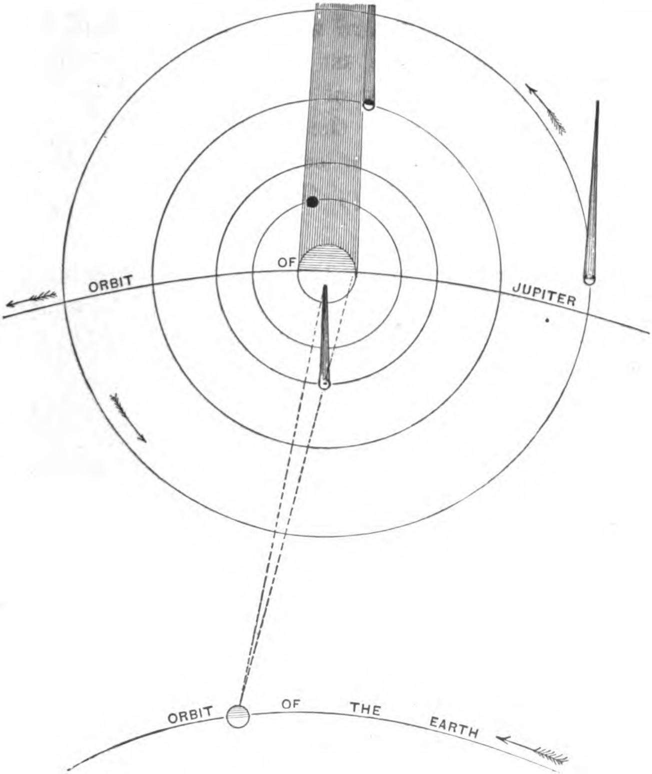
SATELLITES OF JUPITER

Number and Name.	Mean distance from Jupiter.	Diameter.	Density: Water as 1.	Sidereal period.		
				D.	H.	M.
V. No name........	112,000	100 m.	?	0	11	57
I. Io...............	261,000	2,500 "	1.1	1	18	28
II. Europa.........	415,000	2,100 "	2.1	3	13	14
III. Ganymede......	664,000	3,600 "	1.9	7	3	43
IV. Callisto.........	1,167,000	3,000 "	1.5	16	16	32

The moons are not only distinguished by their various dimensions, but also by the variety of their color. The Ist and IInd have a bluish tint, the IIIrd a yellow, and the IVth a reddish shade. The space occupied by this miniature system is about two and a half million miles in diameter.

Markings and Axial Rotation.— A few astronomers with keen eyes, and telescopes located at mountain elevation, have published observations of faint narrow markings on some of the major satellites of Jupiter. From their periodic changes they find that satellite I revolves once on its axis in 12 h. 24 m.; and that satellites III and IV turn round, just as our moon does, once on their axes while traveling once round the planet in their orbits.

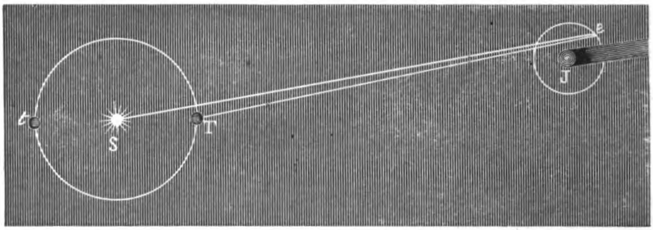
ECLIPSES OF THE MOONS.—Jupiter, like all celestial bodies not self-luminous, casts into space a cone of shade. The Ist, IInd, and IIIrd satellites revolve in orbits but very little inclined to the plane of the planet's orbit. During each revolution they pass between the sun and Jupiter, producing a solar eclipse; and also, by passing through the shadow of the planet itself, cause to themselves an eclipse of the sun, and to Jupiter an eclipse of a moon. The ivth moon passes through a path more inclined, and therefore its eclipses are less frequent; instead of being



ILLUSTRATING THE ECLIPSES, TRANSITS, AND OCCULTATIONS OF JUPITER'S MOONS

fully eclipsed, it sometimes just grazes the shadow. In alternate periods of about three years it suffers eclipse at every revolution and is not eclipsed at all. Through a telescope we can distinctly watch the disappearance, or *immersion*, of the satellites in the planet's shadow, their reappearance, or *emersion*, and also the *transits* of their shadows as round black dots moving across the disk of Jupiter.

In the preceding figure we see various positions of the major moons: the Ist is eclipsed; the IInd is passing across the disk of the planet, on which its shadow is also thrown; the IIIrd is just behind the planet, and so *occulted* or concealed, while it has not yet entered the shadow; the IVth is in view from the earth.



LIGHT CONSUMES TIME IN TRAVELING THROUGH SPACE

These satellites revolve with great rapidity, as is necessary in order to overcome the superior attraction of the planet and prevent their being drawn to its surface. The Ist goes through all its phases in $1\frac{3}{4}$ days; the IVth, in rather more than a fortnight. A spectator on Jupiter, who could move about at will, might witness, during the Jovian year, 4500 eclipses of the moon (moons), and about the same number of the sun.

Velocity of Light. — By an attentive examination of the eclipses of Jupiter's moons, Römer (a Danish astronomer) in 1617 discovered that the motion of light is not instantaneous, as was then believed. He noticed that the observed times of the eclipses were sometimes earlier and sometimes later than the calculated times, according as Jupiter was nearest the earth or furthest from it. In the opposite figure, let J represent Jupiter; *e*, one of the moons; S, the sun; and T and *t*, different positions of the earth in its orbit. When the earth is at T, the eclipse occurs 16 minutes and 36 seconds earlier than at *t*. That interval of time is required for the light to travel 186,000,000 miles across the earth's orbit, its velocity being about 186,300 miles a second.

JUPITER'S BELTS are dusky streaks of varying breadth and number, usually lying parallel to the planet's equator. A brighter, often rose-colored space marks the equatorial regions. The belts are not permanent, but change sometimes in the course of a few hours. Occasionally only two or three broad belts are visible; at other times, a dozen narrow ones appear. Often spots are seen that are more lasting than the dark stripes. In 1878, a 'Great Red Spot' appeared in the southern hemisphere of Jupiter. Its length was estimated at 8000 miles, and its breadth at 2000 miles. This curious phenomenon is still visible, but much diminished in brightness. Some astronomers have suggested that the seeming permanence of the 'Great Red Spot' indicates that it is a rift through the dense clouds of Jupiter's outer atmosphere, through which we begin to see the solidifying surface of the true planet; but this theory has been disproved by a slow drift of even the great spot itself.

It is supposed that the planet is enveloped in dense clouds, through which light cannot penetrate, and that the globe itself is still heated to a high degree.[1] The parallel appearance of the belts is doubtless due to strong equatorial currents, analogous to our trade winds.

VII. SATURN

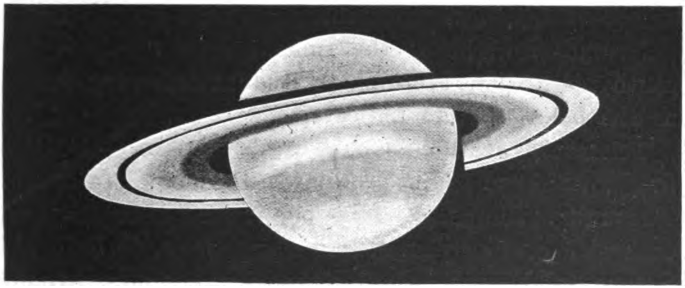
The god of time. Sign, ♄, an ancient scythe

Description. — We now reach, in our outward journey from the sun, the most remote world known to the ancients. It shines with a steady, pale yellow light, which distinguishes it from the fixed stars. Its orbit is so vast that its movement among the constellations may be easily traced through one's lifetime. It requires two and a half years to pass through a single sign of the zodiac; hence, when once known, it may be readily found again. The earth leaves it at conjunction, makes a yearly revolution about the sun, comes to its starting point, and overtakes Saturn in about thirteen days thereafter.[2] Because of its slow, dreary pace, Saturn was chosen by the ancients as the symbol for lead. It is smaller than Jupiter, but more gorgeously attended. Besides a retinue of nine satellites, it is surrounded by a system of rings, some shining with a golden light, and others transparent, — a spectacle as wonderful as it is unique.

[1] Jupiter and Saturn being so large, they have cooled more slowly than the earth and Mars, and are yet only partly solidified. Mars and the earth are thought to typify the middle age; Saturn and Jupiter, the youth; and Uranus and Neptune, the infancy of planetary existence. In the case of Saturn and Jupiter, probably we never see the real planets, but only the outline of their atmospheres. If this theory be true, Jupiter and Saturn now represent the condition in which our earth existed ages ago, before a solid crust had been formed upon its surface.

[2] From this the year of Saturn may be determined. As 13 is to 378 days, so earth's year is to Saturn's year: — 30 years, nearly.

Motion in Space. — Saturn revolves about the sun at a mean distance of nearly 886,000,000 miles. The eccentricity of its orbit is a trifle more than that of Jupiter, so that while, at its perihelion, it comes 45,000,000 miles nearer than its mean distance, at aphelion it swings off as much beyond. We can form some conception of the size of its immense orbit when we remember that it is moving 22,000 miles an hour, and yet, from night to night, we can scarcely detect any change of place. The Saturnian year is equal to



SATURN, ACCORDING TO BARNARD

about thirty of ours, and comprises about 25,000 Saturnian days, each about $10\frac{1}{4}$ hours long.

The Distance from the Earth is found in the same manner as that of the other superior planets, being least in opposition and greatest in conjunction. According as the earth and Saturn occupy different portions of their orbits, the distances between them at different times may vary nearly 300,000,000 miles.

Dimensions. — The diameter of Saturn is about 73,000 miles. Its volume is 700 times that of the earth. Its density is about $\frac{2}{3}$ that of water, or a little more than that of Michigan pine. The Saturnian force of surface gravity is somewhat greater than the terrestrial, so that a stone would fall toward the surface of that immense globe about 18½ feet the first second.

Seasons.—The light and heat of the sun at Saturn are only $\frac{1}{100}$ that which we receive. The axis of Saturn is inclined from a perpendicular to the plane of its orbit about 27°. The seasons therefore are similar to those of the earth. Each of Saturn's seasons lasts more than seven of our years. There is an interval of fifteen years between the autumn and spring equinoxes, and between the summer and winter solstices. For fifteen years the sun shines on the north pole, and a night of the same length envelops the south pole. The atmosphere is doubtless very dense, as the belts seem to indicate.

Telescopic Features. — SATURN'S RINGS. — Galileo first noticed something peculiar in the shape of Saturn. Through his imperfect telescope it seemed to have on each side a small planet, like a supporter, to help old Saturn on his way. Galileo therefore announced to his friend Kepler the curious discovery that 'Saturn is threefold.' As the planet, however, approached an equinox, when the plane of his rings passed through the earth or sun, these attendants vanished. This was a great perplexity to the philosopher, and he never solved the mystery. When the rings were again seen, their real form had not yet become known: they were supposed to be a kind of *handle* attached to the planet on each side.

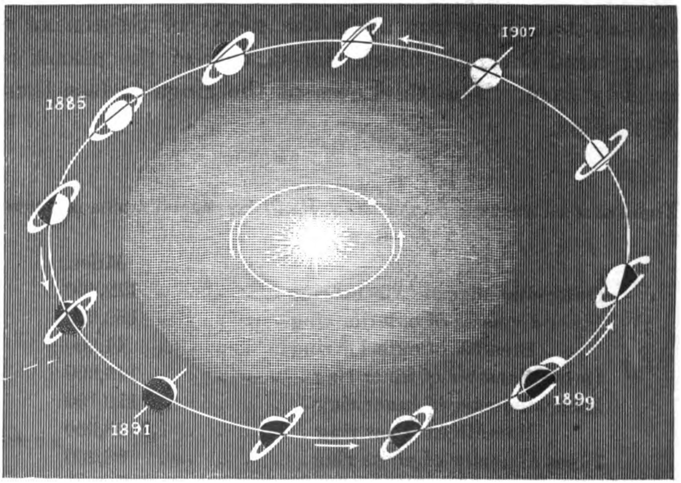
Description of the Rings.—The series consists of three rings of unequal breadth, surrounding the planet in the plane of its equator. The exterior ring is separated from the middle one by a distinct break, while the interior ring seems joined to the middle one. They differ in their brightness; the exterior ring is of a grayish tint; the middle one is the most brilliant, being more luminous than Saturn itself; the interior one is darker and has a purplish tinge. The two outer rings are known as the *bright* rings, and the inner one is called the crape, or *dusky* ring. The exterior and middle rings are both opaque, and cast on the planet a distinct shadow; while the interior one is so transparent that it appears upon the globe of Saturn as a dark band through which the surface of the planet is readily seen. The thickness of the rings is less than 100 miles.

DIMENSIONS OF THE SATURNIAN RING SYSTEM (ACCORDING TO BARNARD)

	Miles.
Outer diameter of exterior ring	172,600
Inner diameter of exterior ring	150,500
Breadth of exterior ring	11,000
Outer diameter of inner ring	146,000
Inner diameter of inner ring	110,100
Breadth of inner ring	18,000
Inner diameter of crape ring	88,200
Breadth of crape ring	11,000
Distance of interior ring from planet . . .	11,700
Breadth of ring system	42,200

Rotation.—The rings revolve around Saturn in the same direction as the planet rotates on its axis. Probably the globe of Saturn is not exactly at the center of the rings, but the displacement is very slight.

Phases of the Rings.—The plane of the rings is inclined about 28° to the ecliptic. In its revolution around the sun, the axis of Saturn remaining parallel to itself, the sun sometimes illumines the northern and sometimes the southern face of the rings. At Saturn's equinoxes, only the edge receives the light, and the rings are invisible to us, except with the most powerful telescopes, and then only as a broken line of light. The body of the planet constantly cuts off the sun's rays from a portion of the rings, and also serves to conceal from our view some of the luminous part. By



APPROXIMATE PHASES OF SATURN'S RINGS

a careful study of the cut, these various positions of the planet and rings, with the favorable times for observation, may be understood.

Composition of the Rings. — It is now known that the rings consist of a cloud of tiny satellites, — too small to be seen separately with the telescope, — revolving about the planet (see 'Nebular Hypothesis,' page 267). It is proved by mathematical analysis that the rings cannot be either solid or liquid, and the spectroscope has shown that the inner part of any given ring travels round the planet more swiftly than its outer edge. This state of things would be possible only with a ring composed of separate particles.

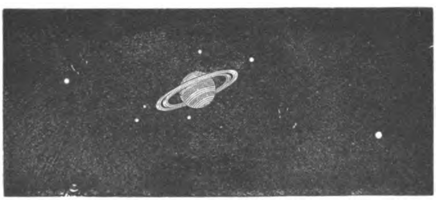
BELTS.—The surface of Saturn is traversed by faint dusky belts of a far less distinct and definite appearance than those upon Jupiter. The equatorial regions are more strongly marked than the other parts of the disk.

COMPOSITION OF THE PLANET. — It is quite probable that Saturn, like Jupiter, has no solid crust, but consists of molten matter surrounded by vapor that continually rises from the heated interior.

Satellites. — Saturn has nine satellites.

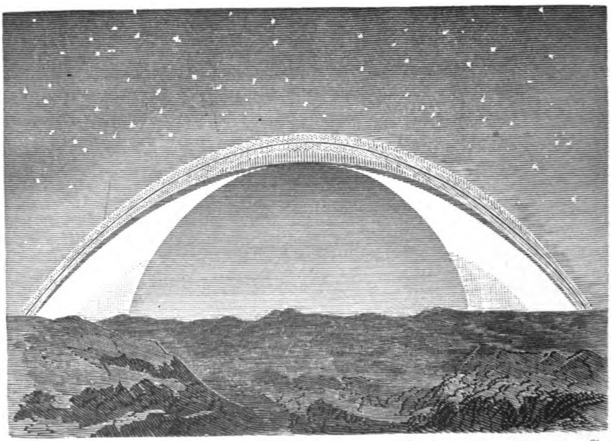
Number.	Names of Saturn's Satellites.	Distance from Saturn in miles.	Approximate diameter in miles.	Sidereal Period in days.
I.	Mimas	117,000	600	0.94
II.	Enceladus	157,000	800	1.37
III	Tethys	186,000	1,200	1.88
IV.	Dione	238,000	1,100	2.73
V.	Rhea	332,000	1,600	4.51
VI	Titan	771,000	2,700	15.94
VII.	Hyperion	934,000	500	21.29
VIII.	Japetus	2,225,000	2,000	79.33
IX	Phoebe	7,500,000	200	16 months.

Titan, the largest, is almost as large as Mercury, while Phoebe is so small that it was not discovered till the year 1899. Enceladus and Mimas are among the faintest of twinklers, and can be seen only with a powerful tele-



SATURN AND SATELLITES

scope. They were first detected by Herschel, 'threading like pearls the silver line of light' to which the ring, then seen edgewise, was reduced, — advancing off it at either end, returning, and then hiding themselves behind the planet. Hyperion also is extremely faint. The first four of Saturn's moons are nearer to the planet than our moon is to the earth, but Phoebe is more than thirty times as distant; so that the diameter of the Saturnian system is not less than 15,000,000 miles.



IDEAL LANDSCAPE ON SATURN, SUPPOSING A SOLID PLANETARY CRUST TO EXIST

Saturnian Scenery. — The magnificence of the scenery upon Saturn must surpass anything with which we are familiar. In the cut is given an ideal view of a landscape located upon the planet, at a latitude of about 28°, taken at midnight. The rings form an immense arch, which spans the sky and sheds a soft radiance around; while, to add to the strange beauty of the night, several moons in all their different phases — full, new, crescent, or gibbous — light up the starry vault.

VIII. URANUS

'Heaven,' the most ancient of the gods. Sign, ♅; H, the initial of Herschel, with a planet suspended from the cross bar

Description. — On the 13th of March, 1781, between 10 and 11 P.M., Sir William Herschel was examining with his great telescope some stars in the constellation Gemini. A small star attracting his attention, he observed it with a higher magnifying power, when, unlike the fixed stars, its disk widened. Watching it for several nights, he detected its motion in space; but mistaking its true character, he announced the discovery of a new comet. A few months' examination revealed the error, and the new body was admitted to be a member of the planetary system.[1]

Uranus may be seen in a dark sky without a telescope, by a person of strong eyesight, if he previously knows its exact position among the stars. Its faintness is due to its great distance from the earth. Were it as near as the sun, it would appear twice as large as Jupiter.

Motion in Space. — Uranus revolves about the sun at a mean distance of nearly 1,800,000,000 miles. Its year exceeds eighty-four of ours.

Dimensions. — Its diameter, according to Barnard, is nearly 35,000 miles. Its density is about equal to that

[1] It is now known that Uranus had previously been observed by other astronomers. Le Monnier at Paris had watched it for twelve successive nights, but pronounced it a fixed star. He had also seen it on previous occasions, and had he been an orderly observer, he would doubtless have detected its planetary character. Arago related that he had been shown one of Le Monnier's observations of this planet written on a paper bag which originally contained hair powder purchased at a perfumer's.

of the water from the Dead Sea. The force of gravity upon the surface of the planet is $\frac{9}{10}$ that upon the earth.

Seasons. — We know practically nothing of the seasons of Uranus. If its axis lies in the plane of its orbit, the sun must wind in a spiral around the planet. The light and heat derived from the sun are less than $\frac{1}{300}$ of that which we receive ; the light has been estimated to be about the quantity that would be afforded by three hundred full moons. The inhabitants of Uranus, if any such exist, can see Saturn, and perhaps Jupiter, but none of the planets within the orbit of the latter.

Telescopic Features. — Few spots or belts have been discovered, and observers differ as to the character of these markings. The time of rotation and the other features so familiar to us in the nearer planets are as yet unknown.

SATELLITES. — Uranus has four moons, of which little is known, except the curious fact that their orbits are nearly perpendicular to the plane of the planet's orbit, and that their movements are apparently retrograde — *i.e.* in the same direction as the hands of a watch. The two inner satellites, named Ariel and Umbriel, are about 250 miles in diameter, and the outer ones, Titania and Oberon, are rather more than double that dimension.

IX. NEPTUNE

The god of the sea. Sign, ♆, his trident

Description. — Neptune is the far-off sentinel at the outpost of the solar system, being the most distant planet of which we have any knowledge. It is invisible to the naked eye, and appears in the telescope as a star of the eighth magnitude.

Discovery. — For many years, the motions of Uranus had been such as to baffle the most perfect calculations. While far-distant Saturn, after his journey of thirty years, came around to his place true to the minute, Uranus defied mathematical analysis, and refused to conform to the time set down for him on the heavenly dial.

At length it was suggested that there must be another planet exterior to Uranus, whose attraction produced these perturbations. So marked was this impression with Herschel, that he wrote: 'We see it as Columbus saw America from the shores of Spain. Its movements have been felt trembling along the far-reaching line of our analysis with a certainty not far inferior to ocular demonstration.'

Finally, two young mathematicians, Leverrier, of Paris, and Adams, of Cambridge, England, each unknown to the other, set about the task of finding the place of this new planet. The problem was this: *Given the disturbances produced by the attraction of the unknown planet, to find its orbit and its place therein.*

Adams, after assiduous labor for nearly two years, completed his calculations and submitted them to Airy, the Astronomer Royal, in 1845. In the summer of 1846, Leverrier laid a paper before the Academy of Sciences in Paris, announcing the position of the unknown planet. Airy, hearing of this, was so impressed with the value of Adams's calculations, that he wrote to Challis, of Cambridge, to search that quarter of the heavens. Challis did as requested, and observed a new star, which afterward proved to be the planet so anxiously sought for, although at that time he failed to ascertain its true character. In September of the same year, Leverrier wrote to Berlin, asking for assistance in searching for the planet. Galle, an assistant at the Observatory, on receiving the request, turned the large telescope to the place indicated, and almost immediately detected a bright star not laid down in a new chart just finished. This proved to be the predicted planet, found within less than a degree of the spot designated by Leverrier.

Such is the history of one of the grandest achievements of the human mind. It stands as an ever-fresh and assuring proof of the exactness of astronomical calculations, and the power of the intellect to understand the laws of the God of Nature.

Motion in Space. — Neptune revolves about the sun at a mean distance of nearly 2,800,000,000 miles. The Neptunian year is equal to nearly 165 terrestrial ones. Its motion in its orbit is the slowest of any of the planets, since it is the most remote from the sun. The velocity decreases from Mercury, which moves at the rate of about 107,000 miles an hour, to Neptune, whose speed is only 12,000 miles an hour.

Dimensions. — Neptune's diameter is about 35,000 miles. Its volume is nearly 100 times that of the earth. Its density is somewhat less than that of Uranus.

Seasons. — As the inclination of its axis is unknown, nothing can be ascertained concerning its seasons. The sun gives to Neptune but $\frac{1}{1000}$ the light and heat which we receive.

Though Neptune is at the extreme of the solar system, the same heavens bend above, the Milky Way is no nearer to the eye, and the fixed stars shine no more brightly. The planets, however, are all too near the sun to be seen, except Saturn and Uranus. The Neptunian astronomers, if there be any, are well situated for measuring the annual parallax of the stars, since Neptune has an orbit of 5,580,000,000 miles in diameter, and hence the angle must be 30 times as great as that which the terrestrial orbit affords.

Telescopic Features. — On account of the immense distance of this planet nothing is known of its rotation or physical features.

SATELLITES. — Neptune has one moon, about the size of ours, at nearly the same distance from it as our own moon is from the earth. The revolution of this body about the planet, which is accomplished in 5 d. 21 h., has furnished the means of calculating the mass of Neptune, which is 17 times that of the earth.

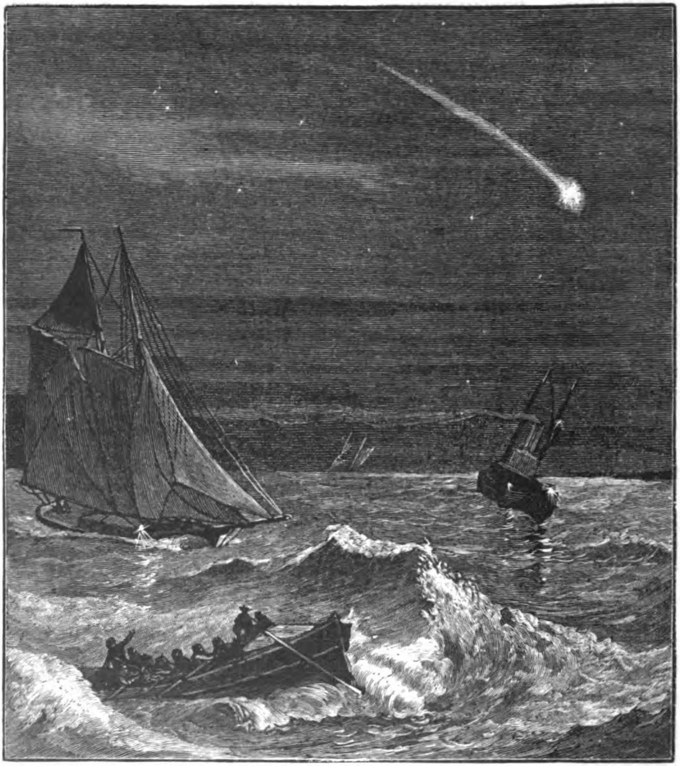
III. METEORS AND SHOOTING STARS

Description. — All are familiar with those luminous bodies that flash through our atmosphere as if stars were indeed falling from heaven. Different names have been applied to them, although the distinction is not very definite.

(1) METEORITES (or aërolites) are those stony or iron masses that descend to the earth.

(2) METEORS are luminous bodies which have a sensible diameter and a spherical form. They frequently pass over a great extent of country, and are seen for some seconds. Many leave behind them a

train of glowing sparks; others explode with reports like the discharge of artillery, — the pieces either continuing their course, or falling to the earth as



A METEOR WITH ITS LUMINOUS TRAIN

meteorites. Some meteors pass on into space; some are vaporized; while others are burned, and the ashes and fragments fall to the ground.

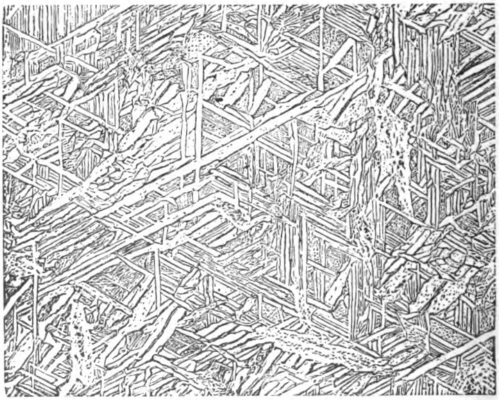
(3) SHOOTING STARS are those evanescent, brilliant points that suddenly dart through the higher regions

of the air, sometimes leaving a fiery train behind, and sometimes not.

1. **Meteorites.** — The fall of meteorites is frequently mentioned and well authenticated. Chinese records tell of one as long ago as B.C. 616, which, in its fall, broke several chariots and killed ten men. A block of stone, equal to a full wagon load, fell into the Hellespont, B.C. 465. By the ancients, these stones were held in great repute. The Emperor Jahangir, it is related, had a sword forged from a mass of meteoric iron which fell in the Punjab in 1620. In 1795, a mass was seen, by a plowman, to descend not far from where he was standing. It threw up the soil on every side, and penetrated some distance into the solid rock beneath. In 1807, there was a shower of stones, one weighing two hundred pounds, at Weston, Connecticut. A mass once fell in South America that was estimated to weigh fifteen tons. When first discovered, it was so hot as to prevent all approach. Upon its cooling, many efforts were made, by some travelers who were present, to detach specimens, but its hardness was too great for the tools that they possessed. In Yale University cabinet there is a mass of meteoric iron weighing 1635 pounds.

METEORITES CONSIST OF ELEMENTS which are familiar. The analysis of these celestial objects gives us names as commonplace as if they had known a far less romantic origin, — iron, tin, copper, nickel, cobalt, lime, magnesium, oxygen, sulphur, phosphorus; in all, about twenty elements have been found. This fact is interesting as revealing something of the chemistry of the regions of space, concerning which we otherwise know little. The compounds, however, are so peculiar as to distinguish a meteorite from other substances. For example, meteoric iron is an alloy that has never been found in terrestrial minerals, and contains much nickel. By polishing the surface of iron meteorites and etching with nitric acid, the crystalline structure, almost unique, is revealed as in the adjacent engraving.

2. Meteors. — The records of meteors are even more wonderful. It is related that at Crema, Italy, one day in the fifteenth century, the sky at noonday became



PECULIAR CRYSTALLINE STRUCTURE OF METEORIC IRON

dark, — a cloud of appalling blackness overspreading the heavens. Upon this cloud appeared the semblance of a great peacock of fire flying over the town. This suddenly changed to a huge pyramid, which rapidly traversed the sky. Thence arose awful lightnings and thunderings, amid which there fell upon the plain, rocks, some of which weighed one hundred pounds. In 1803, a brilliant fireball was seen traversing Normandy with great velocity, and some moments after, frightful explosions, like the noise of cannon, were heard coming from a black cloud hanging in the clear sky; they were prolonged for five or six minutes. These discharges were followed by a shower of heated stones, some weighing over twenty-four pounds. In 1819, a meteor was witnessed in Massachusetts and Maryland, the diameter of which was estimated at half a mile. In July, 1860, a brilliant fireball passed over the state of New York, from west to east, and was last seen far out at sea. On the evening of February 12, 1875, a magnificent meteor 'illumined the entire state of Iowa, and parts of Missouri, Illinois, Wisconsin, and Minnesota. The aërolites that have been collected show its weight to have been fully five thousand pounds.'

3. Shooting Stars. — Among the earliest accounts of star showers is one which relates that, in 472, the sky at Constantinople appeared to be alive with flying stars and meteors. In some Eastern annals we are told that in October, 1202, 'the stars appeared like waves upon the sky. They flew about like grasshoppers, and were dispersed from left to right.' It is recorded that in the time of King William II there occurred in England a wonderful shower of stars, which 'seemed to fall like rain from heaven. An eyewitness, seeing where an aërolite fell, cast water upon it, which was raised in steam, with a great noise of boiling.'[1]

SHOWERS OF 1799 AND 1833. — The most remarkable accounts are those of the showers of November

[1] Rastel says concerning it: 'By the report of the common people in this kynge's time, diverse great wonders were seene, and therefore the kynge was told by diverse of his familiars that God was not content with his lyvyng.'

12, 1799, and November 13, 1833. Humboldt, in describing the former, says the sky was covered with innumerable fiery trails, which incessantly traversed the sky. From the beginning of the phenomenon, there was not a space in the heavens three times the diameter of the moon that was not filled every instant with the celestial fireworks, — large meteors blending constantly their dazzling brilliancy with the long phosphorescent paths of the shooting stars. (See notes, pages 323, 324.)

The latter shower was most brilliant on this continent, and was visible from the lakes to the equator. Glowing lines swept over the sky like the flakes of a snowstorm. Large meteors darted across the heavens, leaving luminous trains behind them that were visible sometimes for half an hour; they generally shed a soft white light; occasionally, however, yellow, green, and other colors varied the scene. Irregular fireballs, almost stationary, glared in the sky. In many sections the people were terror-stricken by the awful spectacle, and supposed that the end of the world had come.

Inferior showers were seen in 1831 and 1832, and in the succeeding years, until 1839. These did not compare in brilliancy with the remarkable phenomenon of 1833. There was an interval of about 34 years between the great showers of 1799 and 1833; this seemed to indicate another shower in 1866 or 1867.

In November, 1866, the people of both hemispheres were literally awake to the subject. Newspapers aroused the most sluggish imaginations with thrilling accounts of the scenes presented in 1799 and 1833. Extemporized observatories were established at every convenient point. Watchmen were stationed, and the city bells were to be rung on the appearance of the first wandering celestial visitor. The exact night was not definitely known, but, for fear of a mistake, the 11th, 12th, and 13th were generally observed. The anxious vigils, the fruitless scannings of the sky, the disappointment, the meteors that were dimly thought to be seen, — all these were recorded in the memory of the temporary astronomers of that year.

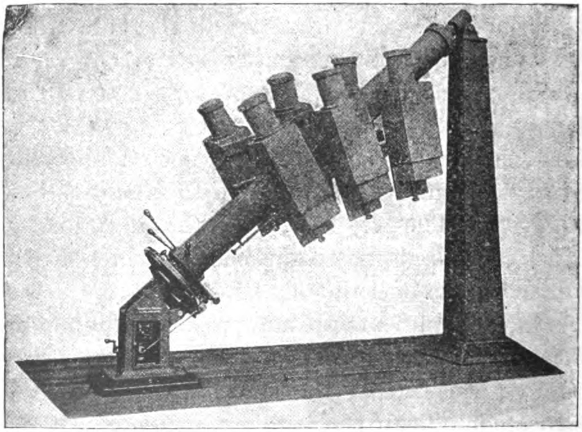
While, however, the people of America were thus disappointed, there was presented in England a display brilliant indeed, though inferior to the one of 1833. The staff at Greenwich Observatory counted about 8000 meteors.

In November, 1867, the long-expected shower was seen in this country, but it failed to satisfy the public anticipation. The sky was, however, illumined with shooting stars and meteors, some of which exceeded Jupiter or Venus in brilliancy.

The brighter meteors are now recorded by photography: cameras guided by clockwork to follow the stars are pointed at that part of the dark sky where meteors are expected. Then the brilliant meteor, as it flashes across the sky, makes its own exposure; and on developing the negative, a straight and dark narrow line is seen crossing it among the black spots, which are stellar images.

Foreshadowing the return of the November meteors, or Leonids, at the end of the nineteenth century, many hundreds were counted in this country during a feeble display near the middle of November, 1898. From the 12th to the 15th of November, 1899, also at the same epoch of 1900, a repetition of the magnificent showers of 1833 and 1866 may be expected; but the bright moon will in the former year dull the brilliancy of the display. No harm can come to the earth from these interplanetary visitors, because they are completely vaporized by the atmosphere when about forty miles above the surface of the earth.

Number of Meteors and Shooting Stars. — The late Professor Newton estimated that the average number of meteors that traverse the atmosphere daily, and



APPARATUS FOR PHOTOGRAPHING TRAILS OF METEORS

which are large enough to be visible to the eye on a dark, clear night, is 7,500,000; and if to these the telescopic meteors be added, the number would be increased to 400,000,000. In the space traversed by the earth, there are, on the average, in each volume the size of our globe (including its atmosphere), as many as 13,000 small bodies, each one capable of furnishing a shooting star visible under favorable circumstances to the naked eye.

Annual Periodicity of the Star Showers. — On almost any clear night, from five to seven shooting stars may be seen each hour, but in certain months they are much more abundant. Professor Todd names the following principal dates: —

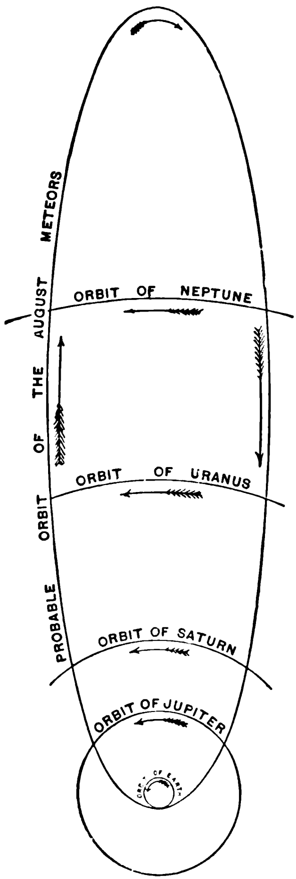
Lyrids, April 18.	Leonids, November 13.
Perseids, August 10.	Andromedes, November 26.
Orionids, October 19.	Geminids, December 7.

The showers take their names from the constellations whence they seem to radiate.

Origin. — Meteors and falling stars are produced by small bodies — planets in miniature — revolving, like our earth, around the sun. Their orbits intersect the orbit of the earth, and if, at any time, they reach the point of crossing exactly with the earth, there is a collision. Their mass is so small that the earth is not jarred any more than a railway train would be by a small pebble thrown against it.

These small bodies may come near the earth and be drawn to its surface by the force of gravity; or they may sweep through the higher regions of the atmosphere, and then escape its grasp; or, finally, they may, under certain conditions, be compelled to revolve many times around the earth as satellites.

The November meteors move at the rate of 26 miles a second in a direction nearly opposite that of the earth. They therefore meet our atmosphere with a relative velocity of nearly 44 miles a second. As they sweep through the air, the friction partly arrests their motion, and converts it into heat and light. The body thus becomes visible to us. Its size and direction determine its appearance. If very small, it is consumed in the upper regions, leaving only the luminous trail of a shooting star. If of large size, it may sweep along at a high elevation, or plunge directly toward the ground. Becoming highly heated in its course, it sheds a vivid light, while, unequally expanding, it sometimes explodes, throwing off large fragments which may fall to the earth as meteorites, or continue their separate course. The cinders of the consumed portion rain down on us as fine meteoric dust. About 100 tons of meteoric matter fall upon the earth daily from outer space.



ORBIT OF THE AUGUST METEORS

Meteoric Orbits. — These little bodies revolve individually about the sun, but myriads of them follow the same orbits. When the earth passes through such an orbit, a star shower follows. This accounts for their regular appearance at certain seasons of the year. The November meteors are not, like the August ones, uniformly distributed through the orbit, but are principally collected in a swarm or shoal that has a period of $33\frac{1}{4}$

years; hence the August shower occurs quite regularly each summer, while the great November one happens only three times in a century. The orbit of the November stream extends beyond that of Uranus. The point where it crosses the earth's orbit moves forward about 50″ per annum, and thus that star shower occurs about a day later at each return. It takes three or four years for this swarm to pass the node, showing that the shoal of meteors extends along $\frac{1}{12}$ of the entire orbit. The earth in its annual revolution about the sun encounters several hundred of these meteoric orbits, which produce the showers at different times throughout the year.

The Physical Relation between meteors and comets is now generally acknowledged. The orbit of the August meteors is known to be identical with Comet III (1862) (Swift's), and that of the November 14th shower corresponds with Comet I (1866) (Tempel's). The small showers of November 24 and 27 are thought to be produced by meteors traveling in the path of the two dissevered parts of Biela's comet.

The grand problem of meteoric astronomy to-day is to identify the numerous meteoric paths, and to detect their allied comets. Being thus intimately associated, they must have a common history. Newton, the great advocate of this theory, broadly asserts that every meteoric stone was once a part of a comet, and every meteoric shower consists of broken fragments of some known or unknown comet.

Radiant Point. — The meteors are, of course, moving in essentially parallel lines; but, by an optical illusion, they seem to radiate in all directions from a definite region of the sky, hence known as the radiant point. The same illusion is seen if, looking upward, we watch snowflakes falling during a calm. Those coming directly toward our eyes seem to be motionless, and the rest to separate from them in diverging lines. This is the effect of perspective, and the 'radiant point' is really the 'vanishing point' of the parallel lines through which the meteors are moving. A star (μ) in the blade of the Sickle is near the point from which the meteors in the November shower radiate, while a star in Perseus (γ) is near the radiant point of the August shower.

Height. — The average height of shooting stars above the earth is about seventy miles at their appearance, and fifty at disappearance.

Weight. — The average weight of shooting stars does not differ much from one grain; but meteorites often weigh many tons.

IV. COMETS

We come now to notice a class of bodies the most fascinating, perhaps, of any in astronomy. The suddenness with which comets sometimes flame out in the sky, the enormous dimensions of their fiery trains, the swiftness of their flight, the strange and mysterious forms they assume, their departure as unheralded as their advent, — all seem to bid defiance to law, and partake of the marvelous. Superstitious fears have been excited by their appearance, and they have been looked upon in every age as —

> 'Threatening the world with famine, plague, and war;
> To princes, death; to kingdoms, many curses;
> To all estates, inevitable losses;
> To herdsmen, rot; to plowmen, hapless seasons;
> To sailors, storms; to cities, civil treasons.'[1]

[1] Thus the comet of B.C. 43, which appeared just after the assassination of Julius Cæsar, was looked upon by the Romans as a celestial chariot sent

Description. — The term comet signifies a ***hairy body***. A comet consists usually of three parts, — the *nucleus*, a bright point in the center of the *head;* the *coma* (hair), the cloudlike mass surrounding the nucleus; and the *tail*, a luminous train extending generally in a direction opposite to the sun. There are comets without tails, and others with several tails, while some lack even the nucleus. A comet without a nucleus consists merely of a fleecy mass, known to be a comet from its orbit and rapid motion.

COMET WITHOUT A NUCLEUS

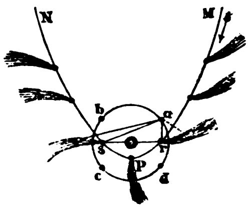
COMET WITH A NUCLEUS

Comets are not confined, like the planets, to the limits of the zodiac, but appear in every quarter of the heavens, and move in every conceivable direction. When first seen the comet resembles a faint diffused spot of light upon the dark background of the sky: as it approaches the sun, the brightness increases, and the tail begins to show itself. Generally it is brightest near

to convey his soul heavenward. An old English writer observes: 'Cometes signifie corruptions of the ayre. They are signes of earthquakes, of warres, of changyng kyngedomes, great dearthe of corn, yea, a common death of man and beast.' Another remarks: 'Experience is an eminent evidence that a comet, like a sword, portendeth war; and a hairy comet, or a comet with a beard, denoteth the death of kings, as if God and nature intended by comets to ring the knells of princes, esteeming bells in churches upon earth not sacred enough for such illustrious and eminent performances.'

perihelion, and gradually fades away as it recedes, until it is finally lost, even to the telescope.[1]

The Time of Greatest Brilliancy depends somewhat on the position of the earth. If, as represented in the figure, the earth is at *a* when the comet, moving toward perihelion, is at *r*, the comet will appear more distinct than when it is more distant at P, although at the latter point it is really brighter. If, however, the earth is at *c* at the time of perihelion, the comet will be much more conspicuous. Again, if the earth is passing from *a* to *b* during the time the comet is near the sun, it will appear less brilliant than if the earth were moving from *c* to *d*, as we should then be much nearer it during its greatest actual brightness.



PART OF ORBIT OF A COMET

Number of Comets.—Kepler remarks that 'there are as many comets in the heavens as fish in the sea.'

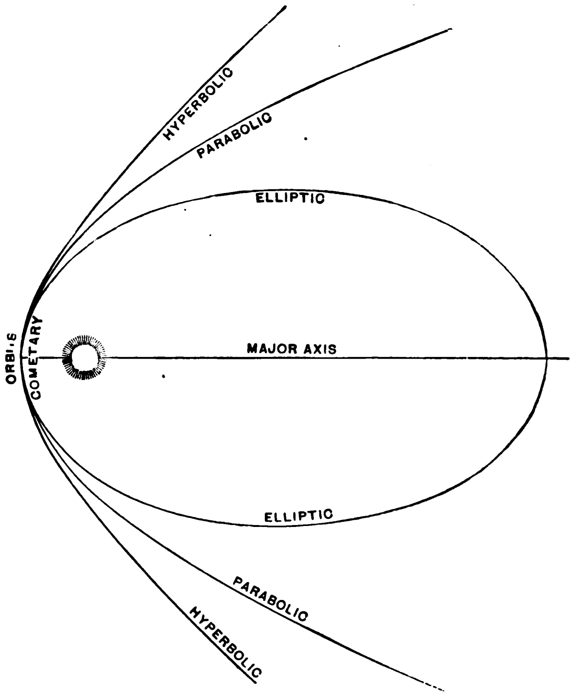
[1] While a comet remains in regions beyond the planets, where the temperature is below —140° C., its matter must be chiefly solid or liquid. On its approach to the sun, its enveloping atmosphere (if none existed, one will now be formed) will expand, and the nucleus will appear surrounded by a blaze of light, feeble at first, but becoming more and more brilliant, and so producing the head, or coma, of the comet. Many comets do not go beyond this first phase, and, being exposed only to a moderate heat, remain telescopic. Others, piercing further the solar system, and reaching a higher temperature, develop a more abundant atmosphere. The sun, while attracting to himself the nucleus, has power to repel some of the matter of the atmosphere; how or why, we know not. Enough, that certain parts fly off as if driven by a gale, so making the tail, which increases more and more until the atmosphere is exhausted. Meanwhile, remarkable changes take place in the nucleus. Eruptions occur. Pieces are sometimes thrown off large enough to form a new comet, and showers of sparklike particles, with occasionally stony masses, fill the orbit of the comet with meteoric bodies.

Arago, basing his calculations on the number known to exist between the sun and Mercury, has estimated that there are 17,500,000 within the solar system. Of this vast number, few are visible to the naked eye, and a still less number attract observation, owing to their inferior size and brilliancy. Many are doubtless lost to our sight by being above the horizon in the daytime only. During the total solar eclipse of 1882, observers in Egypt photographed a brilliant comet near the sun; also in Chile, a faint one in 1893.

Orbits of the Comets. — Comets obey the law of gravitation, and some of them belong to the solar system. Like the planets, they revolve around the sun, though they differ in the form of their orbits. While the planets move in paths varying little from the circular, and thus never depart so far from the sun as to be invisible in our telescopes, the comets travel in extremely elongated (flattened) ellipses, so that they can be observed by us through only a small portion of their paths.

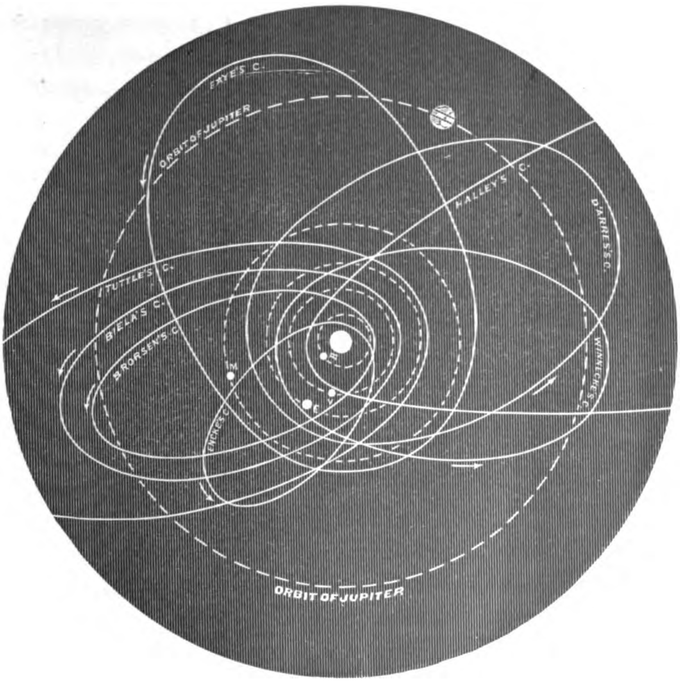
In the following diagram are represented the three general classes of cometary orbits. A comet traveling along an elliptical orbit, though it may pass far from the sun, will yet return within a fixed time; one pursuing either a parabolic or hyperbolic curve cannot return, as the two sides separate from each other more and more. Many of the comets of the first class have been calculated, and they have repeatedly visited our portion of the heavens; while those of the other classes, having once visited our system, go away forever, seeking perhaps in far-off interstellar space another sun, which in turn they will abandon as they did our own.

Calculation of a Comet's Return. — As we can observe so small a proportion of the entire orbit, it is very difficult, indeed sometimes impossible, to decide whether it is an *hyperbola*, an *ellipse*, or a *parabola*. A few comets are known to move in elliptical paths, and



THREE FORMS OF COMETARY ORBITS

their orbits have been so accurately computed that it is possible to predict the time of their appearance. Other comets may never return, or at least not for centuries hence. They may be paying our sun their first visit; or, if they have swept through the solar system before, it may have been at so remote a time that no record is preserved. Under these circumstances, it is difficult to determine the place of these



PROJECTIONS OF A FEW COMETARY ORBITS ON THE PLANE OF THE ECLIPTIC

apparently erratic wanderers ; yet, in spite of all obstacles, many have been tracked into space far beyond the telescopic view.

Distance from the Sun. — Some comets at their perihelion sweep near the sun. Thus the one of 1680 came where the temperature was estimated by Newton to be about 2000 times that of red-hot iron.[1] The nearest approach known is that of the comet of 1843, whose perihelion distance was but 30,000 miles from the surface of the sun; in fact, it doubled around that body in two hours' time. The greatest aphelion distance yet calculated is that of the comet of 1844, which is over 400,000,000,000 miles. The velocity varies, of course, with the position in the orbit. The comet of 1680 moved in perihelion at the rate of over 277 miles a second; while in aphelion its velocity is only about six miles an hour.

Density of Comets. — The quantity of matter contained in a comet is exceedingly small. Even telescopic stars are visible through the denser parts. The comet of 1770 became entangled among Jupiter's moons, and remained there four months without interfering with their movements; indeed, so far from that, its own orbit was so much changed by their proximity, that, from a periodical return of 5½ years, it has not been seen since. We have good reason to suppose that the earth, in 1861, passed through the tail of a comet, its presence being indicated only by a peculiar phosphorescent mist. So that even should our earth run full-tilt against a comet, the shock might be quite imperceptible.[2] Still, however lightly

[1] The comet of 1680 excited such terror in Europe that a medal was struck to quiet the fears of the people. The inscription read thus: 'The star threatens evil things; trust only! God will turn them to good.' Newton calculated the orbit of this comet and proved that the comet moves around the sun in obedience to the law of gravity.

[2] 'However dangerous might be the shock of a comet, it might be so slight that it would only do damage to that part of the earth where it actually struck; perhaps, even, we might cry quits, if, while one kingdom were devastated, the rest of the earth were to enjoy the rarities which a body coming from so far might bring to it. Perhaps we should be very

we may speak of the probability of such a collision, we must remember that there are comets of greater solidity. Donati's, for instance, is estimated by some to be about $\frac{1}{700}$ the mass of the earth. The concussion of such a body, moving with the speed of a cannon ball, would undoubtedly produce a very disastrous effect.

Comets shine chiefly by their own and not by reflected light. If, however, their nuclei consist of white-hot matter, a passage through such a furnace would be anything but desirable or satisfactory. After all the calculations of astronomy, our only safety lies in that Almighty Power which traces the path and guides the course alike of planets and comets: He, whose eye marks the fall of the sparrow, sees as well the flight of the worlds He has created.

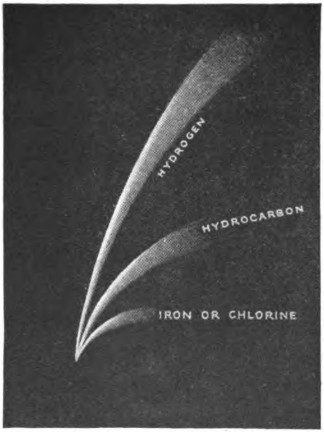
Variations in Form and Dimensions. — Comets appear to be subject to constant variations. They are now thought generally to decrease in brilliancy at each successive revolution about the sun. The same comet may present itself sometimes with a tail, and sometimes without. When the comet first appears, there is commonly no tail visible, and the light is faint. As it approaches the sun, however, its brightness increases, the tail shoots out from the coma, and grows daily in length and splendor. Supernumerary tails, shorter and less distinct than the principal one, dart out, but they

surprised to find that the *debris* of these masses that we despised were formed of gold or diamonds; but who would be the more astonished — we or the comet dwellers who would be cast upon our earth? What strange beings each would find the other!' — *Lettre sur la Comète*, by M. De Maupertuis.

Young says, 'It seems, on the whole, more probable that a comet is only a cloud of dust and vapor — a smoke-wreath — than that there is at the center any solid kernel. A comet is a mere airy nothing.'

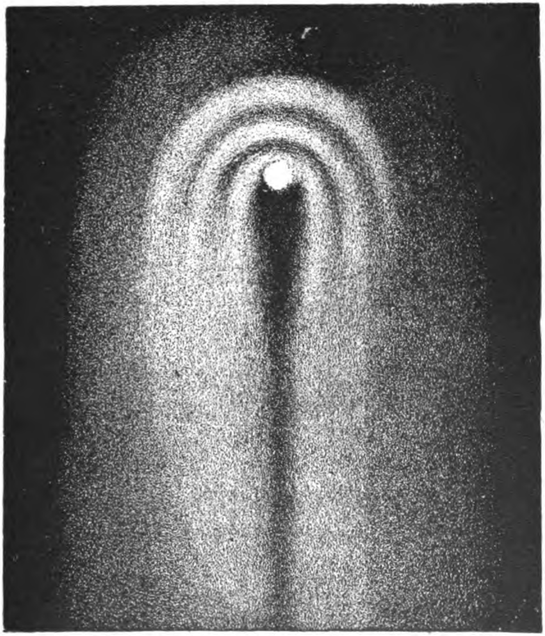
generally soon disappear, as if from lack of material. The tail of the comet of 1843, just after the perihelion, increased in length 5,000,000 miles a day. As the tail was thus extended, the nucleus was correspondingly contracted, so that this comet actually 'exhausted its head in the manufacture of its own tail.'

Constitution of Comets. — The spectroscope (page 272) has made it possible to analyze the light of comets, and so ascertain in part their composition. Hydrocarbons are the most conspicuous elements; also iron, sodium, and magnesium, in a state of vapor. The tails are divided into three classes, according to their curvature, and the density of the elements concerned. (1) If very dense, as chlorine or iron, the tails are of the short, bushy type and sharply curved. (2) If of the intermediate type of curvature, like Donati's comet on page 204, then the tail is due to ejections of hydrocarbon vapor. (3) The straightest tails of all are due to hydrogen, one of the lightest elements known. A solar repulsion is concerned in producing all cometary tails.



TYPES OF COMETARY TAILS

Remarkable Comets. — Among the many comets celebrated in history, we shall notice only some of those that appeared in the nineteenth century. The *great comet* of 1811 was a magnificent spectacle, considered by the Russians to presage Napoleon's invasion. The head was 112,000 miles in diameter; the nucleus was 400 miles; while the tail, of a beautiful fan shape, stretched out 112,000,000 miles. 'The aphelion distance of this comet is fourteen times that of Neptune,



HEAD OF COGGIA'S COMET, 1874

or 40,000,000,000 miles. It is announced to return in thirty centuries!' To what profound depths of space, beyond the solar system, beyond the reach of the telescope, must such a journey extend!

THE COMET OF 1835 is known as Halley's comet. This is remarkable as being the first comet whose period of revolution was satisfactorily established. Halley, on examining the accounts of the great comets of 1531, 1607, and 1682, suspected that they were reappearances of the same comet, whose period he fixed at about seventy-five years.[1] He finally ventured to predict the return of the comet near the end of 1758 or beginning of 1759. Although Halley did not live to see his prophecy fulfilled, great interest was felt in the result. It was not destined, however, for a professional astronomer to be the first to detect the comet. A peasant near Dresden saw it on Christmas night, 1758. We shall see it again in 1910.

DONATI'S COMET OF 1858

THE COMET OF 1843 was so brilliant that it was

[1] The history of this comet, as it has been traced back by its period of seventy-five years, is quite eventful. It was seen in England in 1066, when it was looked upon with dread as the forerunner of the victory of William of Normandy. It was then equal to the full moon in size. In 1456, its tail reached from the horizon to the zenith. It was supposed to indicate the success of Mahomet II, who had already taken Constantinople, and then threatened the whole Christian world. Pope Calixtus III, therefore, ordered extra *Ave Marias* to be repeated by everybody, and also the church bells to be rung daily at noon (whence originated the custom now so universal). A prayer was added as follows : 'Lord, save us from the devil, the Turk, and the comet.' In 1223, it was considered the precursor of the death of Philip Augustus of France. The first recorded appearance of Halley's comet was B.C. 130, when it was supposed to herald the birth of Mithridates.

visible in full daylight. It was so near the sun at perihelion as almost to graze his surface.

ENCKE'S COMET has a period of only $3\frac{1}{3}$ years. A most interesting discovery was thought to have been made from observations upon its motion. For many years the comet returned each time to perihelion about $2\frac{1}{2}$ hours earlier than the calculations indicated. Hence Encke was led to conjecture that space is filled with a thin, resisting medium capable of retarding the comet's motion, and thus contracting its orbit. This hastening of its return being no longer observed, it is supposed that in earlier years Encke's comet must have regularly encountered a shoal of meteoric matter which it does not now meet.

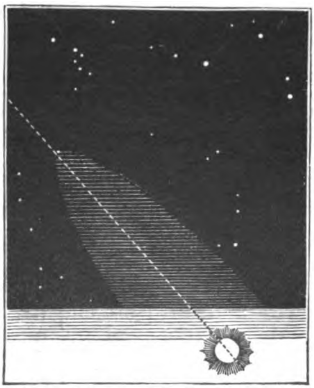
DONATI'S COMET (1858) was the subject of universal wonder. When first discovered, in June, it was 240,000,000 miles from the earth. In August, traces of a tail were noticed, which expanded in October to about 50,000,000 miles in length. This comet, though small, has never been exceeded in the brilliancy of the nucleus and the graceful curvature of the tail. It will return in about 2000 years.

THE GREAT COMET OF 1882 had, soon after passing its perihelion, a nucleus as bright as a star of the first magnitude, and a tail 60,000,000 miles long. The aphelion of its orbit is six times further than Neptune from the sun, and the comet's period is estimated at between eight and nine centuries.

Since 1892 several comets have been first discovered by means of photography, one of them at the Yale Observatory in 1898, when plates were being exposed for catching trails of the Leonids in November of that year. No astronomer had previously seen these comets, but after they were once found on the photographic plates, they were subsequently observed and their orbits ascertained. No great comet has appeared since 1882; but a new and brilliant one may at almost any time burst into view from the depths of interstellar space.

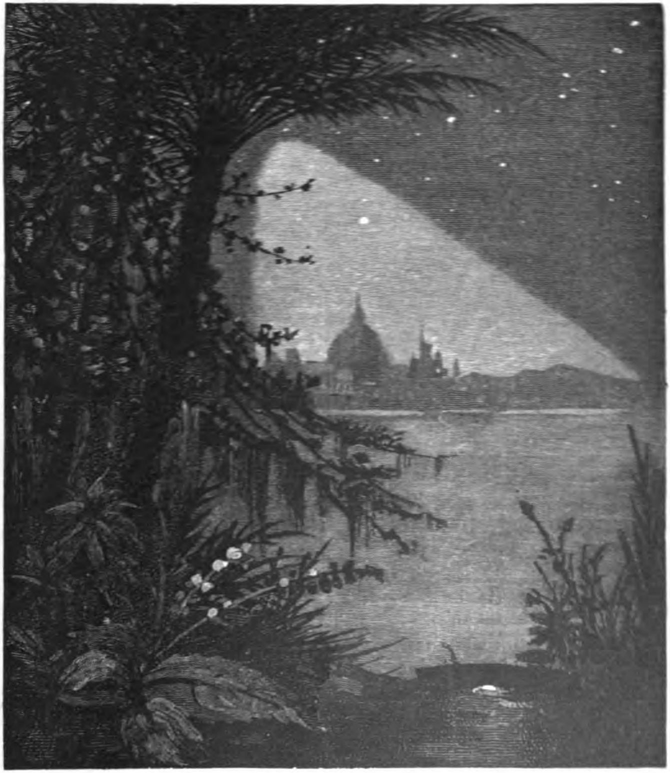
V. ZODIACAL LIGHT

Description.—If we watch the western horizon in March or April, just after sunset, we shall sometimes see the short twilight of that season illuminated by a faint ill-defined nebulous light, of a conical shape, traceable upward often as high as the Pleiades. In September and October, at early dawn, the same appearance can be detected near the eastern horizon. The light can be seen in this latitude only on the most favorable evenings, when the sky is perfectly clear and the moon absent. Even then it may sometimes be confounded with the Milky Way or aurora borealis. At the base, it is of a reddish hue, so bright as occasionally to efface the smaller stars. In tropical regions, the zodiacal light is visible the year round, and shines with a brilliancy sufficient, says Humboldt, to cast a sensible glow on the opposite part of the heavens.



SHAPE OF THE ZODIACAL LIGHT, WITH REFERENCE TO THE SUN AND THE ECLIPTIC

Origin. — The commonly received opinion is that the zodiacal light is caused by a faint, cloudlike ring, perhaps a meteoric zone, that surrounds the sun, and becomes visible to us only when the sun himself is hidden below the horizon. Others maintain that, since



ZODIACAL LIGHT, MUCH INTENSIFIED

it has been seen in tropical regions in the east and the west simultaneously, it can be explained only on the theory of a nebulous ring surrounding the earth within the orbit of the moon.

Gegenschein, or Counterglow. — This is a faintly marked patch of light which a few keen-eyed astronomers have seen in that part of the nightly sky nearly opposite where the sun is. Sometimes bands have been traced, very faintly, both ways along the zodiac, connecting it with the zodiacal light. It is best seen in September and October, in Sagittarius and Pisces, and affords a fine test of one's powers of vision. The light of this counterglow is, perhaps, sunlight reflected from clusters or shoals of small interplanetary bodies, too small to be seen individually.

PRACTICAL QUESTIONS

1. Would the earth rise and set to a lunarian?
2. Could there be a transit of Neptune?
3. Why does Mars's inner moon rise in the west?
4. In what part of the sky do you always look for the planets?
5. Show how it was impossible for the darkness that occurred at the time of the Crucifixion of Christ to have been caused by an eclipse of the sun.
6. Is there any danger of a collision between the earth and a comet?
7. How are meteorites distinguished?
8. When do we see the old moon in the west after sunrise?
9. When do we see the moon high in the eastern sky in the afternoon before the sun sets?
10. When is a planet morning, and when evening, star?
11. Is the sun really hotter in summer than in winter?
12. Why is a planet invisible at conjunction?
13. Must an inferior planet always be in the same part of the sky as the sun? A superior planet?
14. Why, in summer, does the sun, at rising and at setting, shine on the north side of certain houses?
15. What effect does the volume of a planet have upon the force of gravity at its surface?

16. In what part of the heavens do we see the new moon? The old moon? The crescent moon?

17. What is the Golden Number in the almanac?

18. Why do we see more lunar than solar eclipses?

19. In what direction do the horns of the moon turn?

20. Is the tidal wave an actual movement of the water?

21. Why does the sun 'cross the line' in some years on March 21, and in others on March 22?

22. Do we ever see the sun where it really is?

23. At Edinburgh, Scotland, there are times when the sun rises at 3¼ o'clock A.M. and sets at 8½ o'clock P.M., and the twilight lasts the entire night. When and why is this?

24. Which is the longest day of the year?

25. Is the moon nearer to us when it is at the horizon, or at the zenith?

26. How many solar eclipses would happen each year if the orbits of the earth and the moon were in the same plane?

27. Is there any heat in moonlight?

28. Can we see the moon during a total lunar eclipse?

29. Which of the planets are repeating a portion of the earth's history?

30. How many times does the moon turn on its axis each year?

31. Can you explain the different signs used in the almanac?

32. Show how the moon is a prophecy of the earth's future.

33. Does the sun really rise and set?

34. Are the bright portions of the moon mountains or plains?

35. Which of the heavenly bodies are self-luminous?

36. Why is not a solar eclipse visible on the whole earth?

37. What is meant by the mean distance of a planet?

38. What keeps the earth in motion around the sun?

39. Do we ever see the sun after it sets?

40. When does the earth move the most rapidly in its orbit?

41. Have we conclusive evidence that any planet is inhabited?

42. When is the twilight the longest? The shortest? Why?

43. What is a moon?

44. To a person in the south temperate zone, where would the sun be at noon?

45. Is it correct to say that the moon revolves about the earth, when we know that, according to the law of physics, they must both revolve about their common center of gravity?[1]

46. During a transit of Venus do we see the body of the planet itself on the face of the sun?

47. How many real motions has the sun? How many apparent ones?

48. How many real motions has the earth?

49. Can an inferior planet have an elongation of 90°?

50. How do we know the intensity of the sun's light on the surface of any of the planets?

51. Why is the Tropic of Cancer placed where it is?

52. What planets would float in water?

53. How do the moons of Jupiter appear during their transit across the disk of that planet?

54. Explain why the shadow of the satellite precedes the satellite itself when Jupiter is passing from conjunction to opposition, but follows it between opposition and conjunction.

55. What facts point to the conclusion that Mars may, perhaps, have passed his planetary prime?

56. Why may we conceive that Saturn and Jupiter are yet in their planetary youth?

57. Show how, if the nebular hypothesis (p. 267) be accepted, the fashioning of a planet must require an enormous length of time.

58. Do we know the cause of gravitation?

[1] Strictly speaking, the moon does not revolve around the earth, any more than the earth around the moon; but, by the principle of action and reaction, the center of each body moves around the common center of gravity of the two bodies. The earth being eighty times as heavy as the moon, this center is situated within the former, about three quarters of the way from its center to its surface. — NEWCOMB'S *Astronomy*, p. 91.

III

THE SIDEREAL SYSTEM

'*He telleth the number of the stars; He calleth them all by their names.*'

PSALM cxlvii. 4.

THE SIDEREAL SYSTEM

- (I) THE STARS
  - (1) FIXED STARS
  - (2) PARALLAX AND DISTANCE
  - (3) MOTION
  - (4) STARS ARE SUNS
  - (5) OUR SUN A STAR
  - (6) SOLAR SYSTEM IN MOTION
  - (7) NUMBER OF STARS
  - (8) SCINTILLATION
  - (9) MAGNITUDE
  - (10) CAUSE OF DIFFERENCE IN BRIGHTNESS
  - (11) NAMES
  - (12) THE CONSTELLATIONS
  - (13) INVENTION OF CONSTELLATIONS
  - (14) SIGNS AND CONSTELLATIONS NOT AGREEING
  - (15) PERMANENCE OF CONSTELLATIONS
  - (16) VALUE OF STARS
  - (17) ANCIENT VIEWS
  - (18) THREE ZONES
- (II) THE CONSTELLATIONS
  - (1) NORTHERN CIRCUMPOLAR CONSTELLATIONS for Latitude of New York
    - (1) HOW TRACED
    - (2) URSA MAJOR
    - (3) URSA MINOR
      - (a) Description
      - (b) Principal Stars
      - (c) Mythological Hist.
      - (d) Distance of Polaris
      - (e) Latitude
    - (4) DRACO
    - (5) CEPHEUS
    - (6) CASSIOPEIA
  - (2) EQUATORIAL CONSTELLATIONS
    - (1) HOW TRACED
    - (2) PERSEUS
    - (3) ANDROMEDA
    - (4) ARIES
    - (5) TAURUS
    - (6) AURIGA
    - (7) PISCES
    - (8) CETUS
    - (9) GEMINI
    - (10) ORION
    - (11) CANIS
    - (12) LEO
    - (13) CANCER
    - (14) VIRGO
    - (15) HYDRA
    - (16) CANES VENATICI
    - (17) BERENICE'S HAIR
    - (18) BOÖTES
    - (19) HERCULES
    - (20) CORONA
    - (21) SERPENTARIUS
    - (22) LIBRA
  - (3) THE SOUTHERN CONSTELLATIONS
    - (23) SCORPIO
    - (24) SAGITTARIUS
    - (25) CAPRICORNUS
    - (26) CYGNUS
    - (27) LYRA
      - (a) Description
      - (b) Principal Stars
      - (c) Mythological Hist.
- (III) DOUBLE STARS, COLORED STARS, NEBULÆ, ETC.
  - (1–6) DOUBLE STARS, COLORED STARS, VARIABLE STARS, TEMPORARY STARS, STAR CLUSTERS, NEBULÆ
  - (7) MAGELLANIC CLOUDS
  - (8) THE MILKY WAY
  - (9) THE NEBULAR HYPOTHESIS
- (IV) CELESTIAL CHEMISTRY
  - (1) SPECTRUM ANALYSIS
  - (2) SPECTROSCOPE
  - (3) REVELATIONS CONCERNING SUN
  - (4) CONCERNING STARS
  - (5) CONCERNING NEBULÆ
  - (6) CONCERNING SOLAR FLAMES
- (V) TIME
  - (1) SIDEREAL
  - (2) SOLAR
  - (3) MEAN SOLAR
  - (4–14) STANDARD TIME, SUNDIAL, ETC.
- (VI) CELESTIAL MEASUREMENTS
  - (1) TO FIND DISTANCE OF PLANETS FROM SUN
  - (2) TO FIND MOON'S DISTANCE FROM EARTH
  - (3) TO FIND SUN'S DISTANCE FROM EARTH
  - (4–8) TO FIND LONGITUDE OF A PLACE, ETC.

THE SIDEREAL SYSTEM

I. THE STARS

IN our celestial journey we have reached Neptune, the sentinel outpost of the planetary system. We are now nearly 2,800,000,000 miles from our sun. Yet we are apparently no nearer the fixed stars than when we started. They twinkle as serenely there in the far-off sky as to us here on the earth. The heavens by night, with the exception of a few changes in the planets, look familiar. Between them and us there is still a vast chasm which no imagination can bridge; a distance so immense that figures are meaningless, and we can only call it *space*, — so profound that to us it is limitless, though beyond we see other worlds twinkling, like distant lights over a waste of waters.

So far are the stars removed from us, that we see only the light they send, but not the surface of the worlds themselves. They are merely glittering points of light. The most powerful telescope fails to produce a sensible disk. This constitutes a marked difference between a planet and a fixed star.

The Annual Parallax of the Fixed Stars. — When speaking of this subject on page 126, we said that 186,000,000 miles, or the diameter of the earth's orbit, is the unit for measuring the parallax of the fixed stars. Yet when the stars are viewed from even the opposite points of our orbit, they manifest so slight a change of place that to observe it is a very delicate feat of astronomy. The difficulty of measuring the stellar parallax may be judged from the fact that 1″ measures the angle at which a globe three tenths of an inch in diameter would be seen when a mile away.

At the present time, it is considered that the star Alpha (α) Centauri in the southern heavens is the nearest to the earth. David Gill, Her Majesty's Astronomer at the Cape of Good Hope, determined the parallax of α Centauri to be 0″.75. This would make its distance 275,000 astronomical units; 275,000 × 93,000,000 miles = over $25\frac{1}{2}$ trillion miles. Light would require about $4\frac{1}{2}$ years to travel this enormous distance. Vega's parallax is placed not far from 0″.1. Hence Vega, the star toward which the sun is traveling with its family of planets, shines upon us from the inconceivable distance of 160 *trillion miles.*

These figures convey to our mind no idea of distance. Our imagination fails to grasp the thought, or to picture the vast void across which we are gazing. We remember that light moves at the rate of 186,300 miles a second. A ray at that speed would, in one day, plunge out into the abyss beyond Neptune six times the distance of that planet from the sun. Yet it must sweep on at this prodigious speed, day and night, for $4\frac{1}{2}$ years to span the gulf and reach a stopping point at the nearest fixed star. It has been estimated that the average time required for the light of the smallest stars visible to the naked eye to reach the earth is about 125 years. What, then, shall we say of those far-distant ones whose faint light appears as a mere fleecy whiteness even in the most powerful telescopes? The conclusion is irresistible that the light we receive set out on its sidereal journey far back in the past, perhaps before the creation of man!

The Light Year. — Just as geographers do not express the distance from New York to London in inches, so astronomers no longer use the mile as the unit of distance in expressing the remoteness of a star. Even the sun's distance of 93,000,000 miles is scarcely long enough for convenient use as a unit. But they have adopted as their unit of stellar distance, the space traveled by a wave of light in a year. This amounts to nearly six trillions of miles. When, therefore, we say that the distance to Alpha Aquilæ, the brightest star in the constellation of the Eagle, is 16 light years, we express the same thing as by saying geometrically that its parallax is $0''.20$, or that its distance from us is about 95 trillions of miles.

Motion of the Fixed Stars. — It will aid us still further in comprehending the immense distances of the stars, to learn that, though they seem to be fixed, they are moving much more swiftly than any of the planets. Thus, Arcturus speeds through space at the astonishing rate of 200,000 miles an hour, or nearly twice that of Mercury, and more than three times that of the earth. Yet, through all our lifetime, we shall never be able to detect but the slightest change in its position. Eight centuries would be required for it to move over a space equal to the moon's apparent diameter.

The Stars are Suns. — The vast distance at which the stars are known to be precludes the thought of their shining, like the planets or the moon, by reflecting back the light of our sun. They must be self-luminous, and are each, perhaps, the center of a system of planets and satellites.

Our Sun a Star. — As we see only the suns of these distant systems, so their inhabitants could see only the sun of our system, and that as a *small star*.

A PART OF THE CONSTELLATION GEMINI

Our System in Motion. — Like all the other stars, our sun is in motion. It is sweeping onward, with its retinue of worlds, 150,000,000 miles a year, toward a point in the constellation Lyra, not far removed from its brilliant star Vega, which shines nearly overhead early in September evenings. Formerly the Pleiades were thought to be the center around which this great movement is taking place, but astronomers now consider the idea as a mere speculation.

The Number of the Fixed Stars. — When we look at the heavens on a clear night, the stars seem innumerable. To count them, one would think almost as interminable a task as to number the leaves on the trees. It is, therefore, somewhat startling to learn that the entire number visible to the most piercing eyesight does not exceed 6000, while few can discern more than 4000. The number, however, which may be seen with a telescope is marvelous. On the opposite page is shown a portion of the heavens where the naked eye sees but six stars. Could we examine the same region of the sky with more powerful instruments, new constellations would doubtless be descried in the infinite depths of space.

Scintillation. — The twinkling of the fixed stars is due to interference of light. The air, being unequally dense, warm, and moist in its various strata, transmits very irregularly the different colors of which white light is composed. Now one color prevails over the rest, and now another, so that the star appears to alter its hue incessantly. White stars, as Sirius, twinkle most at a given altitude, and red stars, as Betelgeux and Antares, least. As the purity and density of the air vary, the twinkling of the stars also changes, and, therefore, it is always greatest near the horizon.[1]

[1] Humboldt says that at Cumana, in South America, where the air is remarkably pure and uniform in density, the stars cease to twinkle after they have risen 15° above the horizon. This gives to the celestial vault a

Magnitude of the Stars. — As the telescope reveals no disk of even the nearest stars, we know little about their true size. The finest spider thread, placed at the focus of the instrument, hides the star from the eye. When the moon passes in front of a star, the occultation is instantaneous, and not gradual, as in the case of the planets. Classification depends, therefore, merely upon their relative brightness. The most conspicuous are termed *stars of the first magnitude;* of these there are about twenty. The number of second-magnitude stars in the entire heavens is 65; of the third, about 200; of the fourth, 500; of the fifth, 1400; of the sixth, 5000; of the seventh, 20,000; of the eighth, 68,000; and of the ninth, 240,000. Few persons can see fainter stars than those of the fifth or sixth magnitude.

The Difference in the Brightness of the stars may result from a difference in their distance, size, or intrinsic brightness. Hence it follows that the faintest stars may not be the most distant from the earth.

Names of Stars. — Many of the brightest stars received proper names at an early date; as Sirius, Arcturus. The chief stars of each constellation are distinguished by the letters of the Greek alphabet;[1]

peculiarly calm and soft appearance. — It should be noticed that interference occurs only when the light emanates from a point. A body that subtends a visual angle, *i.e.*, has a sensible disk, like a planet, cannot twinkle.

[1] The Greek alphabet is as follows: —

Α	α	Alpha	Ι	ι	Iota	Ρ	ρ	Rho
Β	β	Beta	Κ	κ	Kappa	Σ	σ	Sigma
Γ	γ	Gamma	Λ	λ	Lambda	Τ	τ	Tau
Δ	δ	Delta	Μ	μ	Mu	Υ	υ	Upsi'lon
Ε	ε	Epsi'lon	Ν	ν	Nu	Φ	φ	Phi
Ζ	ζ	Zeta	Ξ	ξ	Xi	Χ	χ	Chi
Η	η	Eta	Ο	ο	Omic'ron	Ψ	ψ	Psi
Θ	θ	Theta	Π	π	Pi	Ω	ω	Omeg'a

the brightest one being usually called Alpha (α), the next Beta (β), etc., — the name of the constellation, in the genitive case, being put after each; as α Arietis, β Lyræ,[1] δ Geminorum, etc.

Star catalogues are issued, containing the stars arranged in order of their right ascension, and numbered for convenience of reference. Argelander's series of maps contain more than 320,000 stars, brighter than the tenth magnitude, correctly charted in position. Similar charts are now made with great rapidity and accuracy by means of photography. About fifteen observatories in all parts of the world combined in 1887 to photograph the entire firmament. This work will cost about $2,000,000, and will be completed early in the twentieth century. It will include all stars to the thirteenth magnitude.

The Constellations. — From the earliest ages, the stars have been arranged in constellations, for the purpose of more readily distinguishing them. Some of these groups were named from their supposed resemblance to certain figures, such as perching birds, pugnacious bulls, or contorted snakes, while others do honor to the memory of classic heroes.

> 'Thus monstrous forms, o'er heaven's nocturnal arch,
> Seen by the sage, in pomp celestial march;
> See Aries there his glittering bow unfold,
> And raging Taurus toss his horns of gold;
> With bended bow the sullen Archer lowers,
> And there Aquarius comes with all his showers;
> Lions and Centaurs, Gorgons, Hydras, rise,
> And gods and heroes blaze along the skies.'

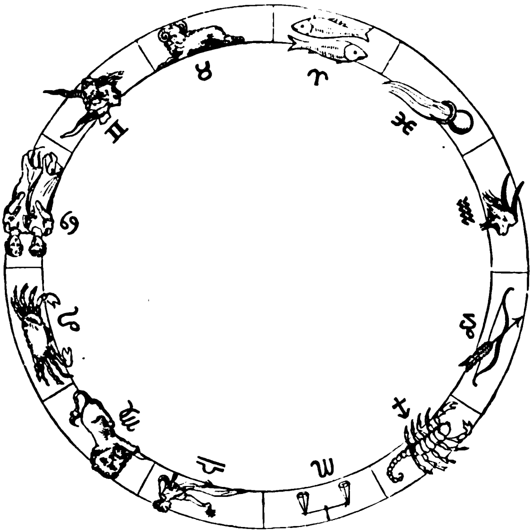
[1] This means α of Aries, β of Lyra, δ of Gemini; the genitive case in Latin being equivalent to the preposition *of*.

With a few exceptions, the likeness is purely fanciful. Not only are the figures uncouth, and the origin often frivolous, but the boundaries are not distinct. Stars occur under different names; while one constellation encroaches upon another.[1] Though, however, the constellations are thus rude and imperfect, there seems little hope of any change. Age gives them a dignity that insures their perpetuation.

The Invention of Constellations goes back to ages of which no record remains. By some it has been ascribed to the Greeks. When the signs of the zodiac were named, they doubtless coincided with the constellations. Aries (the ram) was so called because it rose with the sun in the spring time, and the Chaldean shepherds named it from the flocks, their most valued possession. Then followed in order, Taurus (the bull) and Gemini (the twins), called from the herds, which were esteemed next in value. At the summer solstice, the sun appears to stop, and, crablike, to crawl backward; hence the name Cancer (the crab). When the sun is in Leo, the brooks being dry, the lion leaves his lurking place and becomes a terror to all. Virgo comes next, when the virgins glean in the summer harvest. At the autumnal equinox, the days and nights are equally balanced, and this is beautifully represented by Libra (the scales). The vegetation decays in the fall, causing sickness and death; the Scorpion, which stings as it recedes, is suggestive of this Parthian warfare. Sagittarius (the archer) tells of the hunting month.

[1] Chambers well remarks, 'Aries should not have a horn in Pisces and a leg in Cetus, nor should 13 Argûs pass through the Unicorn's flank into the Little Dog. 51 Camelopardalis might with propriety be extracted from the eye of Auriga, and the ribs of Aquarius released from 46 Capricorni.'

Capricornus (the goat, which delights in climbing lofty precipices) denotes that at the winter solstice the sun begins to climb the sky on his return north. Aquarius (the water bearer) is a natural emblem of the rainy season. Pisces (the fishes) is the month for fishing.



THE SIGNS AND CONSTELLATIONS, AS THEY NOW COMPARE IN THE HEAVENS, THE FORMER HAVING FALLEN BACK 30° EACH

Signs and Constellations do not agree. — By the precession of the equinoxes, as we have before described on page 112, the signs have fallen back along the ecliptic about 30°, so that those stars which were, during the infancy of astronomy, in the sign of Aries (♈) are now in Taurus (♉), and those which were in the sign Pisces (♓) are now in Aries (♈).

Permanence of the Constellations. — The general appearance of the constellations and the figures which the stars form are due to the position we occupy. Could we cross the gulf of space beyond Neptune, the stars now so familiar to us would look strangely enough in their new groupings. As one in riding through a forest sees the trees apparently increase in size and open up to view before him, while they decrease in size and close in behind him, forming clusters and groups which constantly change as he passes along, so, as our earth travels with the solar system on its immense sidereal journey, the stars will gradually grow larger and brighter in front, while those behind us will appear smaller and dimmer.

Since, in addition to this, the stars themselves are in motion with varying velocity and in different directions, the constellations must change still more rapidly, so as ultimately to transform the appearance of the heavens. In time, the 'Bands of Orion' will be loosened, and the 'Seven Sisters' will glide apart. Such are the distances, however, that although these movements have been going on for ages past, no variation has occurred, since the creation of man, that is perceptible, save to the watchful astronomer.

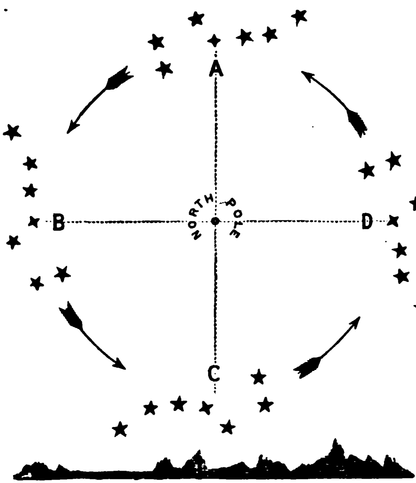
Value of the Stars in Practical Life. — The stars have been called 'landmarks of the universe.' They seem to be placed in the heavens by the Creator, not alone to elevate our thoughts and expand our conceptions of the infinite and eternal, but to afford us, amid the constant fluctuations of our own earth, something unchangeable and abiding. Every object about us is constantly shifting, but over all shine the eternal stars, each with its place so accurately marked that to the astronomer and the geographer no deception is possible. To the mariner, the heavens become a dial plate, the figures on its face set with glittering stars, along which the moon travels as a shining hand that marks off the hours with an accuracy no watch can ever rival. As he stands on the deck of his vessel, far out at sea, a single observation of the sun or the stars decides his location on the waste of waters almost as accurately as if he were at home, and had caught sight of some old landmark he had known from boyhood. In all the intricacies of surveying, the stars furnish the only immutable guide. Our clocks vainly strive to keep time with the celestial host. Thus, by an evident plan of the Creator, even in the most common affairs of life we are compelled to look for guidance from the shifting objects of earth up to the heavens above.

ANCIENT VIEWS. — Anaximenes (B.C. 500) thought that the stars were for ornaments, and were nailed like bright studs into the crystalline sphere. Anaxagoras considered that they were stones whirled up from the earth by the rapid motion of the ether, and that its inflammable properties set them on fire and caused them to shine as stars. Some schools of the Grecian philosophers — the Stoics, Epicureans, etc. — believed that they were celestial fires kept alive by matter that constantly streamed up to them from the center of the heavens. The stars were at one time said to feed on air; at another, to be the breathing holes of the universe.

Three Zones of Stars. — If we recall what was said on page 96, concerning the paths of the stars and the appearance of the heavens at different seasons of the year, we shall see that the constellations are naturally divided into three zones. The *first* embraces those which are always above our horizon; the *second*, those which are above our horizon only part of the time each twenty-four hours; and the *third*, those whose paths just graze our southern horizon, or are never seen above it.

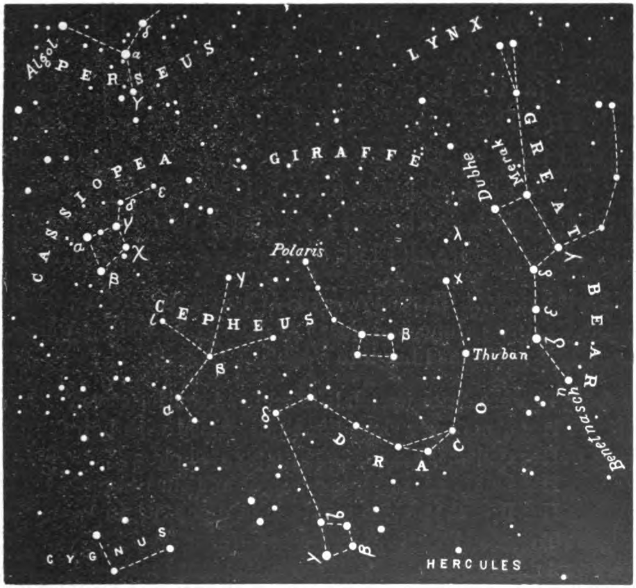
II. THE CONSTELLATIONS

1. The Northern Circumpolar Constellations are visible in our latitude every night. They may easily be traced by holding the book up toward the northern sky in such a way that Polaris and the Big Dipper on the map and in the heavens agree in position, and then locating the other constellations by comparison.



VARYING POSITIONS OF THE DIPPER

As the stars revolve about Polaris, their places in relation to the northern horizon will vary with every successive night through the year. The cut on the next page, and the map opposite page 11, represent them as they are seen at midnight of the winter solstice. At six P.M. of that day, the right-hand side of the cut should be held downward, and the Big Dipper will be directly below the North Star. At six A.M., the left-hand side should be at the bottom, and the Dipper will be above Polaris. From day to day, this aspect will change, each star coming a little earlier to the meridian, or to its position on the preceding night. The rate of this progression is six hours, or 90°, in three months.



MAP No. 1

(Northern Circumpolar Constellations; pole star near the middle)

Ursa Major is represented as the figure of a great bear. It contains 133 stars visible to the naked eye. This constellation has been celebrated among all nations. It is remarkable that the shepherds of Chaldea in Asia and the Iroquois Indians of America gave to it the same name.

PRINCIPAL STARS. — A noticeable cluster of seven stars — six of the second and one of the fourth magnitude — forms what is familiarly termed the ***Dipper***. In England it is styled Charles's Wain, from a fancied resemblance to a wagon drawn by three horses tandem.[1] Mizar (ζ) has a minute companion, Alcor. A person with average eyesight may readily detect it. Megrez (δ), at the junction of the handle and the bowl, is to be marked particularly, since it lies almost exactly in the colure passing through the autumnal equinox. Dubhe and Merak are termed the Pointers, because they point out the polar star. The bear's right fore paw and hind paw[2] are each marked by two small stars, as shown in the cut; a similar pair nearly in line with these denote the left hind paw (see ξ, map No. 4).

Mythological History. — Diana had a beautiful attendant named Callisto. Juno, the queen of heaven, becoming jealous of the maid, transformed her into a bear.

'The prostrate wretch lifts up her head in prayer,
Her arms grow shaggy, and deformed with hair;
Her nails are sharpened into pointed claws,
Her hands bear half her weight and turn to paws.
Her lips, that once would tempt a god, begin
To grow distorted in an ugly grin.
And lest the supplicating brute might reach
The ears of Jove, she was deprived of speech.
How did she fear to lodge in woods alone,
And haunt the fields and meadows once her own!
How often would the deep-mouthed dogs pursue,
Whilst from her hounds the frighted hunters flew.'

[1] Five stars of the Dipper are drifting away from the sun, at the rate of 17 miles a second, seeming to form a family or group by themselves. Proctor's *Easy Star Lessons* gives charts representing the appearance of the Dipper for 100,000 years.

[2] It is well to notice that Dubhe and Merak are about 5° apart; Dubhe and Benetnasch are about 25° apart; the paws of the bear are 15° apart; while Polaris is about 30° distant.

Some time afterward, Callisto's son, Arcas, being out hunting, pursued his mother and was about to transfix her with his uplifted spear, when Jupiter in pity transferred them both to the heavens, and placed them among the constellations as Ursa Major and Ursa Minor.

Ursa Minor is represented as the figure of a small bear. It contains twenty-seven stars, of which only three are of the third, and four of the fourth, magnitude.

PRINCIPAL STARS. — A cluster of seven stars forms the *Little Dipper*. Three of them are small, and are seen with difficulty. Polaris, at the extremity of the handle, has been known from time immemorial as the North Polar Star. Until the mariner's compass came into use, it was the star

> 'Whose faithful beams conduct the wandering ship
> Through the wide desert of the pathless deep.'

Polaris does not mark the exact position of the pole, since that is about 1¼° toward the Pointers. Owing to the gradual change in the direction of the earth's axis (see 'Precession of the Equinoxes,' page 109), this distance will gradually diminish, until in time (A.D. 2120) it will be only ½°: then it will increase again, until, in the lapse of ages, 12,000 years hence, the brilliant star Vega (α Lyræ) will fulfill the office of polar star for those who shall then live on the earth.[1]

[1] Of the nine Pyramids which are standing at Gizeh, Egypt, six have openings facing the north. These lead to straight passages which descend at a uniform angle of about 26° and lie in the meridian ; that is, point due north. If a person, about 4000 years ago, should stand at the lower end of one of these passages and look out, he would see the star Thuban, which was then the polar star (the bright star nearest the true pole), at the hour when it was directly below the pole. The supposed date of the building of these pyramids (the Great Pyramid, B.C. 2100) agrees with that epoch, and naturally suggests that the builders had some special design in this peculiar construction.

THE DISTANCE OF POLARIS is so great that, though the star is moving through space at the rate of ninety miles a minute, this tremendous speed is imperceptible to us. It requires nearly fifty years for its light to reach the earth; so that, when we look at Polaris, we know that the ray which strikes our eye set out on its journey through space half a century ago. We cannot state positively that the star is now in existence, since if it were destroyed to-day it would be nearly fifty years before we should miss it.

CALCULATION OF LATITUDE FROM POLARIS. — By an observer at the equator, Polaris is seen near the horizon. If he goes north, the horizon is depressed, and Polaris seems to rise in the heavens. When it has reached the height of a degree, the observer is said to have passed over a degree of latitude on the earth's surface. As he moves farther north, the polar star continues to ascend; its distance above the horizon denoting the latitude of each place in succession, until at the north pole, if one could reach that point, Polaris would be seen almost immediately overhead; it would be directly overhead, if the star were exactly at the true pole of the heavens.

Draco is represented by the figure of a long, sinuous serpent, stretching between Ursa Major and Ursa Minor, partly encircling the latter constellation, and finally reaching out its head almost to the body of Hercules.

PRINCIPAL STARS. — Four small stars form a quadrilateral figure at the head; a fifth, of the fourth magnitude, which is scarcely visible, marks the end of the nose; several scattered groups and little triangles of small stars denote the position of the various coils of the body; thence, an irregular line of stars traces the dragon's tail around between Ursa Major and Ursa Minor. Thuban, lying midway between γ of the Little Dipper and ζ of the Big Dipper, is noted as the polar star of forty centuries ago.

MYTHOLOGICAL HISTORY.—Jupiter had carried off Europa. Agenor, her father, sent her brother Cadmus in pursuit of his lost sister, bidding him not to return until he was successful in his search. After a time Cadmus, weary of his wanderings, inquired of the oracle of Apollo concerning the fate of Europa. He was told to cease looking for his sister, to follow a cow as a guide, and when she rested, there to build a city. Hardly had Cadmus stepped out of the temple, when he saw a cow slowly walking along. He followed her until she came upon the broad plains where Thebes afterward stood. Here she stopped. Cadmus, wishing to offer a sacrifice to Jupiter in gratitude for the delightful location, sent his servants to seek for water. In a dense grove near by was a fountain guarded by a fierce dragon (*Draco*), and sacred to Mars. The Tyrians, approaching this and attempting to dip up some water, were attacked, and many of them killed, by the enormous serpent, whose head overtopped the tallest trees. Cadmus, becoming impatient, went in search of his men, and on arriving at the spring, saw the sad disaster. He forthwith fell upon the monster, and after a severe battle succeeded in slaying him. While standing over his conquered foe, he heard a voice from the ground bidding him take the dragon's teeth and sow them. He obeyed. Scarcely had he finished when the earth began to move and the points of spears to prick through the surface. Next, nodding plumes shook off the clods, and the heads of armed men protruded. Soon a great harvest of warriors covered the entire plain. Cadmus, in terror at the appearance of those giants, whom he termed Sparti (*the sown*), prepared to attack them, when suddenly they turned upon themselves, and never ceased their warfare till only five of the crowd survived. These, making peace with one another, joined Cadmus, and assisted him in building the city of Thebes.

Cepheus is represented as a king in regal state, with a crown of stars on his head, while he holds in his hand a scepter which is extended toward his wife, Cassiopeia. The constellation contains thirty-five stars visible to the naked eye.

PRINCIPAL STARS. — The brightest star is Alderamin (α), in the right shoulder. Alphirk (β), in the girdle, is at the common vertex of several triangles, which point out respectively the left shoulder (ι), the left knee (γ), and the right foot. The head, which lies in the Milky Way, is marked by a little triangle of three stars. This forms, with α, β, and ι, quite a regular quadrilateral figure. A bright star of the fifth magnitude, close to Polaris, points out the left foot.

Cassiopeia[1] is represented as a queen seated on her throne. On her right is the king; on her left, Perseus, her son-in-law; above her, Andromeda, her daughter. The constellation contains sixty-seven stars visible to the naked eye.

PRINCIPAL STARS. — A line drawn from Megrez (δ), in Ursa Major, through Polaris and continued an equal distance, will strike Caph (β) in Cassiopeia. This star is noticeable as marking, with the others named, the equinoctial colure. It is on the same side of the true pole as Polaris. The principal stars form the figure of an inverted chair, which is very striking and may readily be traced.

2. Equatorial Constellations. — The constellations we shall now describe lie south of the circumpolar groups. Only a portion of their paths is above our horizon. In using the maps, the observer is supposed to stand with

[1] For the mythological history of Cassiopeia, see Perseus and Andromeda. The names of the principal stars in the Chair make a mnemonic word, — βαγδε, *bagde*. The student can often form such an association of the letters, and will find the device an aid to his memory. (Compare Virgo, page 240.)

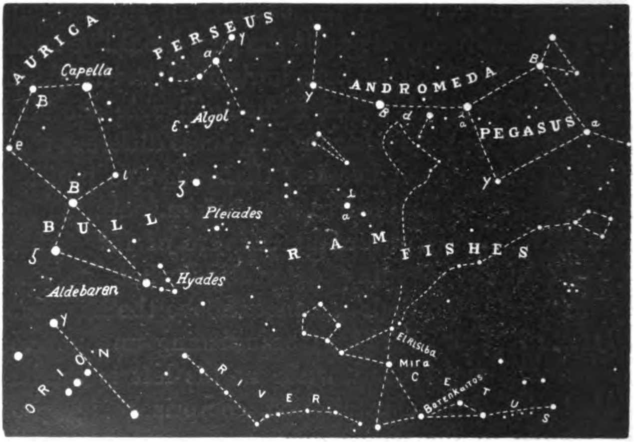
his back toward Polaris, and to be looking directly south. Commencing with Perseus and Andromeda, so intimately connected with the other members of the royal family just described, we pass eastward in our survey, and notice the various constellations as they slowly defile in silent march across the sky.

The next map represents the constellations on or near the meridian at nine o'clock in the evening of the winter solstice. On the evening of the autumnal equinox, the left-hand side of the map should be turned downward toward the eastern horizon. On the evening of the vernal equinox, the right-hand side should be turned to the western horizon. At these different times, the asterisms, though keeping their relative positions, will be diversely inclined to the horizon. As the stars apparently move westward at the rate of 15° an hour, the time of the evening determines what stars will be visible, and also their distances above the horizon.

Perseus is represented as brandishing an enormous sword in his right hand, while at his left is the head of Medusa. The constellation comprises eighty-one stars visible to the naked eye.

PRINCIPAL STARS. — The most prominent figure is called the *Segment of Perseus*. It consists of several stars arranged in a line curving toward Ursa Major. Algenib (α), the brightest of these, is of the second magnitude. Algol (page 253), in the midst of a group of small stars, marks the head of Medusa. Between the bright stars of Perseus and Cassiopeia is a beautiful star cluster visible to the naked eye.

MYTHOLOGICAL HISTORY. — Perseus, from whom this constellation was named, was the son of Jupiter and Danaë. His grandfather, Acrisius, having been informed by the oracle that his grandson would be the instrument of his death, put the mother and child in a coffer and set them adrift on the sea. Fortunately, they floated near the island Seriphus, where they were rescued and kindly treated by a brother of Polydectes, king of the country. When Perseus had grown up, he was ordered by Polydectes to bring him, as a marriage gift, the head of Medusa. Now Medusa was once a beautiful maiden, who dared to compare her ringlets with those of Minerva; whereupon the goddess changed her locks into hissing serpents, and made her features so hideous that she



MAP No. 2
(Constellations bordering on the zodiac)

turned to stone every living object upon which she fixed her Gorgon gaze. Perseus was at first overpowered at the thought of undertaking this enterprise; but Mercury promised to be his guide, and to furnish him with his winged shoes; Minerva loaned him her wonderful shield, that was bright as a mirror; and the Nymphs gave him, in addition, Pluto's helmet, which made the bearer invisible. Thus equipped, Perseus mounted into the air and flew to the ocean, where he found the three Gorgons, of whom Medusa was one, asleep. Fearing to gaze in her face, he looked upon the image reflected in Minerva's shield, and with his sword severed Medusa's head from her body. The blood gushed forth.

and with it the winged steed *Pegasus*. Grasping the head, Perseus flew away. The other Gorgons, awaking, pursued him, but he escaped their search by means of Pluto's helmet. As he flew over the wilds of Libya, in his aerial route, the blood dripping from the gory head of the monster produced the innumerable serpents for which that country was afterward noted.

Andromeda is represented as a beautiful maiden chained to a rock.

PRINCIPAL STARS. — Algenib and Algol in Perseus form, with Almach (γ) in the left foot of Andromeda, a right-angled triangle opening toward Cassiopeia. This figure is so perfect that the stars may easily be recognized. The girdle is pointed out by Mirach (β), and two other stars which form a line slightly curving toward the right foot. The breast is denoted by a very small triangle composed of three stars, — δ of the fourth magnitude, another of the fifth magnitude just south, and an exceedingly minute star a little at the west. Alpheratz (α), in the head of Andromeda, belongs also to *Pegasus*. This star, with three others, — Algenib (γ), Markab (α), and Scheat (β), — all of the second magnitude, constitute the *Great Square of Pegasus*. The brightest stars of these two constellations form a figure strikingly like the Big Dipper. Algenib and Alpheratz lie very near the equinoctial colure which passes through Caph.

MYTHOLOGICAL HISTORY. — Cassiopeia had boasted that her daughter Andromeda was fairer than the Sea Nymphs. They appealed, in great indignation, to Neptune, who sent a sea monster (*Cetus*) to devastate the coast of Ethiopia. To appease the deities, her father Cepheus was directed by the oracle to bind his daughter to a rock, to be devoured by Cetus. Perseus, returning from the destruction of Medusa, saw Andromeda in her forlorn condition. Struck by her beauty and tears, he offered to liberate her at the price of her hand. Her parents joyfully consented, and, in addition, offered a royal dower. Perseus slew the terrible monster, and, freeing Andromeda, restored her to her parents. All the prominent actors in this scene were honored with seats among the constellations. The Sea Nymphs, it is said, in petty spite of Cassiopeia, prevailed that she should be placed where for half of the time she hangs with her head downward, — a fit lesson of humility. *Cepheus*, her husband, shares in her punishment.

Aries, the *ram*, was anciently the first constellation of the zodiac. It is now the *first sign*, but the *second constellation*. On account of the precession of the equinoxes, the constellation Pisces occupies the first sign.

PRINCIPAL STARS. — The most noted star is α Arietis (Alpha of Aries, more commonly called simply Arietis), in the right horn. This lies near the path of the moon and is one of the stars by which terrestrial longitude is reckoned. A line drawn from Almach to Arietis will pass through a beautiful figure of three stars called *The Triangles*.

MYTHOLOGICAL HISTORY. — Phrixus and Helle were the children of Athamas, king of Thessaly. Being persecuted by Ino, their stepmother, they were compelled to flee for safety. Mercury provided them a ram which bore a golden fleece. The children were no sooner placed on his back than he vaulted into the heavens. In their aerial journey, Helle becoming dizzy fell off into the sea, which was afterward called the Hellespont, now the Dardanelles. Phrixus having reached Colchis in safety, offered the ram in sacrifice to Jupiter and gave the golden fleece to Aetes, his protector. The Argonautic expedition in pursuit of this golden fleece, by Jason and his followers, is one of the most romantic of mythological stories. It is, undoubtedly, a fanciful account of the first important maritime expedition. Rich spoils were the prizes to be secured.

Taurus consists of the head and shoulders of a *bull*, which is represented in the act of plunging at Orion.

PRINCIPAL STARS. — The *Hyades*, a beautiful cluster in the head, forms a distinct V. The brightest of these is Aldebaran, a fiery red star of the first magnitude.[1] The *Pleiades* (Job xxxviii. 31), or the Seven Sisters, is the most conspicuous group in the sky (page 217). It contains a large number of stars, six of which are visible to the naked eye. The myth runs that there were seven anciently, but that Electra left her place in order not to behold the ruin of Troy, which was founded by her son Dardanus. Other myths relate that the *Lost Pleiad* was Merope, who married a mortal. Alcyone is the brightest Pleiad. El Nath (β) and ζ point out the horns of Taurus.

MYTHOLOGICAL HISTORY. — This is the animal whose form Jupiter assumed when he bore off Europa. The Pleiades were the daughters of Atlas, and Nymphs of Diana's train. They were distinguished for their unblemished virtue and mutual affection. The hunter *Orion* having pursued them one day, in their distress they prayed to the gods, when Jupiter, in pity, transferred them to the heavens.

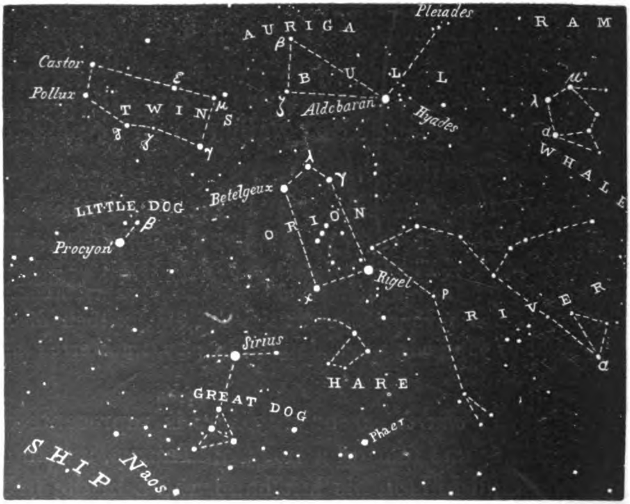
Auriga, the *charioteer* or *wagoner*, is represented as a man resting one foot on a horn of Taurus, and holding a goat and kids in his left hand and a bridle in his right.

THE PRINCIPAL STARS are arranged in an irregular five-sided figure. Capella, the goat star, is of the first magnitude. Thirty-two years are required for its light to reach the earth. Near by is a tiny triangle, formed of three small stars called the *Kids*. Menkalinan (β) is in the right shoulder, θ in the right hand, β (com-

[1] Aldebaran is estimated to move through the heavens and away from the sun at the rate of about thirty miles a second. (See pages 215, 275.) A number of the bright stars between Aldebaran and the Pleiades have a common motion of about 10″ a century toward the east.

mon to Auriga and Taurus) the right foot, and ι the left foot. Capella, β, and δ (a star in the head) form an approach to an equilateral triangle. The origin of this constellation is unknown.

Pisces, the *fishes*, is represented by two fishes tied together by a long ribbon. It consists of small stars, which can be traced only in the absence of the moon.



MAP No. 3
(Constellations mostly south of the zodiac)

Cetus, the *whale*, is a huge sea monster, slowly plowing his way eastward, midway between the horizon and the zenith. It may easily be found, on a clear night, by means of the numerous figures given in the map.

Gemini, the *twins*, represents the twin brothers Castor and Pollux.

THE PRINCIPAL STARS are Pollux and Castor, of the first and second magnitudes. Castor is resolved by the telescope into two stars, whose angular distance from each other is 5″, the angle that one inch would subtend 1150 yards distant. The constellation is clearly distinguished by two nearly parallel rows of stars, which, by a slight effort of the imagination, may be extended into the constellations Taurus and Orion.

MYTHOLOGICAL HISTORY. — Castor and Pollux are noted, — the former for his skill in training horses, the latter for boxing. They were tenderly attached to each other, and were inseparable in their adventures. They accompanied Jason on the Argonautic expedition. A storm having arisen during this voyage, Orpheus played on his wonderful lyre and prayed to the gods; whereupon the tempest was stilled, and starlike flames shone upon the heads of the twin brothers. Sailors, therefore, considered them as patron deities, and the balls of electric flame seen on masts and shrouds, now called St. Elmo's fire, were named after them. Afterward, Castor was slain. Pollux being inconsolable, Jupiter offered either to take him up to Olympus, or to let him share his immortality with his brother. Pollux preferred the latter, and so the brothers pass alternately one day under the earth, and the next in the Elysian Fields. Not only did sailors thus confide in their watch over navigation, but soldiers believed them to return, mounted on snow-white steeds and clad in rare armor, to take part in the hard-fought battles of the Romans.

'Back comes the chief in triumph
  Who in the hour of fight
Hath seen the great Twin Brethren
  In harness on his right.
Safe comes the ship to haven,
  Through billows and through gales,
If once the great Twin Brethren
  Sit shining on the sails.' — *Lays of Ancient Rome.*

Orion is represented as a hunter attacking Taurus. He has a sword in his belt, a club in his right hand, and the skin of a lion in his left. This is one of the most clearly defined and conspicuous constellations in the heavens.

PRINCIPAL STARS. — Four brilliant stars, in the form of a parallelogram, mark the outlines of Orion. Betelgeux, a beautiful ruddy star of the first magnitude, is in the right shoulder; Bellatrix (γ), of the second magnitude, is in the left shoulder; Rigel, of the first magnitude, is in the left foot; and Saiph (κ), of the third magnitude, is in the right knee. Two small stars near λ form with it a small triangle, and λ itself is the vertex of a larger triangle composed of λ, γ, and Betelgeux. Near the center of the parallelogram are three stars forming the *Belt of Orion.* This group is also called the Bands of Orion (Job xxxviii. 31), Jacob's Rod, and the Yard. It received the last name because it forms a line 3° long, divided into equal parts by a star in the center. These divisions are useful for measuring the apparent distances of stars from one another. Running from the belt southward is an irregular line of stars which marks the sword; west of Bellatrix is a curved line denoting the lion's skin. South of Orion are four stars forming a beautiful figure styled *The Hare.*

MYTHOLOGICAL HISTORY. — Orion was a famous hunter. Becoming enamored of Merope, he desired to marry her. Œnopion, her father, opposing the choice, put out the eyes of the unwelcome suitor. The blinded hero followed the sound of a Cyclops's hammer until he came to Vulcan's forge. Vulcan, taking pity, instructed Kedalion to conduct him to the abode of the sun. Placing his guide on his shoulder, Orion proceeded to the east, and at a favorable place

'Climbing up a narrow gorge,
Fixed his blank eyes upon the sun.'

The healing beams restored him to sight. As a punishment for having profanely boasted that he was able to conquer any animal the earth could produce, he was bitten in the heel by a scorpion. Afterward, Diana placed him among the stars; where *Sirius* and *Procyon*, his dogs, follow him, the *Pleiades* fly before him, and far remote is the *Scorpion*, by whose bite he perished.

Canis Major and Canis Minor, the *Great Dog* and the *Little Dog*, contain each a single star of the first magnitude, Sirius and Procyon.[1] These two, with Betelgeux, Phaet in the Dove, and Naos in the Ship form a huge figure known as the Egyptian X. Sirius, the dog star, is the most brilliant star in the heavens. It is coming toward the earth at the rate of ten miles a second. More than eight years are required for its light to reach us.[2] (See note, p. 327.) Between the Dogs is the constellation *Monoceros*, or *Unicorn.*

Leo is represented as a rampant lion. It is one of the most beautiful constellations in the zodiac.

THE PRINCIPAL STARS are arranged in the form of a sickle. Regulus, in the handle, is a brilliant star of the first magnitude. It is almost exactly in the ecliptic. Zosma (δ) lies in the back of the lion, θ in the thigh, and Denebola (β), of the second magnitude, in the tail.

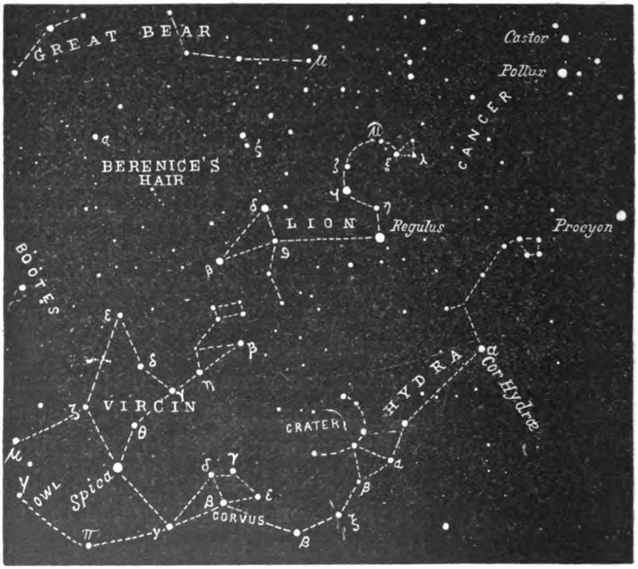
Cancer includes the stars that lie irregularly scattered between Gemini, Head of Hydra, Procyon, and Leo. In the midst of these is a luminous spot, called Præsepe, or the Beehive, which an ordinary glass will resolve into stars.

[1] Procyon, like Sirius, was formerly considered a star of evil omen, and as bringing bad weather. 'Who that is learned in matters astronomical,' said Digges, the astrologer, 'noteth not the great effects at the rising of the star called the Litel Dogge?'

[2] In 1862 Alvan Graham Clark, the famous telescope maker, discovered a companion of Sirius, whose distance from the star is on the average nearly equal to Neptune's distance from the earth.

Virgo is represented as a beautiful maiden with folded wings, bearing in her left hand an ear of corn.

THE PRINCIPAL STAR, Spica, in the ear of corn, is of the first magnitude, and is used for determining longitude at sea. Denebola, Cor Caroli (Map No. 5), Arcturus, and Spica form a figure about 50° in length,



MAP NO. 4

(The zodiac runs diagonally down and across the chart, from right to left)

called the Diamond of Virgo. Five third-magnitude stars, ε, δ, γ, η, β (the mnemonic word is *bēgde*), make a corner known among the Arabian astronomers as 'the retreat of the howling dog.'

MYTHOLOGICAL HISTORY.—Virgo was the goddess Astræa. According to the poets, the early history of man was the golden age. It was a time of innocence and truth. The gods dwelt among men, and perpetual spring delighted the earth. Next, came the silver age, less tranquil and serene, but still the gods lingered and happiness prevailed. Then followed the brazen and iron ages, when wickedness reigned supreme. The earth was wet with slaughter. The gods left the abodes of men, one by one, Astræa alone remaining; until finally she too, last of all the immortals, bade the earth farewell. Jupiter thereupon placed her among the constellations.

Hydra is a long, straggling serpent, having its head near Procyon and extending its tail beyond Virgo, a total distance of more than 100°.

THE PRINCIPAL STAR is Cor Hydræ, of the second magnitude. It is a lone star, and may easily be found by a line drawn from γ Leonis through Regulus, and continued about 23°. The head is marked by a rhomboidal figure of four stars of the fourth magnitude lying near Procyon. Several little triangles may be formed of them and other small stars lying near. The *Crater*, or cup, is a beautiful and very striking semicircle of six stars of the fourth magnitude directly south of θ Leonis. *Corvus* (β, ϵ, γ, δ), the raven, lies 15° east of the Cup. ϵ Corvi is in the equinoctial colure.

MYTHOLOGICAL HISTORY. — Hydra was a fearful serpent which in ancient times infested the lake Lerna. Its destruction constituted one of the twelve labors of Hercules. The raven was formerly white, it is said, but was made black on account of its proneness to tale bearing.

Canes Venatici, the *hunting dogs*. This constellation contains the bright star Cor Caroli (α), which is found by a line passing from Benetnasch (η Ursæ Majoris) through Berenice's Hair to Denebola.

Berenice's Hair is a beautiful cluster midway between Cor Caroli and Denebola. Near by is a single bright star of the fourth magnitude.

Mythological History. — Berenice was the wife of Ptolemy. Her husband going upon a dangerous mission, she promised to consecrate her beautiful tresses to Venus if he should return in safety. Soon after the fulfilment of this vow, the hair disappeared from the temple where it had been deposited. Berenice being

Map No. 5

(Constellations north of the zodiac)

much disquieted at this loss, Conon, the astronomer, announced that the locks had been transferred to the heavens, in proof of which he pointed out this cluster of hitherto unnamed stars. All parties were satisfied with this happy termination of the difficulty.

Boötes, the *bear driver*, is represented as a huntsman grasping a club in his right hand, while in his left he holds by the leash his two greyhounds (*Canes Venatici*), with which he is pursuing the Great Bear continually around the north pole.

PRINCIPAL STARS. — Arcturus (Job ix. 9), a magnificent star of the first magnitude, is in the left knee. It forms a large, nearly equilateral triangle with Denebola and Spica, and also one with Denebola and Cor Caroli. It travels nearly five miles a second toward the earth. Its light reaches the earth in 160 years. Mirach (ϵ) lies in the girdle, δ in the right shoulder, Alkaturops (μ) in the club, β in the head, and Seginus (γ) in the left shoulder. Seginus forms with Cor Caroli and Arcturus a triangle, right-angled at Seginus. Three small stars in the left hand of Boötes lie near Benetnasch.

MYTHOLOGICAL HISTORY. — Boötes is supposed to have been Arcas, the son of Callisto. (See Ursa Major.)

Hercules is represented as a warrior clad in the skin of the Nemean lion, holding a club in his right hand and the dog Cerberus in his left. His foot is near the head of Draco, while his head lies 38° south and his club reaches 10° beyond.

THE PRINCIPAL STAR is Ras Algethi (α Herculis). This forms an isosceles triangle with β and δ. A peculiar figure of four stars (π, η, ζ, ϵ), north of these, marks the body. (See Maps, Nos. 5, 6, and 7.) The left knee is pointed out by θ, and the left foot by γ.

MYTHOLOGICAL HISTORY. — This constellation immortalizes the name of one of the greatest heroes of antiquity. Hercules was the son of Jupiter and Alcmena. While he was yet lying in his cradle, Juno, in her jealousy, sent two serpents to destroy him. The precocious infant, however, strangled them with his hands. By the cunning artifice of Juno, Hercules was made subject to Eurystheus, his elder half-brother, and compelled to perform all his commands. Eurystheus enjoined upon him a series of the most difficult and dangerous enterprises that could be conceived, which have been termed the 'Twelve Labors of Hercules.' Having completed these tasks, he afterward achieved others equally celebrated. Near the close of his life he killed the centaur Nessus. The dying monster charged Dejanira, the wife of Hercules, to preserve a portion of his blood as a charm to use in case the love of her husband should ever fail her. In time, Dejanira thought she needed the potion, and Hercules having sent for a white robe to wear at a sacrifice, she steeped the garment in the blood of Nessus. No sooner had Hercules put on the fatal robe than the venom stung his bones and boiled through his veins. He attempted to tear it off, but in vain. It stuck to his flesh, and tore off great pieces of his body. The hero, finding he must die, ascended Mount Œta, where he erected a funeral pyre, spread out the skin of the Nemean lion, and laid himself down upon it. Philoctetes applied the torch. With perfect serenity of countenance Hercules awaited approaching death —

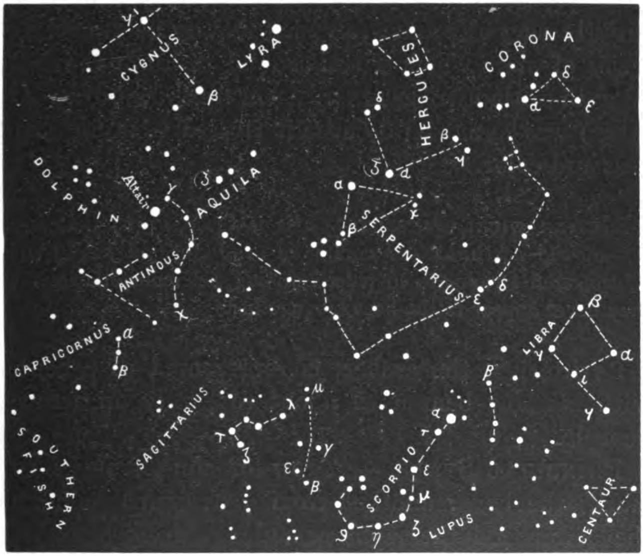
> 'Till the god, the earthly part forsaken,
> From the man in flames asunder taken,
> Drank the heavenly ether's purer breath.
> Joyous in the new unwonted lightness
> Soared he upward to celestial brightness,
> Earth's dark, heavy burden lost in death.' — SCHILLER.

Corona Borealis consists of six stars arranged in a semicircular form. The brightest of these is Alphecca. This makes a nearly equilateral triangle with Mirach (ϵ) and δ in Boötes. It forms an isosceles triangle with Mirach and Arcturus.

Serpentarius, or **Ophiuchus**, the *serpent bearer*, is represented as a man grasping in both hands a prodigious serpent, which is writhing in his grasp.

PRINCIPAL STARS. — Ras Alhague (α), in the head, is of the second magnitude. It is about 5° from Ras Algethi. They form a pair of stars conspicuous like the pairs in Gemini, Canis Minor, Canis Major, etc.; β marks the right shoulder, and κ the left. There is a small cluster near β, called *Taurus Poniatowskii.* An irregular square of four stars, near γ Herculis, denotes the head of the Serpent.

Mythological History. — This constellation perpetuates the memory of Æsculapius, the father of medicine. He was so skillful that he restored several persons to life; whereupon Pluto com-



Map No. 6

(The zodiac curves downward through the lower part of the map)

plained to Jupiter that his kingdom was in danger of being depopulated. Therefore Jupiter struck him with a thunderbolt, but afterward placed him among the constellations. Serpents were sacred to Æsculapius, because of the superstitious idea that they have the power of renewing their youth by changing their skin.

Libra represents the scales of Astræa (Virgo), the goddess of justice. It may be recognized by the quadrilateral figure formed by its four principal stars.

Scorpio is represented as the figure of a huge scorpion, stretching through 25°. It is a most interesting constellation.

PRINCIPAL STARS. — Antares (α) is a fiery red star of the first magnitude. It marks the heart of the Scorpion. The head is indicated by several stars, the most prominent of which is β, arranged in a line slightly curved. The tail may readily be traced by a series of stars which winds around through the Milky Way in a beautiful manner. Antares (*anti*, like; *Arēs*, Mars) was so named because it rivaled Mars in brightness and color.

MYTHOLOGICAL HISTORY. — This is the scorpion that sprang out of the earth at the command of Juno, and stung Orion. Scorpio and Orion are so placed among the constellations that they never appear in the heavens together.

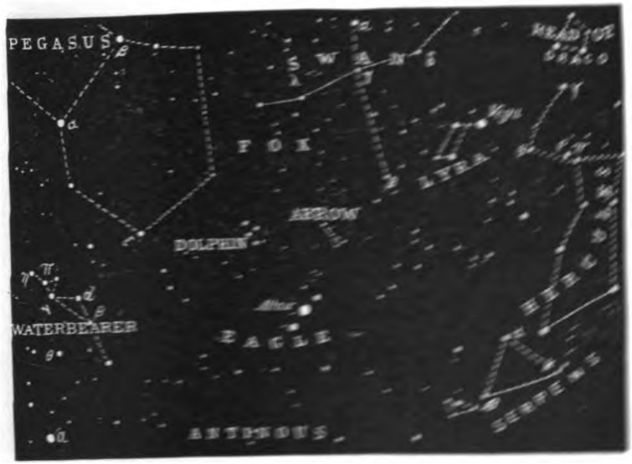
Sagittarius, the archer, is represented as a centaur with his bow bent as if about to let fly an arrow at Scorpio.

PRINCIPAL STARS. — A row of stars from μ to β marks the bow: another from γ eastward points out the arrow and the right arm drawn back in bending the bow. North of τ, two stars of the fourth magnitude denote the head of the centaur. The *Milk Dipper*, so called because the handle lies in the Milky Way, is a very striking figure.

MYTHOLOGICAL HISTORY. — This constellation is named in honor of Chiron, one of the centaurs. These monsters were represented as men from the head to the loins, while the remainder of the body was that of a horse — the ancients having so high an opinion of that animal that the union was not considered in the least degrading.

Chiron was renowned for his skill in music, medicine, and prophecy. The most distinguished heroes of mythology were among his pupils. He taught Æsculapius physic; Apollo, music; and Hercules, astronomy.

Capricornus contains no very conspicuous stars. The *Southern Fish* (Map No. 6) has one star of the first magnitude, Fomalhaut (*α*, Map No. 7), which on a clear

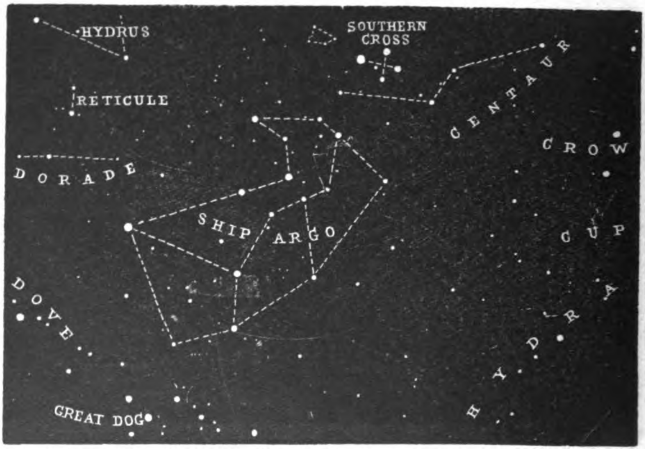


[illegible]

[illegible]

summer evening may be [illegible]
the zenith. *Antinous and* [illegible]
lation. It contains a [illegible]
tude, Altair. This [illegible]
one in a row of three [illegible]
denotes the tail of the [illegible]
named [illegible] and the [illegible]
the *Dolphin* contains [illegible]
diamond. It is sometimes [illegible]

Cygnus, the *swan*, is a remarkable group of stars, the principal ones being so arranged as to form a large and beautiful cross. The upright piece lies along the Milky Way. It is composed of four stars, three of which, Deneb (α), γ, and β, are bright, while the fourth is a variable star. No. 61, a minute star, scarcely visible to the naked eye, is noted as being the nearest to the earth of all the fixed stars in the northern hemisphere (p. 252).

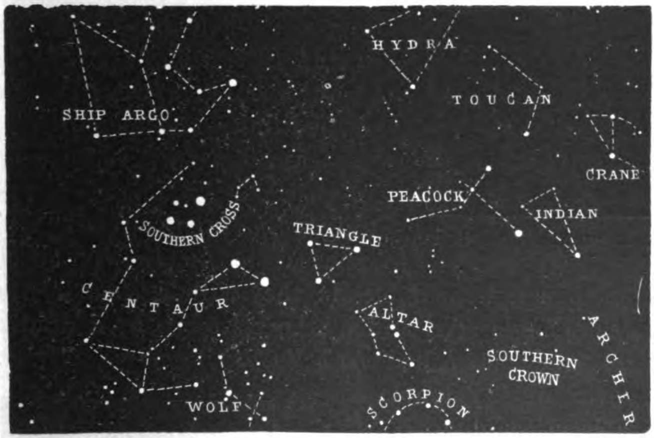


MAP No. 8
(Extreme southern constellations)

Lyra, the *harp*, contains one brilliant blue star, Vega (page 227). Close by it is a parallelogram of four smaller stars, by which it may easily be recognized.

MYTHOLOGICAL HISTORY. — This is the celestial lyre upon which Orpheus discoursed such ravishing music that wild beasts forgot their fierceness and gathered about him to listen, while the rivers ceased to flow, and the very rocks and trees stood entranced.

3. Southern Constellations. — We now imagine ourselves viewing the stars visible to a person far south of the equator. The constellations are reversed with reference to the horizon. The two stars which, in the northern hemisphere, compose the base of the parallelogram in Orion, form here the upper side. Sirius is above Orion. All the northern circumpolar constellations are hidden from view. At the southern pole there is no conspicuous star, but the richness and number of the neighboring stars compensate in part for this defi-



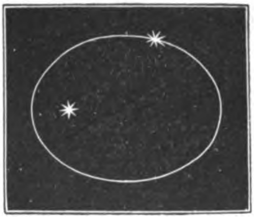
MAP No. 9
(Extreme southern constellations)

ciency. Here is the magnificent constellation Argo, in which we find Canopus, looked upon anciently as next to Sirius in brilliancy : η, a variable star, now surpasses it in brightness.

Nearly at the height of the south pole, blazes the *Southern Cross;* below is the *Centaur*, containing two stars of the first magnitude and five of the second ; and above is Hydrus, where shines Achernar, another beautiful star of the first magnitude.

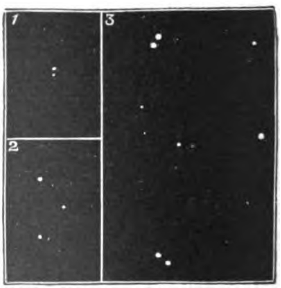
III. DOUBLE STARS, COLORED STARS, NEBULÆ, ETC.

1. Double Stars. — To the naked eye, all the stars appear single. With the telescope, over 10,000 have been found to be double. Thus, Polaris consists of two stars about 18″ apart; Rigel has a companion about 10″ from it; and Sirius, one distant 7″. A good opera glass will separate ε Lyræ into two components.



ORBIT OF A DOUBLE STAR

In case two stars happen to lie very nearly in the same straight line from us, though at immense distances from each other, their light will blend: they will be seen by the eye as a single star, and by the telescope as a double star. They are called *optically double* stars. Many, however, of the double stars have been found to be *physically* connected. Each double star of this class forms a binary system of two suns revolving in an elliptical orbit about their common center of gravity, like the planets in the solar system, in accordance with Newton's law of gravitation. In a few instances there are combinations of *triple*, *quadruple*, and even



ε LYRÆ

1. As seen in an opera glass.
2. As seen in a small telescope.
3. As seen in a telescope of great power.

septuple stars. Thus ε Lyræ is a *double-double* star, while θ Orionis is a system of six suns. The components of a double star commonly differ in brightness; so that frequently the fainter one is nearly lost in the brilliancy of its companion sun.

THE PERIODS of about 50 systems have been ascertained. Thus, ξ Ursæ Majoris is a double star, and the two stars of which it is composed have performed an entire revolution of 60 years about each other since they were found to be connected. About 20 binary stars now known have periods of less than a century, while others have periods which seem to extend, in some cases, beyond a thousand years. As the spectroscope has enabled us to ascertain that some stars are moving toward us and others from our world (page 275), this marvelous instrument has also led to a further discovery of the utmost importance, which has been related as follows: —

'It was Bessel who first wrote of the "astronomy of the invisible," and his prediction has been marvelously fulfilled by the recent discovery of spectroscopic binaries. They are binaries whose components are so near each other that the telescope cannot divide them, and whose spectra, therefore, overlie. As the orbits of binary systems stand at all possible angles in space, a few will appear almost edge on. Let the two components be in conjunction, as referred to the solar system; clearly their spectra will be identical. But when they reach quadrature, one will be receding from the earth and the other coming toward it. A given line in the compound spectrum then will appear double, on account of displacement due to motion of the components in opposite directions. Measure the displacement, and observe the period of its recurrence. This gives the velocity of the components relatively to each other, the dimensions of their orbit, and their mass in terms of the sun.' — TODD's *New Astronomy*, page 454.

Mizar was the first binary so discovered, in 1889; the period of its invisible companion is 52 days, and the mass of the system exceeds the sun's forty fold. Many others have been found, and the most rapid of all yet known is μ Scorpii, whose period is only 1d. 10h. 42m. 30s. In all cases the secondary body is so close to the central star as to be forever beyond the power of telescopes alone to visualize.

ORBITS. — Generally speaking, it is not possible to ascertain the dimensions of the orbits of the double stars, until their distances from us are definitely known. 'Taking the estimated distance of 61 Cygni (450,000 times the sun's distance from the earth) as a basis, the companions of that system cannot cultivate a very intimate acquaintance, since they must be over a billion miles apart. From these data, astronomers have attempted even to calculate the mass of some of the double stars. 61 Cygni, although scarcely visible to the naked eye, and known to be the second nearest to us of any of the fixed stars, is estimated to weigh one third as much as our sun.'

2. Colored Stars. — We have already noticed that the stars are of various colors. Sirius is white; Antares, red; and Capella, yellow; while Vega has a blue tint, and Castor has a green one. In the pure transparent atmosphere of tropical regions, the colors are far more brilliant. There, oftentimes, the nocturnal sky is a blaze of jewels, — the stars glittering with the green of the emerald, the blue of the amethyst, and the red of the topaz.

In the double and multiple stars, every color is presented in all its richness and beauty; while there are also combinations of colors complementary to each other. Here is a green star with a blood-red companion; here an orange and a blue sun; there a yellow and a purple one. The triple star γ Andromedæ is formed of an orange-red sun and two others of an emerald green.

Every tint that blooms in the flowers of summer flames out in the stars at night. 'The rainbow flowers of the footstool and the starry flowers of the throne' proclaim their common Author; while rainbow, flower, and star alike evince the same divine love of the beautiful.

We can hardly conceive the effects produced in a system having colored suns. Suppose a planet revolving about ψ Cassiopeiæ, for instance. This is illuminated by a red, a blue, and a green sun. Sometimes, by the succession of these suns, a cheerful green day would present a charming relief to a fiery red one; and that might be still further subdued by a gentle blue one. The odd contrast of color and the vicissitudes of extreme heat and cold that obtain on such a world, present a picture which our fancy can sketch better than words can paint.

3. The Variable Stars have periodic changes of brilliancy. The following are most conspicuous: —

ALGOL, in the Head of Medusa, is a star of the 2.3 magnitude for about two and a half days, when it suddenly decreases, and in about four hours descends to the 3.5 magnitude. It then rekindles, and in about five hours is again as brilliant as ever.

MIRA, the *wonderful*, a star in the Whale, has a period of eleven months. At maximum it is ordinarily of the second magnitude for about twelve days. It then decreases for three months until it becomes invisible to the naked eye. This period of darkness lasts five months; it then rebrightens for three months, until it regains its former luster. Occasionally, however, it fails to brighten at all beyond the fourth magnitude, while on one occasion its light was almost equal to that of Aldebaran. Sometimes no perceptible change takes place for a month; then again there is a sensible alteration in a few days.

THE REASON OF THIS VARIABILITY is not certainly understood. It has been suggested, in the case of Mira, that it may be a globe rotating on its axis, and that different portions of its surface, illuminated to different degrees of intensity, are thus presented to us. Others have conceived that there may be satellites revolving about these suns, and that when their dark bodies interpose between the stars and our earth, they eclipse the light wholly or in part. This is now regarded as the true explanation of the variability of Algol and other stars of which it is the type.

About one thousand variable stars are now known, one half of which have recently been found in stellar clusters like the one figured on page 257. Their light varies rapidly, in many cases within a few hours; and no less than 125 were found by comparing photographs of the great cluster ω Centauri. The shortest known period of a variable star is that of No. 91 in this cluster, which goes through all its fluctuations of brightness in the remarkably brief duration of six hours, eleven minutes.

4. **The Temporary Stars** suddenly blaze out in the heavens, and then gradually fade away. The most celebrated one burst forth in Cassiopeia, in the year 1572. Tycho Brahe says: 'One night as I was ex-

amining the celestial vault, I saw with unspeakable astonishment a star of extraordinary brightness in Cassiopeia. Struck with surprise, I could scarcely believe my eyes. To convince myself that there was no illusion, I called the workmen of my laboratory and the passers-by, and asked them if they saw the star which had so suddenly made its appearance. It could be compared only with Venus at her quadrature, being seen distinctly at midday.' Its color was at first white, then yellow, and finally red. Its brightness decreased gradually until the spring of 1574, when the star disappeared from view and has not since been seen. As two brilliant stars had previously appeared in Cassiopeia, at intervals of about three centuries, they have been thought, by some, to be identical, being explained as a variable star of long period.

Since this discovery by Tycho Brahe, numerous instances have been recorded of stars which have suddenly burst forth, and have then either faded out entirely, or remained as faint telescopic objects. In the latter case, they are termed *New stars*. One of this kind appeared in Corona Borealis, in 1866. At first it was of the second magnitude, but in a week changed to the fourth, and in a month diminished to the ninth.

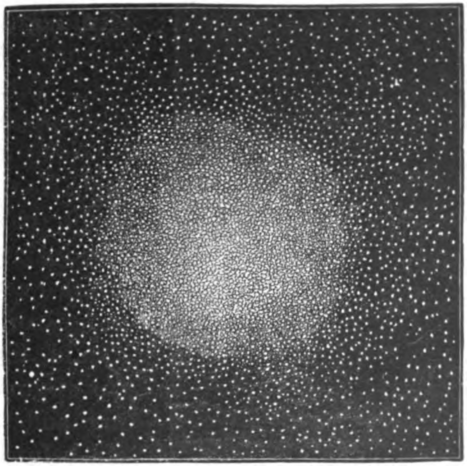
In 1876 a remarkable star was discovered in the constellation Cygnus. It was then about the third magnitude, and blazed out suddenly, like most of these strange objects. But it faded away rapidly, and in 1895 it was fainter than the fourteenth magnitude. In August, 1885, a star of the seventh magnitude was found in the constellation Andromeda, within the famous nebula. This, too, faded rapidly, becoming in a few months less than half as bright. One of the most interesting temporary stars was discovered in 1892 by a Scotch amateur whose equipment was only a star atlas and a little pocket telescope magnifying ten times. It was at once verified, optically at the Royal Observatory, Edinburgh, as well as on the photographic plates at Harvard College Observatory. When discovered, it was of the fifth magnitude, but gradually grew brighter for a month or two, when it began to fade, brightening temporarily, but in general decreasing in brilliancy. Some astronomers think it changed into a planetary nebula, since its spectrum became almost identical with the spectra of such bodies. More recently, several new stars have been discovered by photography in the constellations of the southern hemisphere. Most of these temporary or new stars are in or lie adjacent to the Milky Way.

Some stars have disappeared from the heavens, and are styled *Lost stars*. The changes which are thus constantly taking place are calculated to make the expression 'eternal stars' seem a very indefinite phrase.

EXPLANATION. — These phenomena are as yet little understood. The investigations of spectrum analysis indicate that the star of 1866 consisted of *glowing hydrogen gas*. We can suppose that the gas was evolved by some convulsion, and, taking fire, wrapped the entire globe in flames. This does not involve the idea of destruction, but only a change of form: a dark star may thus become luminous, or a bright one may be extinguished.[1]

[1] The process of apparent creation and destruction seems to be going on in the heavens immediately before the eye of the astronomer, though usually with inconceivable slowness. New stars flash light, old stars are lost, worlds burst into flame, and their glowing embers fade into darkness. Are they recreated into new worlds? We know not. We only perceive

5. **The Star Clusters** are groups of stars so massed together as to present a hazy, cloudlike appearance, which the telescope resolves into multitudes of separate stars. Several of them have common names, — the Pleiades, the Beehive in Cancer, the Hyades, and the group in the sword handle of Perseus. The principal stars of which some of them are composed can be



STAR CLUSTER IN THE TOUCAN

distinguished by the naked eye, although by the use of a small opera glass or spyglass the number is increased.

In the southern sky, there are clusters still more remarkable. In the Cross is a group of 110 stars of various colors, red, blue, and green, so that looking on it, says Herschel, is 'like gazing into a casket of precious gems.' A cluster in the Toucan is compact in

that the same Almighty power which fitted up this earth for our home is yet at work among the worlds about us, and we are thus witnesses of His eternal presence.

the center, where it is of an orange-red color; the exterior is composed of pure white stars, making a border of exquisite contrast.

It is generally conceded that there is some close physical relation existing between the stars composing such an 'archipelago of worlds,' but its nature is a mystery. They seem generally crowded together toward the center, blending into a continuous blaze of light. Yet, although they appear so densely compacted, it is probable that, if we could change our standpoint and penetrate one of these groups of suns, we should find it, on our approach, opening and spreading out before us, until, in the midst, the suns would shine down upon us from the heavens, much as the stars do in our own sky.

THE GREAT NEBULA IN ANDROMEDA
(Roberts)

6. **Nebulæ** are faint, misty objects, like specks of luminous cloud. A few are visible to the naked eye, but the telescope reveals thousands. In general, they differ from clusters in not being resolvable into stars when viewed through telescopes. With the constant improvement made in these instruments, however, many so-called nebulæ have been resolved, and thus the

number of clusters has been increased, while new nebulæ have been discovered.

Before the invention of the spectroscope it was thought that all nebulæ were simply groups of stars, which would ultimately be discerned in the more powerful telescopes yet to be made. Spectrum analysis shows, however, that many of these luminous clouds are gaseous, and are not composed of separate stars.

Since all the nebulæ maintain the same position with respect to the stars, their distance must be inconceivably great, and, in order to be visible to us, their magnitude must be proportionately vast. They are distributed more and more abundantly as we approach the two poles of the Milky Way, but are more uniformly scattered over the heavens lying near the southern pole.

It is now generally believed that nebulæ constitute the material for making stars,—are, in fact, *sun germs;* that all stars originally existed as nebulæ; and that every nebula will, in time, be condensed into stars.

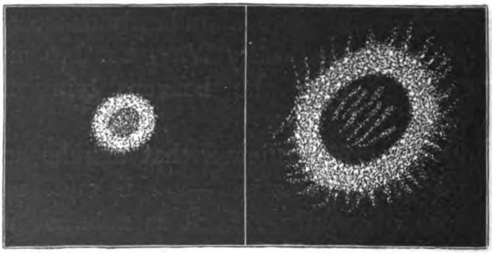
Nebulæ are divided, according to their form, into six classes—*elliptic*, *annular*, *spiral*, *planetary*, *irregular nebulæ*, and *nebulous stars*.[1]

THE ELLIPTIC or merely oval nebulæ are the most abundant. Under this head is classed the *Great Nebula in Andromeda*, which was discovered over a

[1] This division of the nebulæ is purely arbitrary, and used only to introduce some order of arrangement. The apparent shape of some of the nebulæ changes with the power of the telescope through which they are seen. Thus the Great Nebula in Andromeda, as drawn by Bond, is no longer oval, but irregular in form; while the more recent photographs by Roberts (opposite) seem to reveal a stellar system in actual process of evolution. The Ring Nebula of Lyra, seen through the large telescope of to-day, is egg-shaped; while the Dumb-bell Nebula assumes the outline of a chemical retort.

thousand years ago, and is faintly visible to the naked eye. Bond, late of the Cambridge Observatory, partly resolved it into stars, of which he counted 1500, although its nebulous appearance was still retained. Through the telescope it is one of the most glorious objects in the heavens; and it presents many puzzling problems as to its constitution.

The distance of such nebulæ from the earth passes our comprehension. Some astronomers have estimated that a ray of light would require 800,000 years to span the gulf that intervenes. Imagination wearies itself in

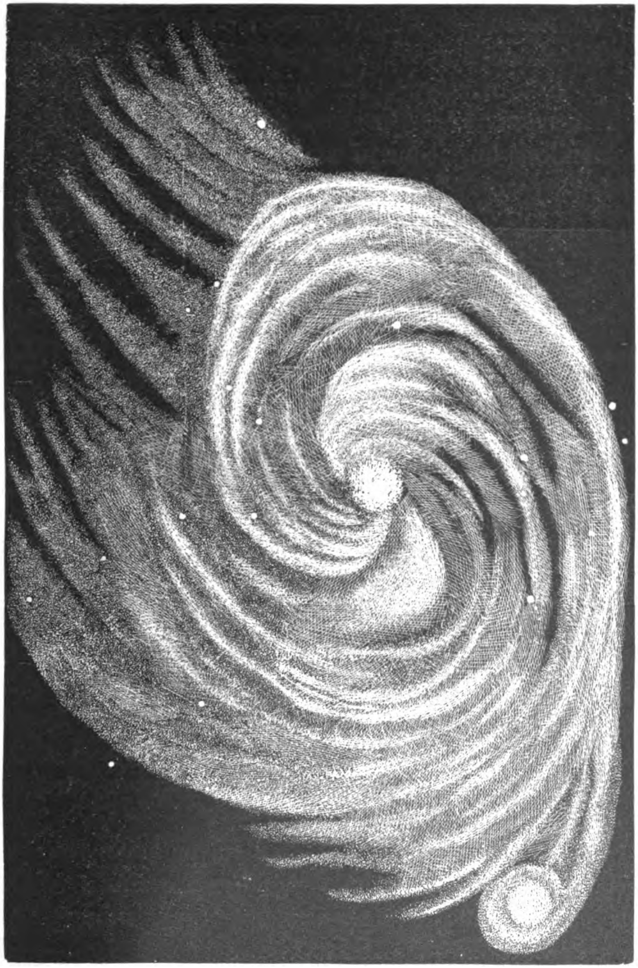


ANNULAR NEBULA IN LYRA

the attempt to understand these figures. They teach us something of the limitless expanse of that space in which God is working the mysterious problem of creation.

THE ANNULAR NEBULÆ have the form of a ring. There are six of these 'ring universes.' In the above cut is a representation of one in Lyra, — first, as seen by Herschel, having in the center a nebulous film like a 'bit of gauze stretched over a hoop'; second, as shown in Lord Rosse's telescope (frontispiece), which resolves the filmy parts of the nebula into minute stars, and reveals a fringe of stars along the edge.

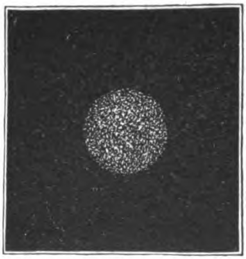
THE SPIRAL OR WHIRLPOOL NEBULÆ are exceedingly curious. The most remarkable one is in Canes



SPIRAL NEBULA IN CANES VENATICI (Lord Rosse)

Venatici. It consists of filmy spirals sweeping outward from a central nucleus, and all overspread with a multitude of stars. Columbus discovered America, and so immortalized his name; what shall we say of the astronomer who discovers a system of worlds? One is lost in attempting to imagine the distance of such a mass, and the forces that produce such a 'tremendous hurricane of matter — perhaps of suns.'

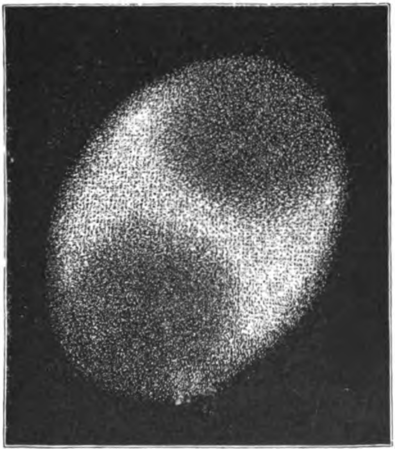
PLANETARY NEBULÆ, by their circular form and pale, uniform light, resemble the disks of the distant planets of our system. Their edges are generally well defined, though sometimes slightly furred. There is one in Ursa Major, which, if located at the distance of 61 Cygni, would fill a space equal to seven times the entire orbit of Neptune.



PLANETARY NEBULA

IRREGULAR NEBULÆ are those which have no definite form. Many present the irregularities of clouds torn by the tempest. Some of the likenesses which may be traced are strangely fantastic; for example, the Dumb-bell Nebula, in the constellation Vulpecula, and the Crab Nebula, near the southern horn of Taurus. There is also one known as the Great Nebula in the Sword-handle of Orion, which bears a faint resemblance to the wings of a bird.

NEBULOUS STARS are so called because they are enveloped by a faint nebula, usually of a circular form. The star is generally seen at the center, although some nebulæ surround two stars, having one in each focus. It is thought that these may be suns possessing immense atmospheres, which are rendered visible somewhat as that of our sun is, in the zodiacal light; and that in like manner our sun may present to other worlds the appearance of a nebulous star.[1]

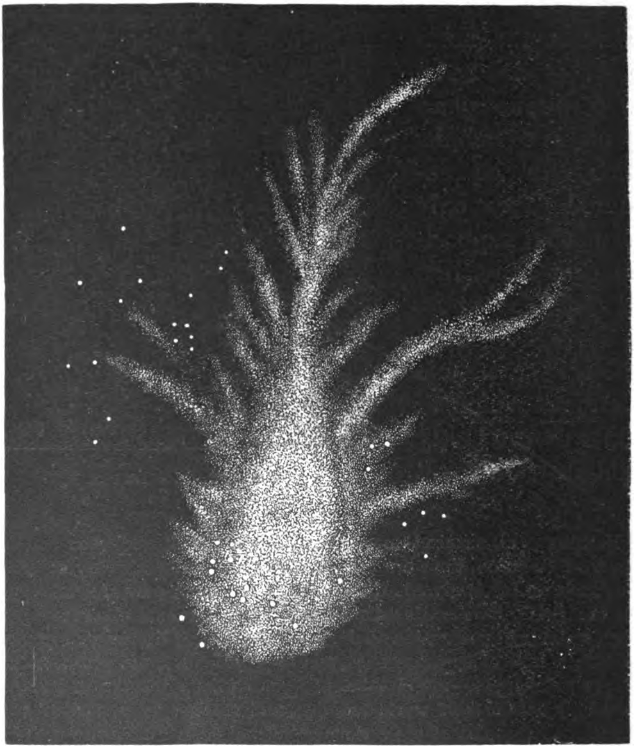


DUMB-BELL NEBULA

VARIABLE NEBULÆ. — Certain changes take place among the nebulæ which can be accounted for only under the supposition that they, like some of the stars, are *variable*. Hind tells us of a nebula in Taurus which in 1852 was distinctly visible with a small

[1] Nothing in all nature is more suggestive of the magnificence and immensity of Creation, than are the nebulous star clusters, many of which are at such an inconceivable distance that the most powerful telescopes show them only as a confused mass of light. A casual observer — even though when led by scientific analogy to resolve each little patch of star-dust into a host of separate suns, and to provide each sun with a retinue of inhabited planets — might think of them as little colonies of suns, set on the very outskirts of world creation, and moving in such close proximity that the peoples of the various worlds might communicate with one another. Yet, were he transported to some planet whirling about one of those far-off star suns, — a multitude of which blend as a single point of light to our human eyes, — he would see the other suns only as fixed stars in the firmament above him; and though many of them might surpass in splendor the glory of our own Sirius, yet all would still remain at such an immense distance as to baffle the research of the most powerful instruments. Thus, too, he would probably find each planet revolving at such a distance from its sister planets as to render the certain knowledge of other inhabited worlds as elusive there as here.

telescope, but in 1862 had vanished entirely out of the reach of a powerful instrument. The Great Nebula in Argo, when observed by Herschel in 1838, had in the center a vacant space containing a star of the first



Crab Nebula in Taurus

magnitude, enshrouded by nebulous matter. In 1863, the nebulous matter had disappeared, and the star was only of the sixth magnitude. These facts as yet defy explanation. They illustrate the vast and wonderful changes constantly taking place in the heavens.

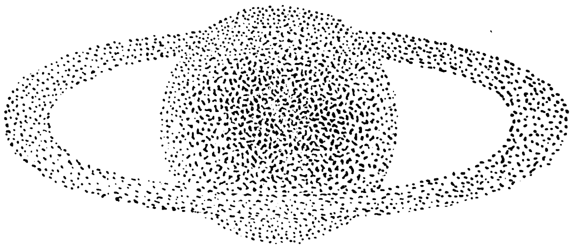
DOUBLE NEBULÆ. — There seems to be a physical connection existing between some of the nebulæ, similar to that already noticed in respect to certain stars. In the case of the latter this interrelation has been proved, since, even at their distances, their movements can yet be traced in the lapse of years. But, owing to the almost infinite distances at which these nebulæ exist, thousands of years, perhaps thousands of centuries, would be necessary to reveal any movement.

7. Magellanic Clouds. — Not far from the southern pole of the heavens, there are two cloudlike masses, distinctly visible to the naked eye, and sometimes known to navigators as Cape Clouds. Sir John Herschel describes them as consisting of swarms of stars, clusters, and nebulæ, seemingly grouped together in the wildest confusion. In the larger, he found 582 single stars, 46 clusters, and 281 nebulæ.

8. The Milky Way. — Via Lactea, or the Galaxy, is a luminous, cloudlike band that stretches across the heavens in a great circle. It is inclined to the celestial equator about 63°. This stream of suns is divided into two branches from α Centauri to Cygnus. To the naked eye, it presents merely a diffused light; but with a large telescope it is found to consist of myriads of stars densely crowded together. Herschel states that 258,000 stars once passed across the field of his great reflector in 41 minutes. With more powerful instruments, probably many thousands more could be seen.

These stars are not uniformly distributed through the entire extent. In some regions, within the space of a single square degree we can discern as many as can be seen with the naked eye in the entire heavens. In other parts there are broad, open spaces. A remarkable instance of this occurs near the Southern Cross: there is a dark, pear-shaped vacancy, with a single bright star at the center, glittering on the blue background of the sky. In viewing it, one is said to be impressed with the idea that he is looking through an opening into the starless depths beyond the Milky Way.

The northern galactic pole is situated near Coma Berenices, and the southern in Cetus. Advancing from either pole toward the Milky Way, the number



PRESENT THEORY OF THE VISIBLE UNIVERSE

of stars increases, at first slowly and then more rapidly, until the proportion at the Galaxy itself is thirty fold that at its poles.

The latest researches appear to indicate that the general shape of the visible universe of stars is similar to that of the planet Saturn, on an enormously magnified scale. Our sun and its family of planets are near the equatorial plane of the ball, and the stars belonging to our stellar family are scattered at all conceivable distances in a globular cluster representing the ball, or central body of the sidereal system. Then, far outside and completely surrounding this cluster is the vast girdle (cleft on one side, as is not shown in the cut) of glittering radiants that compose the Galaxy or Milky

Way; and their individual faintness is mostly due to their exceeding remoteness.

We are, then, to think of our own sun as a star of the second or third magnitude, and of our little solar system as plunged far into the midst of this vortex of worlds, a mere atom along that

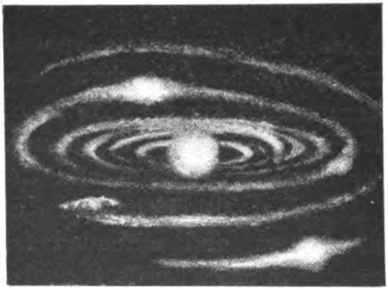
> 'Broad and ample road
> Whose dust is gold and pavement stars.'

9. **The Nebular Hypothesis** is a theory first advanced by Kant and reënforced by Laplace, to show how the solar system may have been formed.[1] As since modified, its outlines are as follows: In the beginning, all the matter which now composes the sun, and the various planets with their moons, filled the space at present occupied by the system, and extended far beyond the orbit of Neptune. In other words, the solar system was simply an immense and embryonic nebula. As its gases condensed they became heated to incandescence. Gradually the outer regions of the mass cooled by radiation. As centuries passed, the attractive force drew the matter inward and condensed it around one or more centers. The nebula then presented the appearance of a nebulous star — a nucleus enveloped by a gaseous atmosphere.

According to a well-known law in physics, — seen in everyday life, wherever matter seeks a center, as in a

[1] We should remember that this theory aims to tell only the way in which our system was developed. The parent nebula must have contained a potential energy equal to all the manifestations of force since made in the entire system. Nothing could be developed from a mass of nebulous matter the germs of which had not been put in it originally by the Creator. The analogies of nature all go to show that the Creator's plan is, in general, not to produce any object in a perfect and matured state; but rather by gradual growth to unfold its full form and function.

whirlpool, in a whirlwind, or even in water poured through a funnel, — a rotary motion was established. As the rotary motion of the nebula increased, the centrifugal force finally overcame at the exterior the attraction of gravitation. A ring of condensed vapor was then left behind. Centuries elapsed, and again, under the same conditions, a second ring was detached. Thus, one by one, concentric rings were separated from the parent nebula, all revolving in the same plane and in the same direction. Each separate ring, becoming gradually consolidated into a single mass, formed a planet.



Hypothetic Nebula

Generally, however, in this process, while still in the vaporous state and slowly condensing, the rings themselves detached other rings that were in turn consolidated into satellites.

In the case of Saturn, several of these secondary rings did not condense into globes, but still remain as rings which revolve about the planet.[1] Mitchel

[1] In the case of the small planets and the rings of Saturn, we may suppose that the rings were composed of matter uniformly distributed; while in the case of the rings that consolidated into planets, there was a nucleus that attracted the rest of the matter to itself. It is barely possible that the rings of Saturn may yet break up and form new satellites, or a new satellite, for that planet. The rings are known to be composed of small meteorites; and these may be attracted, and so picked up, one by one, in succession by the larger, until they form another moon, which will continue to revolve about the planet as the ring does now. — 'The present state of the solar system is a living picture of the entire history of a single

naïvely remarks, 'Saturn's rings were left unfinished to show us how the world was made.' The ring which formed the small planets broke up into fragments, none large enough to attract the rest and thus form a single globe. Without any doubt, the constitution of the asteroidal ring is the same as that of the Saturnian rings — that is, a multitude of separate, excessively small bodies.

The central mass of vapor finally condensed itself into the sun, which remains the largest member of the system. According to this theory, the sun may yet give off another planet, whose orbit will be far interior to that of Mercury.

Probably the earth-moon system forms a conspicuous exception to this general process; and it is likely that our satellite was not separated from our original globe as a ring, but that it divided as a single mass or lump. Its attraction for the earth then raised high tides in the plastic earth, and the moon was then repelled to its present distance by the tidal reaction of the earth, exerted through countless ages.

Recent applications of this important principle have been made to the evolution of stellar systems. The orbits of the known binary systems are about twelve times more eccentric than the paths of the planets and satellites of the solar system. Also, the stars are very

planet. From the sun's fire mist, to ring-girt Saturn; from Saturn, to storm-beaten Jupiter; from Jupiter, to the sunny summer time of our own planet; from Earth, to autumn-browned Mars; and from Mars, to the wintry silence and desolation of the dark gulches of the moon, — there is a series of stages that carries the thought back into the eternity long passed, as well as onward into the measureless depths of the future, and confers upon human intelligence a sort of exemption from the limitations of finite existence.' — WINCHELL.

different in this: that while the mass of the solar system is largely concentrated in the sun, the masses of binary stars are always comparable, and sometimes very nearly equal. Double stars, therefore, are thought to have been developed by the breaking up of nebulæ originally double, of which there are still many examples in the sky; and the process of separation was somewhat akin to that known as 'fission' in the case of protozoans.

After a time, all the sun's heat will be radiated into space, its fire will become extinct, and life on the planets will cease. We know not when this remote event may occur. We cannot fathom the purpose of God in creating and maintaining this system of worlds, nor can we foretell how soon it may complete its mission. We are assured, however, —

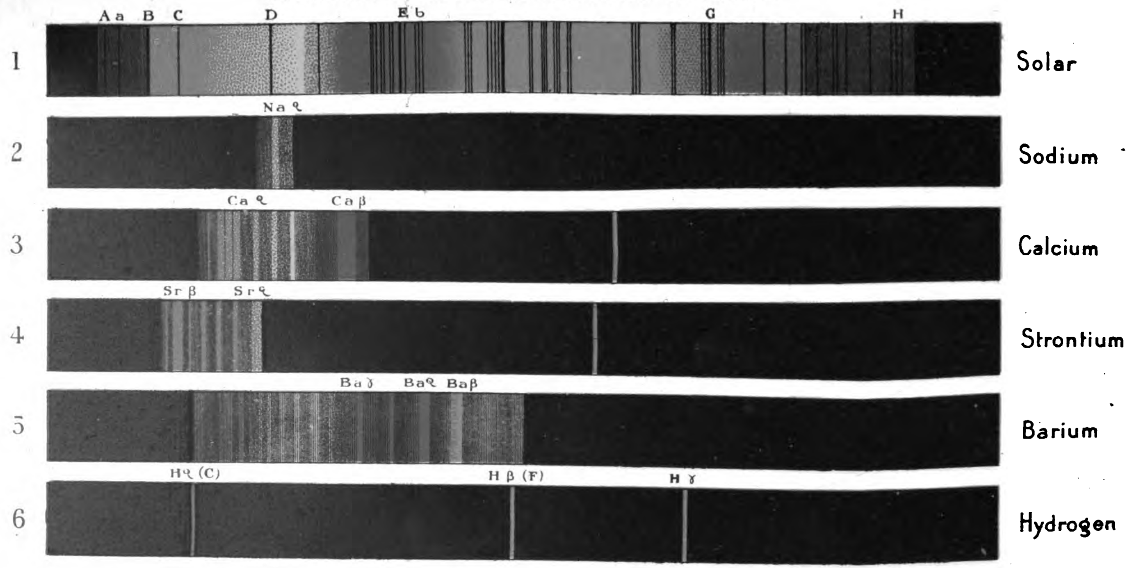
'That nothing walks with aimless feet,
That not one life shall be destroyed,
Or cast as rubbish to the void,
When God hath made the pile complete.'

— *In Memoriam.*

IV. CELESTIAL CHEMISTRY

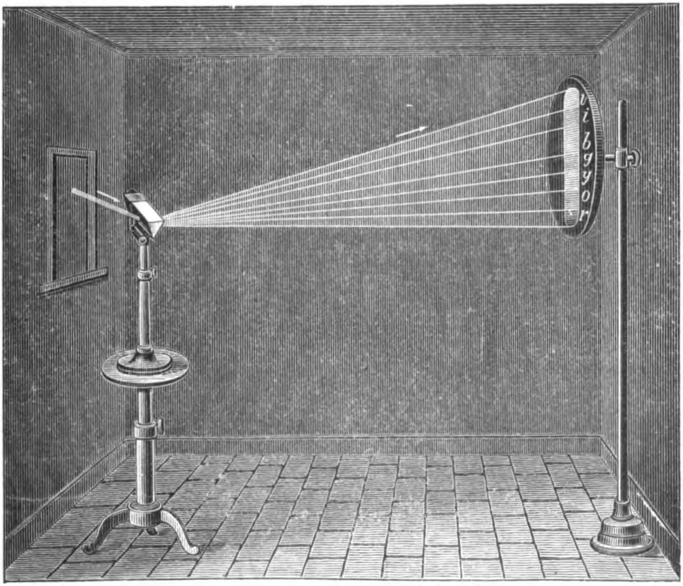
Spectrum Analysis. — The rainbow — that child of the sun and shower — is familiar to all. The brilliant band of colors seen when the sunbeam is passed through a prism is scarcely less beautiful. The ray of light containing the primary colors is here spread out fanlike, and each tint reveals itself. This variously colored band is called a spectrum (plural, *spectra*). There are three different kinds of spectra: —

SPECTRA OF VARIOUS SOURCES OF LIGHT.



1st. When the light of a solid or liquid body, as of iron white-hot, is passed through a prism, the *spectrum is continuous*, and consists of a series of distinct colors, varying from red on one side to violet on the other.

2d. If the light of a burning gas containing any volatilized substance be passed through a prism, the



THE PRISM RESOLVES THE BEAM OF WHITE LIGHT INTO THE SEVEN PRIMARY COLORS

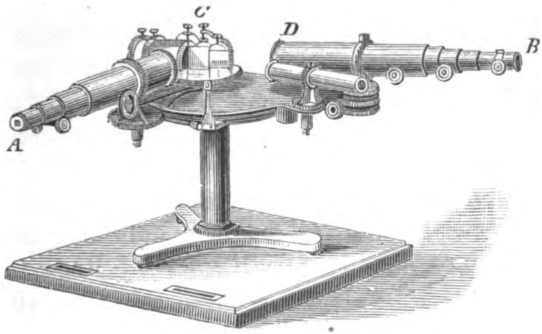
spectrum is not continuous, but is characterized by bright colored lines, —sodium giving two yellow lines; strontium, a red one; silver, two beautiful green ones. Each element produces a definite series which is recognized as a test of its presence.

3d. If a light of the first kind be passed through one of the second, the resultant spectrum is crossed by *dark lines.* Thus, if the white light of an electric lamp shines through a flame containing sodium, instead of the vivid yellow lines so characteristic of that metal, two black lines exactly occupy their place. *A gas absorbs the rays of exactly the same color, or wave length, that it emits.* (See note, page 330.)

The Spectroscope. — This instrument consists of two small telescopes, with a prism mounted between their object glasses. The rays of light enter through a narrow slit at A, and are rendered parallel by the object glass. They then pass through the prisms at C, are separated into the different colors, and, entering the telescope at D, fall upon the eye at B. A third telescope is sometimes attached, which contains a minutely divided scale for measuring the position of the lines. In addition, a mirror may throw in at one side of the slit a ray of sunlight or starlight, and so we can compare the spectrum of the sunbeam with that of any flame we desire.

REVELATIONS OF THE SPECTROSCOPE CONCERNING THE SUN. — The spectrum of the sunbeam is not continuous, but is crossed by a large number of dark lines, called Fraunhofer lines, in honor of the great German optician and telescope maker of that name, who first measured their positions accurately. It is therefore concluded that the sun's light is of the third class just named, and that it is produced by the vivid light of a highly heated body shining through an atmosphere of volatilized substances. This is about seven hundred miles in depth all over the sun, and is called the *reversing layer.* Its existence has been proved by photographing its spectrum at the time of beginning and end of total eclipses of the sun, when the solar crescent is a slender curved line. It is a spectrum showing bright lines.

Not only does spectrum analysis thus shed light on the physical constitution of the sun, but these lines are so distinctive, so marked and varied, that many of the elements of which the sun is composed have thereby been discovered.[1] Thus, for example, iron gives a spectrum of some two thousand lines, differing



A PRISM SPECTROSCOPE

in intensity. In the solar spectrum we have such a multitude of coincidences of dark lines, as to make the conclusion irresistible that iron and other elements are contained in the sun's atmosphere.

If we apply to the sun the method described in detail on page 275 for finding whether a star is coming toward us or going from us, we can verify the sun's rotation on his axis. For on comparing the lines in

[1] The following elements have been detected: sodium, calcium, barium, magnesium, iron, chromium, nickel, cobalt, hydrogen, manganese, aluminium, titanium, palladium, vanadium, molybdenum, strontium, lead, uranium, cerium, cadmium, oxygen, silicon, carbon, scandium, yttrium, zirconium, lanthanum, niobium, neodymium, copper, zinc, glucinum, germanium, rhodium, silver, tin, erbium, potassium, and helium.

the sun's spectrum at his east limb (which is coming toward us) with those of his west limb (going away from us), we find that the rates of their motion exactly agree with the amount of motion as derived from the spots.

Stars are Suns. — The same method of analysis has been applied to the stars. For the most part their spectra are marked by dark lines. Their constitution is therefore similar to that of our sun, and they also exhibit familiar elements. Betelgeux, for example, contains many substances known to us. According to the number, character, and position of the lines in their spectra, the stars have been divided into five distinct classes: —

(I) Stars having broad and intense absorption lines due to hydrogen, and but few lines indicating the presence of other metals; like Sirius and Vega. About half of all the stars show spectra of this type, and they are called Sirians.

(II) Stars whose spectra closely resemble that of the sun, with many hundred fine, dark lines, due to metals; like Arcturus and Capella. They are almost as numerous as the Sirians, and are called Solars.

(III) Stars with many dark bands in their spectra, shading off toward the red; like Antares, and Mira, and the variable stars generally.

(IV) Stars with bands similar to those of (III), but reversed as to the direction of the shading. There are but few of these stars; they have carbon in their atmospheres, and are intensely red in color.

(V) Stars with bright lines in their spectra; not very numerous, and near the Milky Way.

We thus trace in thousands of stars the elements that compose the common objects of our own life. We know that we are akin to nature everywhere, — a part of a system vast as the universe.

THE MOTION OF A STAR may be resolved into two components: one representing its motion at right angles, and the other its motion parallel, to the line of vision. The former component can be determined by the telescope; the latter is revealed by the spectroscope. If the star is moving toward us, the number of vibrations producing any color will be increased, and hence the dark lines corresponding to that color in the spectrum will be pushed beyond their usual place toward the violet end; if going from us, the number of vibrations will be decreased, and the dark lines be pushed toward the red end of the spectrum.[1] The amount of displacement in the spectrum once determined, the velocity of the star toward or from the earth can be calculated by means of well-known laws of optics. Thus we find that Aldebaran, Betelgeux, and Rigel are receding from our solar system at the average rate of about twenty miles a second; while Alpha Arietis, and Spica, also Altair and γ Leonis, are all coming toward the sun, the former pair about ten miles, and the latter nearly twenty-five miles, in every second of time. Technically this is called 'motion in the line of sight.'

Spectra of Nebulæ. — Instead of being marked with dark lines, as are the spectra of the stars, many of the nebulæ exhibit bright lines. This proves such nebulæ to consist, not, like the stars, of an intensely heated nucleus shining through a luminous atmosphere, but of

[1] A similar result is produced in the case of sound. The whistle of an approaching train sounds higher in pitch than when it is receding.

a glowing mass of gas. Out of 60 nebulæ examined by Sir William Huggins, 20 exhibited the bright lines belonging to gases, and all contained hydrogen. Helium, a light gas present in the sun's chromosphere, and discovered in 1895 in certain earthy minerals, is also present in the nebulæ. The spectroscope has proved that the great nebula of Orion is composed of the same elements as the stars of that constellation. This vast nebula is as remote as the stars about it are, and its distance from us is increasing at the rate of eleven miles every second.

The Solar Flames or Prominences, formerly seen only during an eclipse, can now be examined by means of the spectroscope at any time.[1] The sun has thus been found to be a sea of fire swept by the most violent storms.[2] Flames travel over its surface with a velocity of which we can form no conception; one jet shot out 80,000 miles and disappeared in ten minutes. Young describes a protuberance that reached the enormous height of 350,000 miles and then faded entirely away, all within two hours.

[1] 'The red portion of the spectrum will stretch athwart the field of view like a scarlet ribbon with a darkish band across it; and in that band will appear the prominences, like scarlet clouds, so like our own terrestrial clouds, indeed, in form and texture, that the resemblance is quite startling. One might almost think that he was looking out through a partly opened door upon a sunset sky, except that there is no variety or contrast of color; all the cloudlets are of the same pure scarlet hue. Along the edge of the opening is seen the chromosphere, more brilliant than the clouds which rise from it or float above it, and for the most part made up of minute tongues and filaments.'

[2] Such a storm 'coming down upon us from the north would in 30 seconds after it had crossed the St. Lawrence be in the Gulf of Mexico, carrying with it the whole surface of the continent in a mass, not of ruin simply, but of glowing vapor, in which the vapors arising from the dissolution of the materials composing the cities of Boston, New York, and Chicago would be mixed in a single undistinguishable cloud.' — NEWCOMB.

The spectroheliograph, already alluded to on page 60, enables us also to photograph the protuberances all the way round the sun's edge or limb at any time, and records of this permanent character are now made at Paris, in India, and at the Yerkes Observatory of the University of Chicago on every clear day. It is found that the streamers of the sun's corona, seen only during total eclipses, are closely related to well-marked prominences visible at the same time, though the reason underlying the connection is not yet known.

V. TIME

Sidereal Time. — A sidereal day is the exact interval of time in which the earth rotates once on its axis. It may be found by marking two successive passages of a star across the meridian of any place. This rotation is so nearly uniform, that, as recent investigations seem to show, the length of the sidereal day has not varied more than $\frac{1}{80}$ of a second in 2400 years (note, page 95).

The sidereal day is divided into twenty-four equal portions which are called sidereal hours, each of these hours into sixty portions, termed sidereal minutes, and each minute into sixty sidereal seconds.

MANY ASTRONOMICAL CLOCKS are regulated to keep sidereal time. The sidereal day commences when the vernal equinox is on the meridian. Therefore, the time by a sidereal clock does not often point out the hour of the ordinary day. It indicates only how long it is since the vernal equinox crossed the meridian, and thus shows the right ascension of any star which may happen to be on the meridian at that moment. The hours of the clock are easily reduced to degrees (page 36). The astronomer always reckons the hours of the day consecutively up to twenty-four, whether solar or sidereal day.

Recording Time. — The exact clock time when any celestial body crosses the meridian of a place is observed with a telescope called a *transit instrument*, which has in its field of view a reticle of fine spider lines; and the precise time at which any body crosses these lines is recorded automatically by means of an instrument called a *chronograph* (or time writer); the observer simply pressing an electric key when he sees the star upon the line. A newly invented instrument called the *photochronograph* records transits of stars by means of photography.

Solar Time. — A solar day is the interval between two consecutive passages of the sun's center across the meridian of any place. If the earth were stationary in its orbit, the solar day would be of the same length as the sidereal; but, while the earth is turning around on its axis, it is going forward at the rate of 360° in a year, or nearly 1° a day. When the earth has made a complete rotation, it must therefore perform a part of another rotation through this additional degree, in order to bring the same meridian vertically under the sun.

One degree of diurnal rotation is equal to nearly four minutes of time. Hence the solar day is about four minutes longer than the sidereal day. For the convenience of society, it is customary to call the solar day 24 hours long, and make the sidereal day only 23 h. 56 m. 4 s. in length, expressed in mean solar time. A sidereal day being shorter than a solar one, the sidereal hours, minutes, etc., are shorter than the solar; 24 hours of mean solar time being equal to 24 h. 3 m. 56 s. of sidereal time.

From what has been said, it follows that in 365 solar days the earth makes 366 rotations around its axis relatively to a star.

Mean Solar Time. — The solar days are of unequal length. To obviate this difficulty, astronomers suppose a *mean sun*, whose center is imagined to travel around the equator of the heavens (which is a circle and not an ellipse) with a perfectly uniform motion. When this mean sun passes the meridian of any place, it is *mean noon;* and when the true sun passes the meridian, it is *apparent noon*. This mean day is the average length of all the apparent solar days in the year. The clocks in common use are regulated to keep mean time.[1] When it is twelve by the clock, the sun itself will nearly always be either a little east or a little west of the meridian.

The difference between sun time (apparent solar time) and clock time (mean time) is called the *equation of time*. This is greatest about the first of November, when the sun is over 16¼ minutes in advance of the clock. The sun is the slowest about February 10, when it is nearly 14½ minutes behind mean time.

Mean time and apparent time coincide four times in the year; namely, April 15, June 14, September 1, and December 24. On these days, the sun comes to the noon mark on the sundial precisely at twelve o'clock.

[1] In France, until 1816, apparent time was used; and the confusion was so great, Arago relates, that the town clocks would sometimes differ thirty minutes in striking the same hour. As the time varied every day, no watchmaker could regulate a watch or clock to keep it.

Local and Standard Time. — By the term *mean noon* is understood *local mean noon;* that is, mean noon at any particular place. In a row of towns lying adjacent to one another from east to west, their local noons succeed one another with great rapidity, as the sun crosses the particular meridian of each; but in the case of towns farther apart the local times differ to a greater degree. If, therefore, individual communities keep local time, they are subject to the great inconvenience of correcting for the difference of time, in all matters which concern their communication with neighboring towns, either east or west of them. Especially was this annoying in the management of the great railways running across our country; and since 1883 standard time has been adopted to remedy the difficulty. The country is divided into four great north and south zones; and clocks everywhere in each zone are regulated according to the local mean time of that meridian which is near the middle of each zone, and which corresponds to an integral number of hours from Greenwich. Thus, New England, New York, and the states directly south keep eastern standard time, which is exactly five hours slower than Greenwich time; the belt of states, nearly in the middle of which Chicago is located, keep central time, six hours slower than Greenwich; those around Denver keep mountain time, seven hours slower than Greenwich; and all the states west of this belt keep Pacific time, eight hours slower than Greenwich.

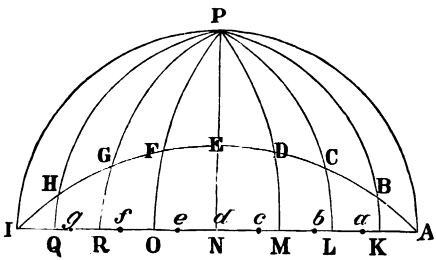
The Sundial. — The *apparent time* of the dial may be readily changed to mean time, by adding or subtracting the number of minutes given in the almanac for each day in the year, under the heading 'sun slow' or 'sun fast.' A noon mark is thus a very convenient method of regulating a timepiece approximately.[1]

Why the Solar Days are of Unequal Length. — There are two reasons for this, — the variable orbital motion of the earth, and the obliquity of the ecliptic. First: the orbit of the earth is an ellipse; and thus the apparent yearly motion of the sun along the ecliptic is variable. In perihelion, December 31, the sun appears to move eastward daily 1° 1′ 11″; while at aphelion, about July 3, only 57′ 11″.3. As the earth in its diurnal motion rotates *uniformly* from west to east, and the sun passes eastward *irregularly*, this must produce a corresponding variation in the length of the solar day. The sun, therefore, from this cause alone, would come to the meridian sometimes before and sometimes after the mean noon, and the two would agree only twice a year.

Second: the sun's apparent motion is along the ecliptic, while the mean sun is supposed to move along the celestial equator, or equinoctial. If the mean sun's uniform motion were along the ecliptic, the obliquity of the ecliptic would still cause an irregularity in the length of the day. The mean sun is therefore supposed to pass along the equinoctial, which

[1] The following manner of obtaining one roughly, without a transit instrument, may be useful. Select a level, hard surface which is exposed to the sun from about 9 A.M. to 4 P.M. Upon this carefully describe, with compasses, a circle eight or ten inches in diameter. Get a piece of heavy wire, six or eight inches in length, one end of which is sharpened. Drive this *perpendicularly* into the center of the circle, leaving it just high enough to allow the extreme end of its shadow to fall upon the circle about 9½ or 10 A.M. Mark this point, and also the place where the end of the shadow touches the circle in the afternoon. Find the point halfway between the two, and a line drawn from that point to the center of the circle will be the *meridian line*, or noon mark.

is perpendicular to the earth's axis, while the ecliptic is inclined to the equinoctial 23° 27′. Let A be the vernal equinox; I, the autumnal; AEI, the ecliptic; ANI, the equinoctial; PK, PL, PM, etc., meridians. Let the distances AB, BC, CD, etc., be equal arcs of the ecliptic, which would be passed over by the sun in equal times, supposing it to move, as the mean sun does, at a uniform speed. Next, on the equinoctial, mark off distances A*a*, *ab*, *bc*, etc., equal to AB, BC, etc. These are equal arcs of right ascension, or hour circles, through which the earth, rotating from west to east, passes in equal times. Now, meridians drawn through these divisions would not agree with those drawn through equal divisions on the ecliptic. Hence, a sun moving at uniform speed along the ecliptic, which is inclined, would not make equal days, although the ecliptic is a perfect circle.



EXPLAINING INEQUALITY OF SOLAR DAYS

Let us see how the mean and apparent solar days would compare. Suppose the real sun to pass in its eastward course from A to B in a certain time; the mean sun moving the same distance would reach the point *a*. The earth, rotating from west to east, would cause the real sun to cross any meridian earlier than the mean sun; hence, apparent time would be faster than clock time. By holding the figure up above us toward the south, we can see how a westerly sun would cross the meridian earlier than an easterly one. Following the same reasoning, we can see that at the solstice, solar and mean time would agree; while beyond that point the mean time would be faster.

The Civil Day is the same in duration as the mean solar day; but it extends from midnight to midnight. Anciently, many nations terminated one day and commenced the next at sunset. Under this plan, 10 o'clock on one day would not mean the same as 10 o'clock on another day. Among the Puritans the day began at 6 P.M. The Babylonians, Persians, and Assyrians reckoned their day as beginning at sunrise. The method of dividing the day into two portions of twelve hours each is said to have been introduced by Hipparchus, B.C. 150, and is now in use over the civilized world. The astronomical method of reckoning the hours consecutively up to twenty-four is much more convenient, and is therefore coming into general favor. The names of the days are derived as follows: —

(1)	Dies Solis	Latin	Sun's day.
(2)	Dies Lunæ	"	Moon's day.
(3)	Tius daeg	Saxon	Tiu's day.
(4)	Wodnes daeg	"	Woden's day.
(5)	Thurnes daeg	"	Thor's day.
(6)	Friges daeg	"	Friga's day.
(7)	Dies Saturni	Latin	Saturn's day.

Change of the Day. — In explaining standard time we showed how the times of different belts succeed one another, each being an hour slower as we go westward. Imagine the succession carried all the way round the earth, and back to the point of starting. A whole day of twenty-four hours will have elapsed at that point, and it will be noon of the next following day of the week. Where did the day change from Thursday to

Friday, for example? All nations agree to make the change arbitrarily at the 180th degree, or twelve hours from Greenwich. This falls in the western part of the Pacific Ocean. So that when we are voyaging from California to Japan, if we reach this meridian on Monday morning, for example, it becomes Tuesday morning the instant we have crossed it. This is often called 'dropping the day.' Similarly when we are homeward bound, if it happens to be Friday evening when we come to the 180th meridian, our record of the days immediately jumps back to Thursday evening, as soon as we have crossed this accepted dividing line of the days.

The Year. — The *sidereal year* is the interval of a complete revolution of the earth about the sun, measured by a fixed star. It comprises 365 d. 6 h. 9 m. 9 s. of mean solar time. The *mean solar year* (tropical year) is the interval between two successive passages of the sun through the vernal equinox. It comprises 365 d. 5 h. 48 m. 46 s. If the equinoxes were stationary, there would be no difference between the sidereal and the tropical years. As the equinoxes retrograde along the ecliptic $50\frac{1}{4}''$ annually, the former is 20 m. 23 s. longer.

The *anomalistic year* is the interval between two successive passages of the earth through its perihelion, which moves eastward about $11''.8$ annually. It is 4 m. 39 s. longer than the sidereal year.

The Ancient Year. — The ancients ascertained the length of the year by means of the *gnomon*. This was a rod or pillar standing on a smooth, horizontal plane on which was a meridian line. When the shadow cast on this line was the shortest, it indicated the summer solstice; and when it was the longest, the winter solstice. The number of days required for the sun to pass from one solstice back to it again determined the length of the year. This they found to be 365 days. As that is nearly six hours less than the true solar year, dates were soon thrown into confusion. If, at a certain date, the summer solstice occurred on June 20, in four years it would fall on the 21st; and thus it would gain one day every four years, until in time the summer solstice would happen in the winter months.

Julian Calendar. — Julius Cæsar first attempted to make the calendar year coincide with the motions of the sun. By the aid of Sosigenes, an Egyptian astronomer, he devised a plan of introducing every fourth year a leap year, which should contain an extra day. This was termed a *bissextile year*, since the sixth (sextilis) day before the kalends (first day) of March was then counted twice.

Gregorian Calendar. — Though the Julian calendar was nearly perfect, it was yet somewhat defective. It considered the year as consisting of 365¼ days, which is eleven minutes in excess. This excess accumulated year by year, until in 1582 the difference amounted to ten days. In that year, the vernal equinox occurred on the 11th of March, instead of the 21st. Pope Gregory undertook to reform the anomaly by dropping ten days from the calendar and ordering that thereafter only centennial years which are divisible by 400 should be leap years. The Gregorian calendar was generally adopted in Catholic countries. Protestant England did not accept the change until 1752. The difference had then amounted to eleven days. These were suppressed and the 3d of September was styled the 14th.[1]

[1] This sweeping change was received in England with great dissatisfaction. De Morgan relates the following: 'A worthy couple in a country

Dates reckoned according to the Julian calendar are termed Old Style (O.S.); and those according to the Gregorian calendar, New Style (N.S.).

Commencement of the Year. — The Jews began their civil year with the autumnal equinox; but their ecclesiastical year, with the vernal equinox. When Cæsar revised the calendar, the Romans commenced the year with the winter solstice (December 22), and it is probable he did not intend to change it materially. He ordered it to date from January 1, in order that the first year of his new calendar should begin with the day of the new moon immediately succeeding the winter solstice. In England, before 1753, the year began on March 25; but when the change was made from Old Style to New, it was also decided to begin the year thereafter with January 1.

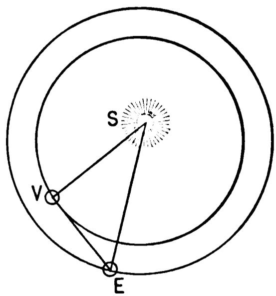
The Earth our Timepiece. — The measure of time is, as we have just seen, the length of the mean day. This is calculated from the length of the sidereal day. Hence, the standard for time is the rotation of the earth on its axis. All weights and measures are based on time. An ounce is the weight of a given bulk of distilled water. This is measured by cubic inches. The inch is a definite part of the length of a pendulum which vibrates seconds in the latitude of London.

town, scandalized by the change of the calendar, continued for many years to attempt the observance of Good Friday on the old day. To this end they walked seriously and in full dress to the church door, on which the gentleman rapped with his stick. On finding no admittance, they walked as seriously back again and read the service at home. There was a widespread superstition that, when Christmas day began, the cattle fell on their knees in their stables. It was asserted that, refusing to change, they continued their prostrations according to the Old Style. In England, the members of the Government were mobbed in the streets by the crowd, which demanded the eleven days of which they had been illegally deprived.'

VI. CELESTIAL MEASUREMENTS

Many persons read the enormous figures which indicate the distances and dimensions of the heavenly bodies with a questioning, indefinite idea, entirely unlike the feeling of certainty with which they read of the distance between two cities, or the number of square miles in a certain state. Many, too, imagine that celestial measurements are so mysterious in themselves that no common mind can hope to grasp the methods. Let us attempt the solution of a few of these problems.

1. To find the Distances of the Planets from the Sun. — In the adjacent figure, E represents the earth; ES, the earth's distance from the sun; V, the planet Venus; and VES, the angle of elongation (a right-angled triangle). It is clear that, as Venus swings apparently east and west of the sun, this angle may be easily measured; also, that it will be the greatest when Venus is in aphelion and the earth in perihelion at the same time, for then VS will be the longest and ES the shortest. Now in every right-angled triangle the proportion between the hypotenuse ES, and the side opposite, VS, changes as the angle at E varies, but with the same angle remains the same whatever may be the length of the



Comparative Distance of Venus and the Earth lines themselves. This proportion between the hypotenuse and the side opposite any angle is termed the *sine of that angle*. Tables are published containing the sines for all angles. In this way the mean distance of Venus from the sun is found to be $\frac{72}{100}$ that of the earth; of Mars, $\frac{4}{3}$ times; of Jupiter, $5\frac{1}{5}$ times, etc.[1]

2. To measure the Moon's Distance from the Earth. — (1) THE ANCIENT METHOD. — As the moon's distance is so much less than that of the other heavenly bodies, it is measured by the earth's semidiameter. The method, an extremely rough one, which was in use among the ancients, was something like the following: In an eclipse of the moon, that body passes through the earth's shadow in about four hours. If, then, in four hours, the moon travels along its orbit a distance equal to the diameter of the earth, in twenty-four hours it would pass over six times, and in a lunar month (about thirty days) 180 times, that distance. The circumference of the lunar orbit, then, must be 180 times the diameter of the earth. The ancients supposed the heavenly orbits to be circles, and as the diameter of a circle is about $\frac{1}{3}$ of the circumference, they deduced the diameter of the moon's orbit as 120 times, and the distance of the moon from the earth as 60 times the semidiameter of the earth.

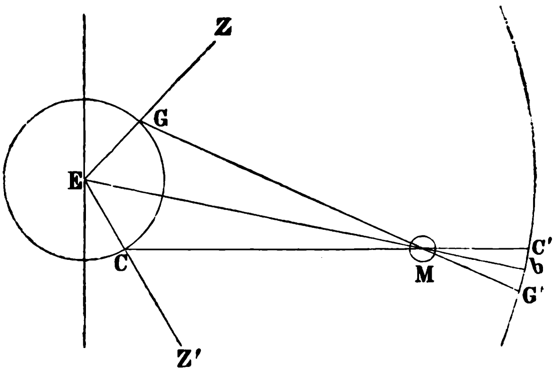
[1] If the pupil has studied trigonometry, he may apply here the simple proportion: —

ES : VS : : Radius : Sine of 47° 15′ = greatest elongation of Venus.

The same result would be obtained by the use of Kepler's third law; and on page 28 we saw how the distances of the planets themselves could be determined by the periodic times, if the distance of the earth from the sun is first known. So that when we have accurately determined the sun's distance from us, we can then decide by either of the methods named the distance of all the planets. Indeed, the sun's distance is, as already remarked, the foot rule for measuring most celestial distances.

(2) Modern Method by the Lunar Parallax. — Under the head of parallax (page 124), we saw how, in common life, we obtain a correct idea of the distance of an object by means of our two eyes. One eye alone gives no notion of distance. Just, then, as we use two eyes to find how far from us an object is, so the astronomer uses two astronomical eyes, or observatories, located as far apart as possible, to find the parallax of a heavenly body. In the next figure, M represents the moon; G, an observatory at Greenwich; and C, another at the Cape of Good Hope. At the former, the distance from the north pole to the center of the moon, measured on a meridian of the celestial sphere, is found to be 108°. At the latter station, the distance from the south pole to the moon's center is measured in the same way, and found to be 73½°. The sum of these angles is 181½°. Now, the entire distance from the north pole around to the south pole, measured on a meridian, can be only half a great circle, or 180°. This difference of 1½° must be the difference in the position of the moon, as seen from the two observatories. For the observer at the former station will see the moon projected on the celestial sphere at G′, and in measuring its distance from the north pole will measure an arc *b*G′ further than if he were located at E, the center of the earth. The observer at the latter station will see the moon projected on the celestial sphere at C′, and in measuring its distance from the south pole will measure an arc *b*C′ more than if he were located at E, the center of the earth. The sum of *b*G′ and *b*C′, or G′C′, is the difference in the position of the moon as seen from the two stations; and it enables us to ascertain the moon's parallax. The arc

G′C′ measures the angle C′MG′; that angle is equal to the opposite angle GMC = $1\frac{1}{2}°$. Now, in the four-sided figure GECM, the sides GE and CE are equal radii of the earth = 3956 miles; while the distance from G to C is the difference in the latitude of the two places. The angles ZGM and Z′CM being the zenith distances of the moon, are known, and so the angles MGE and MCE are easily found. EM, the moon's distance from the center of the earth, is thus readily computed by a simple trigonometrical formula.

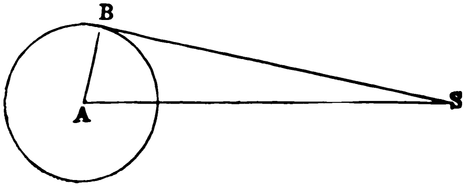


MEASURING DISTANCE OF MOON'S CENTER FROM THE EARTH'S CENTER

(3) THE HORIZONTAL PARALLAX OF THE MOON is most commonly found by estimating her distance, not from the north and south poles, as just explained under the general meaning of the term *parallax*, but from a fixed star. The moon's horizontal parallax is 57′, which makes its distance about 60 times the earth's semi-diameter (page 288).[1]

[1] In the figure on the next page, let S represent the moon, sun, or any other heavenly body; AB, the semidia[illegible] of the earth; and ASB, the

3. To find the Sun's Distance from the Earth. — This might be estimated by obtaining the solar parallax in the same manner as the lunar parallax. It would be necessary only to take the sun's distance from the north and south poles respectively at Greenwich and the Cape of Good Hope, subtract 180° from the sum of the two angular distances, and proceed as in determining the moon's distance. The difficulty in this method lies in the fact that when the sun shines, the air currents give the sun's image a tremulous motion; so that it becomes impossible to observe so small



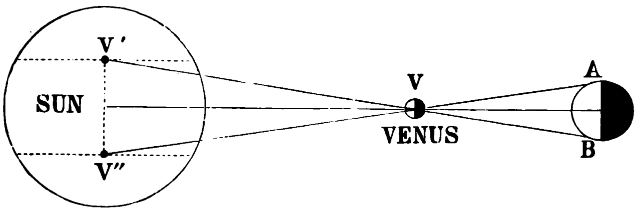
ANGLE AT S IS SUN'S HORIZONTAL PARALLAX

an angle as the sun's parallax with any accuracy. Neither can the parallax be ascertained, as in the case of the moon, by measuring the distance from a fixed star, since when the sun shines the stars near by are invisible even in a telescope. Astronomers have therefore been compelled to resort to other methods.

(1) CALCULATION OF SOLAR PARALLAX BY OBSERVING MARS. — We have already seen that the distance of Mars from the sun is $\frac{4}{3}$ that of the earth from the sun. If, therefore, we can find Mars's distance from the earth, we can multiply it by three, and

horizontal parallax of the body. Then, by the following trigonometrical formula, the distance from the earth may easily be calculated — AS : AB :: Radius : sine of ASB.

so obtain the distance of the sun from the earth. In 1862, in 1877, and again in 1892, when Mars was in opposition, it came very near us, for it was in perihelion while the earth was in aphelion, so that its distance (as since ascertained) was only about 34,000,000 miles. Astronomers at Greenwich and the Cape, and at various American and European observatories, calculated the distance of the planet from the north and south poles of the heavens, as well as from several fixed stars, in the manner just explained for obtaining the lunar parallax. These observations gave a solar parallax of 8″.94,[1] making the sun's distance 91,430,000 miles.



HOW DISTANCE OF VENUS IS FOUND BY A TRANSIT OF VENUS

(2) CALCULATION OF SOLAR PARALLAX BY OBSERVATION OF THE TRANSIT OF VENUS. — In the figure, let A and B represent the position of two observers stationed at opposite sides of the earth. At the time of the transit, the one at A will see the planet Venus as a round black spot at V″ on the sun's disk, while the one at B will see it at V′. The distance V′V″ is the difference in the position of Venus as seen from the two stations on the earth. The distance AB is the diameter of the earth. The distance V′V″ is as much greater than AB as VV″ is greater than VA. The distance of Venus from the sun is known, by Prob. I,

[1] By the formula on page 291, we have, AS : AB :: Radius : Sin 8″.94.

to be .72 that of the earth. The distance of Venus from the earth must, then, be 1.00 – .72 = .28. Hence, VV'', the distance from the sun to Venus, = .72 ÷ .28 = 2.5 times the length of AV, the distance of Venus from the earth. Therefore, V'V'' is equal to 2½ times AB, the earth's diameter. Knowing the hourly motion of Venus, it is necessary only for each observer to find when the planet's disk enters upon and leaves the sun's disk, to determine the length of the path (*chord*) it traces. A comparison of the length and position of these chords will give the length V'V'' in seconds of arc.

The advantage of this method is that, as the distance V'V'' is two and a half times AB, an error in measuring that distance affects the solar parallax less than one fifth.

TIME OF A TRANSIT OF VENUS.[1] — This is an event of rare occurrence. It happens only at intervals of 8, 105½; 8, 121½, years, etc. Were the planet's orbit in the same plane as the ecliptic, one transit would take place during each synodic revolution; but as it is inclined about 3½°, the transit can occur only when the earth is at or near one of the nodes at the same time with the planet when in inferior conjunction. As the nodes of Venus now fall in those parts of the earth's orbit which

[1] **The first transit ever seen was witnessed by Horrox, a young amateur astronomer residing near Liverpool. His calculations fixed upon Sunday, November 24, 1639 (o.s.). He, however, commenced his watch of the sun on Saturday preceding. The following day he resumed his observation at sunrise. The hour for church arriving, he repaired to service as usual. Returning to his labor immediately afterward, he says: 'At this time an opening in the clouds, which rendered the sun distinctly visible, seemed as if Divine Providence encouraged my aspirations; when — oh most gratifying spectacle! the object of so many earnest wishes — I perceived a new spot of perfectly round form that had just entered upon the left limb of the sun.'**

we pass in the beginning of June and December, transits always occur early in those months.

THE TRANSIT OF JUNE THIRD, 1769, excited great interest. King George III fitted out an expedition to Tahiti, under the command of the celebrated navigator, Captain James Cook. In order to make the angle as great as possible, and to increase the difference of the chords, or paths of the planet across the sun, astronomers were sent to all the most favorable points of observation — St. Petersburg, Pekin, Lapland, California, etc. They gave a solar parallax of 8″.58, making the sun's distance 95,293,000 miles.[1]

The transits of December 8, 1874, and December 6, 1882, were carefully observed by several government expeditions. The result is a solar parallax of 8″.84.

The next transits will happen: —

June 8	2004.	December 11 . . .	2117.
June 6	2012.	December 8 . . .	2125.

Transits of Mercury are more frequent; but owing to the nearness of the planet to the sun, they are of no practical value in determining the solar parallax. The last two occurred on May 10, 1891, and November 10, 1894. The next one happens on November 14, 1907, and will be wholly visible in the United States.

[1] Le Gentil, sent out by the French Academy to observe the transit of 1761 in the East Indies, was prevented from making his first port by the war with England. High winds afterward kept him out at sea till the transit was over. He then resolved to remain abroad until after the transit of 1769. Eight long years passed, and the morning of June 3, 1769, dawned bright and beautiful. Le Gentil, with his instruments all in place, was counting the moments for the long-awaited transit to begin; when, suddenly, the sky grew black with clouds, and a tropical storm, the first in days, swept by. Meantime, Venus came and went, and the ill-fated Le Gentil had again lost the opportunity of years. He was prostrated by his bitter disappointment, and it was two weeks before he could hold his pen to write the story of his sec[illegible]lure.

(3) Calculation of Solar Parallax by the Velocity of Light. — This is now a favorite method because physicists have ascertained very accurately that a wave of light travels 186,300 miles in a second of time; and we know, from observations of eclipses of Jupiter's satellites, that sunlight consumes 998 seconds in journeying across the diameter of our orbit round the sun. Therefore our distance from that central luminary is $\frac{186,300 \times 998}{2}$, or about 93,000,000 miles. Calculating by trigonometry how large an angle the radius of the earth's equator would subtend, if seen at this distance, we find it to be very nearly 8''.8. Therefore this is the solar parallax.

(4) Calculation of the Solar Parallax from Observations of Small Planets. — This method has already provided a very close value of the sun's distance, and the discovery in 1898 of small planet No. 433 (Eros) will, on account of its remarkable orbit, make it possible to find the sun's parallax eventually with very great accuracy. As the minimum distance of Eros from the earth is about 13,000,000 miles, or about half that of Venus, the method is much more precise than that of a transit of Venus. In principle the parallax of Eros is measured the same as that of Venus, except that its displacement is measured among the stars, instead of upon the disk of the sun, as is done in the case of Venus. Then the sun's distance is calculated by Kepler's third law, having previously found the periodic time of Eros. In 1900 Eros will be in a very favorable position for this important observation; but the best opportunity will not arrive till the year 1924.

Changes in the Estimate of the Solar Paral-

LAX. — About 1824, Encke deduced 8″.58 as the probable result of the observations upon the transit of 1769. This conclusion was accepted for nearly thirty years, and the corresponding solar distance of 95,293,000 miles is found in all the older text-books. About 1860, Leverrier announced that he could reconcile the theories regarding certain of the planets only by assuming a greater solar parallax. As the result of various calculations, together with the material furnished by the observations upon the planet Mars in 1862, a new parallax of 8″.94 was obtained. This has been accepted by all until recently, and was used in early editions of this work. It is now known to be too large, and astronomers are making every effort to determine this most important factor in celestial measurements. The parallax at present received is about 8″.80, which represents a mean solar distance of 92,885,000; in round numbers, 93,000,000, as given in the present edition.

The difficulty of determining the solar parallax accurately will be seen when one is told that the change from the value of 8″.58 to that of 8″.94, was a change in the angle equal to that of the angular breadth of a human hair when seen at a distance of 125 feet. Yet this changed the distance of the sun from 95,293,000 miles to 91,430,000 miles.

4. To find the Longitude of a Place.[1] — (1) THE SOLAR METHOD. — If the sailor can see the sun early in the morning or late in the afternoon, he watches it

[1] Notice that the astronomer can *predict* with the utmost precision. He announces that on such a year, month, day, hour, and second, a celestial body will occupy a certain position in the heavens. At the time indicated, we point our telescope to the place, and, at the instant, true beyond the accuracy of any timepiece, the orb sweeps into view! A prediction of the

closely with his sextant, and reads off the angle of its altitude above the horizon several times in succession. By combining this with the sun's declination and the latitude as found at noon, a short computation gives him the local time, that is, the time on the geographical meridian where his ship is located. He then compares the local time thus determined with the Greenwich time as kept by the ship's chronometers. The difference in time reduced to degrees is the longitude.

(2) THE LUNAR METHOD. — On account of the difficulty in obtaining a watch that will keep the exact Greenwich time through a voyage of many months' duration, the moon is more generally relied upon than the chronometer. The Nautical Almanac is always published, for the benefit of sailors, three years in advance. It gives the distance of the moon from the principal fixed stars which lie along its path, at every third hour through the night. The sailor has only to determine with his sextant the moon's distance from any fixed star, and then, by referring to his almanac, find the corresponding Greenwich time. By comparing this with the local time, as found from observations of the sun, and reducing the difference to degrees, he obtains the longitude.

5. To find the Latitude of a Place. — (1) By means of the sextant find the elevation of the pole above the horizon, and this gives the latitude directly (figure on page 96).

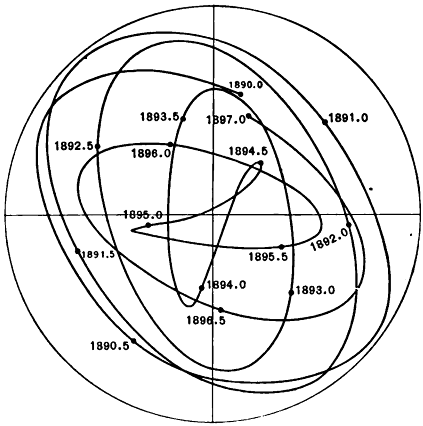
Nautical Almanac is received with as much confidence as if it were a fact contained in a book of history. 'On the trackless ocean, this book is the mariner's trusted friend and counselor; daily and nightly its revelations bring safety to ships in all parts of the world. It is something more than a mere book. It is an ever-present manifestation of the order and harmony of the universe.'

(2) In the same manner, determine the height of the sun above the horizon at noon. The sun's declination for that day (as laid down in the almanac) added to or subtracted from this, gives the height of the equinoctial above the horizon. Subtract this result from 90°, and the remainder is the latitude.

'Place an astronomer on board a ship; blindfold him; carry him by any route to any ocean on the globe, whether under the tropics or in one of the frigid zones; land him on the wildest rock that can be found; remove his bandage and give him a chronometer regulated to Greenwich or Washington time, a transit instrument with the proper appliances, and the necessary books and tables, and in a single clear night he can tell his position within a hundred yards by observations of the stars.'

When latitudes are observed very accurately, it is found that they are subject to a slight variation the world over. This is due to an oscillation of the earth's axis of rotation within the earth itself. The true north pole is not, therefore, a fixed point on the earth's surface, but it travels round irregularly in an ellipse whose major axis is about sixty, and minor about forty, feet long. This ellipse is continually varying in position, and the pole makes a complete circuit of it in about thirteen months (see next figure). As every point of the equator is exactly 90° from the pole, evidently the location of the equator upon the earth's surface must also fluctuate; therefore, as latitude is distance from the equator, latitudes must likewise change. This is known to astronomers as *variation of latitude.*

6. To find the Circumference of the Earth. — If the earth were a perfect sphere, it is obvious that degrees of latitude would be of the same length wherever measured on its surface. Each would be $\frac{1}{360}$ of the entire circumference. If, however, a person should set out from the equator, and travel along a meridian toward either pole, and, when the polar star has risen in the heavens one degree above the horizon, mark the spot, and then continue his journey, marking each degree in succession, he would find that the degrees are not of equal length, but increase gradually from the equator to the pole. If, now, the length of a degree be measured at different places, the rate of variation can be found, and then the *average* length be estimated. Measurements for this purpose have been made in Peru (almost exactly at the earth's equator), Lapland, France, England, India, Russia, and elsewhere. So great accuracy has been attained that Airy and Bessel, who solved the problem independently, differed in their estimate of the equatorial diameter but 77 yards, or only $\frac{44}{1000}$ of a mile; and later determinations are even more accordant.



OBSERVED WANDERING OF THE NORTH POLE

7. To find the Relative Size of the Planets. — The volumes of two globes are proportional to the cubes of their like dimensions. The diameter of Mercury is 3000 miles, and that of the earth 7917; then,

The volume of Mercury : the volume of the earth :: $3000^3 : 7917^3$.

The same principle applied to the volume or bulk of the sun gives —

The bulk of the sun : bulk of the earth :: $865{,}400^3 : 7917^3$.

8. To find the Diameter of the Sun. — (1) A very simple method is to hold up a circular piece of paper before the eye at such a distance as exactly to hide the entire disk of the sun. Then we have the proportion,

Dist. of paper disk : dist. of sun's disk :: diam. of paper d. : diam. sun's d.

(2) The apparent diameter of the sun, as seen from the earth, is about 32′; the apparent diameter of the earth as seen from the sun is twice the solar parallax, or 17″.60. Thence, the

Ap. diam. of earth : ap. diam. of sun :: real diam. of earth : real diam. of sun.

(3) Knowing the apparent diameter of the sun, and its distance from the earth, the real diameter is found by trigonometry. In the figure on page 291, let S represent the earth; AB, the radius of the sun; and ASB, half the apparent diameter of the sun. We shall then have the proportion

AS : AB :: radius : sin 16′, the semidiam. of sun.

By a similar method the diameters of the planets are obtained.

PRACTICAL QUESTIONS

1. In what constellation is Job's Coffin? The Letter Y? The Scalene Triangle? The Dipper? In what constellation are the Kids? The Triangles?
2. Name some facts in the solar system for which the nebular hypothesis fails to account.
3. Are any of the stars likely to collide with one another?
4. Is the real day longer or shorter than the apparent one?

5. What fixed star is nearest the earth?

6. How often is Polaris on the meridian of a place?

7. How do we know that the stars are suns?

8. Can a watch keep apparent time?

9. How could a child be eight years old before a return of its birthday?

10. When will a watch and a sundial agree?

11. What bright star will be the pole star next after Polaris?

12. Why is the birthday of Washington celebrated on February 22, when he was born February 11, 1732 (O.S.)?

13. Does the tide have any effect on the length of the day?

14. Will the Big Dipper always look as it does now?

15. How many times does the earth turn on its axis in a year?

16. Does the spectroscope tell us anything concerning the constitution of the moon, or any of the planets?

17. When the United States bought Alaska from Russia, the calendar used there was found to be eleven days behind our reckoning. Why was this?

18. Why do the dates of the solstices and equinoxes vary a day or two in different years?

19. Why are not forenoon and afternoon of the same day, as given in the almanac, of equal length?

20. In what part of the heavens do the stars apparently move from west to east?

21. What year was only nine months and six days long?

22. What day will be the last day of the twentieth century?

23. How do we know that the moon has little, if any, atmosphere?

24. Can you give any other proof of the rotundity of the earth, besides that named in the text?

25. Explain the remark of the First Carrier in Scene I, Act II, *King Henry IV:* 'An't be not four by the day, I'll be hanged: Charles' wain is over the new chimney.'

26. Why does not the earth move with equal velocity in all parts of its orbit?

27. How many Jovian years old are you?

28. Why is the sky blue?

29. At what season of the year in Australia does Christmas occur?

30. What causes the apparent movement of the sun north and south?

31. On what part of the earth is twilight the longest? The shortest?

32. Name the causes which make our summer longer than winter.

33. Why is not total darkness produced when a dense cloud passes between us and the sun?

34. Why does the time of the tide vary from day to day?

35. Why can an annular eclipse be longer than any total eclipse?

36. Why is it colder in winter than in summer?

37. Do the solar spots affect our weather?

38. Can the moon be eclipsed in the daytime?

39. Why are the sidereal days of uniform length?

40. Why are not the solar days of uniform length?

41. What do the moon's phases prove?

42. Why do the sun and moon appear flattened when near the horizon?

43. How many stars can we see with the naked eye?

44. Is there ever an annular eclipse of the moon?

45. Explain why a star rises and sets 366 times during each common year, while the sun rises and sets only 365 times.

46. How many moons are there in the solar system?

47. What causes the twinkling of the stars?

48. Name some of the uses of the stars.[1]

49. Describe the methods by which we determine the distance of the sun from the earth.

50. Why do not the signs and the constellations of the zodiac coincide?

51. When we look at the North Star, how long since the light that enters our eye has left that body?

[1] 'To the astronomer, the fixed stars are immovable boundary stones by which he determines the courses of the wandering heavenly bodies. To the geographer, they are the signal stations according to which he surveys the chart of the earth by the heavens. To the mariner, they are the lights that direct him over the dark paths of the seas. To the hunter, the herdsman, the wanderer, they are a clock. To the farmer, they are a calendar. The historian finds in them many a memorable event in the oldest Grecian history. The poet reads in them the charming Grecian mythology, which has furnished such rich materials to dramatic art; and every person of sensibility receives from them an impulse to worship, meditation, and hope.'

52. In what direction does a comet's tail generally point?

53. What is the cause of shooting stars?

54. Why does the crescent moon appear larger than the dark body of the moon?

55. What is the real path of the moon?

56. What would be the result if the axis of the earth lay in the plane of its orbit?

57. Do we see the same stars at different seasons of the year?

58. Why do we not perceive the earth's motion in space?

59. Did the earth ever shine as a star? Does it now shine as a planet?

60. What is the nebular hypothesis?

61. What is the cause of the solar spots?

62. Under what conditions are we accustomed to transfer motion?

63. Why do not the planets twinkle?

64. Why is the horizon a circle?

65. What causes are gradually increasing the length of the day?

66. What distance does the moon gain in her orbit each year?

67. State the general argument which renders it probable that other worlds are inhabited.

68. Illustrate the uniformity of nature. What thought does this suggest?

69. At what rate are we traveling through space? How is this determined?

70. Why does the length of a degree of latitude increase in going from the equator toward either pole of the earth?

71. How can you detect the yearly motion of the sun among the stars?

72. Have you actually traced the movement of any one of the planets, so as to understand its peculiar and irregular wandering among the stars?

73. How do you explain the varied aspect of the heavens in the different seasons of the year?

74. How does the spinning of a top illustrate the subject of precession?

75. Why do solar eclipses begin on the west limb of the sun and cross to the east, while lunar eclipses begin on the east limb of the moon and cross to the west?

76. Newcomb in his Astronomy says, 'If, when the moon is near the meridian, an observer could in a moment jump from New York to Liverpool, keeping his eye fixed upon that body, he could see her apparently jump in the opposite direction about the same distance.' Explain.

77. When, and by whom, was the basis of the calendar we now use fully established?

78. How much is the Russian reckoning of time behind ours?

79. Is there any gain in having the astronomical and the calendar year agree?

80. What religious festival is fixed each year by the motion of the moon?

81. Why can we, at different times, see *both poles* of the planet Mars?

82. What famous astronomical discovery was made on the first day of the nineteenth century?

83. At the poles of the earth, do any stars rise and set?

84. Name and locate the stars of the first magnitude which are seen in our sky.

85. Name three bright stars which lie near the first meridian.

86. What events were taking place in our history a Saturnian century ago?

87. What is the sun's declination at the winter solstice? At the autumnal equinox?

88. Will the width of the terrestrial zones always remain exactly as now?

89. Is it always noon at 12 o'clock?

90. When the sun's declination is $23\frac{1}{2}°$ N., in what sign is he then located, and what is his R. A.?

91. What is the apparent diameter of the sun?

92. How can a sailor find his latitude and longitude at sea?

93. How many miles on the solar disk represent a second of arc?

94. What is the least latitude at which there will be twilight during an entire midsummer night?

IV

APPENDIX

APPENDIX

TABLE ILLUSTRATING KEPLER'S THIRD LAW

In the second column are the relative distances of the planets from the sun; in the third, the periodic times of the planets; and in the fourth, the squares of the periodic times divided by the cubes of the mean distances:—

Planet	Distance	Periodic Time	$\frac{[\text{Time}]^2}{[\text{Distance}]^3}$
Mercury	0.38710	87.969	133 421
Venus	0.72333	224.701	133 413
Earth	1.00000	365.256	133 408
Mars	1.52369	686.979	133 410
Jupiter	5.20277	4,332.585	133 294
Saturn	9.53858	10,759.220	133 375
Uranus	19.18239	30,688.821	133 422
Neptune	30.03627	60,126.722	133 413

Arago, speaking of Kepler's laws, says: 'These interesting laws, tested for every planet, have been found so perfectly exact that we do not hesitate to infer the distances of the planets from the sun from the duration of their sidereal periods; and it is obvious that this method possesses considerable advantages in point of exactness.'

MEASUREMENTS OF THE EARTH'S DIAMETER

	Airy	Bessel	Clarke (1878)
	Miles	Miles	Miles
Polar diameter	7899.17	7899.11	7899.58
Equatorial diameter	7925.64	7925.60	7926.59
Compression	26.47	26.49	27.01

ORBITS OF THE PERIODIC COMETS

Name of Comet	Periodic Time in Years	Distance from the Sun in Astronomical Units: Least	Distance from the Sun in Astronomical Units: Greatest	Eccentricity of Orbit	Longitude of its Perihelion	Longitude of its Ascending Node	Inclination of Orbit to Ecliptic	Direction of Motion	Next Return to Perihelion
Encke	3.303	0.341	4.095	0.8464	158° 45′ 39″	334° 46′ 43″	12° 54′ 37″	D[1]	1901, August
Tempel	5.218	1.351	4.666	0.5511	306 15 0	121 10 6	12 44 22	D	1904, September
Brorsen	5.456	0.588	5.610	0.8103	116 23 10	101 27 34	29 23 48	D	1901, January
Tempel-L. Swift	5.547	1.090	5.177	0.6522	43 26 41	296 27 10	5 23 25	D	1902, December
Winnecke	5.831	0.924	5.555	0.7147	274 14 39	100 53 12	16 59 34	D	1904, February
De Vico–E. Swift	5.863	1.392	5.111	0.5719	345 19 12	48 44 37	2 57 54	D	1900, July
Tempel	6.538	2.091	4.902	0.4019	241 16 4	72 36 5	10 47 14	D	1905, April
Finlay	6.622	0.989	6.064	0.7195	7 41 34	52 27 43	3 2 2	D	1900, February
D'Arrest	6.675	1.321	5.769	0.6273	319 19 38	146 15 33	15 43 33	D	1903, November
Biela (1)	6.692	0.879	6.223	0.7524	109 40 18	245 46 11	12 21 58	D	
Biela (2)	6.693	0.879	6.224	0.7525	109 40 12	245 45 13	12 22 13	D	
Wolf	6.845	1.603	5.607	0.5553	19 21 38	206 29 4	25 12 16	D	1905, April
Brooks	7.097	1.959	5.427	0.4695	1 48 54	18 1 8	6 3 34	D	1903, November
Faye	7.566	1.738	5.970	0.5490	50 48 47	209 35 24	11 19 40	D	1903, September
Tuttle	13.791	1.027	10.475	0.8215	116 43 41	269 55 0	54 18 11	D	1913, February
Pons-Brooks	71.56	0.776	33.698	0.9550	93 17 15	254 5 42	74 2 36	D	1955, April
Olbers-Brooks	72.65	1.199	33.623	0.9311	149 52 31	84 32 20	44 34 16	D	1960, February
Halley	76.08	0.687	35.224	0.9617	168 42 52	57 10 33	162 13 9	R	1910, February

[1] D signifies *direct*, or eastward; R, *retrograde*, or westward.

QUESTIONS FOR CLASS USE

THESE are for the most part the questions which the author used in his own classes for review and examination. In the historical portion, the pupils may be required to write articles upon the character and life of the various persons named, gathering materials from every attainable source. The teacher should also introduce whatever problems the class can master, taking topics from the article on Celestial Measurements and various mathematical treatises.

INTRODUCTION. — Define Astronomy. Is the earth a planet? Is the moon a planet? What is the sky? Why does it seem concave? What gives it its color? What is the difference in the appearance of a fixed star and a planet? What is the Milky Way? In what direction does it span the heavens? In what season of the year is it most brilliant?

I. THE HISTORY

15, 16. What can you say of the antiquity of astronomy? How far back do the Chinese records extend? Name some astronomical phenomena they contain. Why were these astronomers at fault in failing to announce the eclipse? (*Ans.* Certain religious ceremonies were performed on such occasions, and their omission was believed to expose the nation to the anger of the gods.) Why should the Chaldeans have become versed in this study? How ancient are their records? What discoveries did they make? How does the Asiatic differ from the European mind? What Grecian philosopher early acquired a reputation in this science? What did he teach?

17. What memorable eclipse did Thales predict? What did Anaximander teach? In what century did Pythagoras live? What was his characteristic trait? Did he advance any proof of his system? Explain his theory. How does it differ from ours? What strange views did he hold? When did Anaxagoras live? What did he teach?

18. What theory did Eudoxus advance? What is the theory of the crystalline spheres? What has Hipparchus been styled? What addition did he make to astronomical knowledge? How many stars in our present catalogue (p. 219)? How did Egypt rank in science at an early day? What preparation did the Grecian philosophers make to fit themselves for teachers? How long did Pythagoras travel for this purpose? What can you say of the School at Alexandria? What great work did Ptolemy write?

19. What theory did Ptolemy expound? Was it original? What discovery did Eratosthenes make? Describe that method (p. 298). Show how the movements of the planets puzzled the ancients. What was the theory of cycles and epicycles?

20. Did the ancients believe in the reality of this cumbrous machinery? Did this theory possess any accuracy? Could it be adapted to explain any new motion?

21, 22. What was the remark of Alfonso? Describe the progress of learning among the Saracens. Where was the first observatory in Europe built? When did Spain lose her prominence in scientific studies? What is astrology? What was its association with astronomy?

23. State something of the repute in which astrology was held. Tell what you can of the system. What use did it subserve? What theory was suggested in place of the Ptolemaic? Was the system of Copernicus original? What credit is due him? Describe his idea of apparent motion. How did he apply this to the heavenly bodies?

24. What crudity did he retain? Who was Tycho Brahe? What was his theory? How did it differ from Ptolemy's and Copernicus's? What good did Tycho Brahe accomplish? Had he a telescope? How did Kepler differ from Tycho Brahe?

25–28. What were the two prominent characteristics of Kepler? State his three laws. Tell how he discovered the first. The second. The third. Describe the ellipse. Define focus, perihelion, and aphelion. What remarkable statement did Kepler make? When did Galileo live? What discoveries did he make in physics?

29. What discoveries did he make in astronomy? What advantage did he have over his predecessors? Give an account of

his observations on the moon. On Jupiter's moons. Why did this settle the controversy between the Ptolemaic and the Copernican system? How were Galileo's discoveries received? Give some of the arguments against the new system.

30–32. Who discovered the law of gravitation? Repeat it. How was this idea suggested? What familiar laws of motion aided Newton? How did he apply these to the motion of the moon? Repeat the story of his patient triumph.

33, 34. What is the celestial sphere? Give the two illustrations which show its vast distance from the earth. Why can we not see the stars by day, as by night? What portion of the sphere is visible to us? Name the three systems of circles.

34–39. Name and define (1) the principal circle, (2) the subordinate circles, (3) the points, and (4) the measurements of each system. Define especially, because in common use, zenith, nadir, azimuth, altitude, equinoctial, right ascension, declination, equinox, ecliptic, colure, and solstice. What is N. or S. in the heavens?

39, 40. What is the zodiac? How wide is it? How ancient? How is it divided? Give the names and signs.[1] State the meaning of each (p. 220).

II. THE SOLAR SYSTEM

What bodies compose the solar system? Describe how we are to picture it to ourselves.

THE SUN. — What is its sign? Its distance from us? Illustrate. What is the solar parallax (see pp. 125, 291)? What change has recently been made in the determination of the parallax of the sun, and of its distance from the earth (see p. 296)?

47, 48. How are celestial distances measured? What is the color of the sun? To what is the sun's light equal? To how many moons? To what is its heat equal? Illustrate. What proportion of the sun's heat reaches the earth?

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

49, 50. What is the apparent size of the sun? How does this vary? State the solar dimensions: (1) diameter — illustrate; (2) volume; (3) mass; (4) weight; (5) density. How large did Pythagoras think the sun is? Tell something about the force of gravity on the sun.

51. How much would you weigh if carried to its surface? (The force of gravity on the sun as compared with the earth is 27.6.) How does the sun appear to the naked eye? How can we see the spots? What were formerly the views of astronomers with regard to the sun's face? When were the spots discovered?

52. Tell something about the number of the spots. Their location. Size. What number of miles subtend a second of arc at the distance of the sun?

53, 54. Describe the parts of which the spots are composed. Describe the motion of the spots. How do the spots change in form as they pass across the disk? What does this prove? What is the length of a solar axial rotation?

55. Explain a sidereal and a synodic revolution of a spot. Why do not the spots always move in straight lines? Show how they curve. Tell what you can about the irregular movements of the spots.

56, 57. Illustrate how suddenly they change. What can you say about their periodicity? Who discovered this? Is there any connection between the solar spots and the aurora? What is the law of zones? When is the next minimum of spots? Next maximum? Tell about the influence of the planets on the spots. Do the spots affect the fruitfulness of the season?

58, 59. Does the temperature of the spots differ from that of the rest of the sun? Are the spots depressions in the sun? How much darker are they than the adjacent surface? Is the sun brighter than the Drummond light? (*Ans.* The sun gives out as much light as one hundred and forty-six lime lights would, if each were as large as the sun and were burning all over.)

60. What are the faculæ? Describe the mottled appearance of the sun. What is the shape of the bright masses? What is a granule? What is its size? Where are the faculæ seen to be most numerous? How does the spectroheliograph reveal them?

60–63. Describe the constitution of the sun according to Wilson's theory. How did this theory account for the spots? The penumbra? The nucleus? The umbra? The faculæ?

63–65. What is the present theory (Kirchhoff's)? Name the four different portions of the sun. Define the nucleus. The photosphere. The chromosphere. The corona. What are the protuberances? How are the spots produced? The umbra? The penumbra? Upon what discoveries does this theory depend (p. 276)? What is the cause of the heat of the sun? Will the heat ever cease?[1]

THE PLANETS. — Name the six characteristics common to the planets. Compare the two groups of the major planets. Draw an ellipse, and name the various parts.

68. Define the ecliptic. The plane of the ecliptic. Why is the ecliptic so called (p. 142)? Define the ascending node. The descending node. Line of the nodes. Longitude of the node. Tell what you can with regard to the comparative size of the planets.

69–72. What is conjunction? Name the earliest that are recorded. What do you say concerning the probability of the planets being inhabited?[2] State the conditions of life on the different planets. What are the two divisions of the planets?

73–75. What causes the apparently irregular movements of the planets? Define heliocentric and geocentric places. Illustrate. In

[1] If we accept the nebular hypothesis (p. 267), we must suppose that the heat is produced by the condensation of the nebulous matter and consequent chemical changes. The sun is radiating its heat constantly, and, at some time, its light will go out, in turn, as that of the earth and the planets has before it. This theory is of especial interest, as it shows that the sun, as well as the rest of the solar system, has a certain fixed existence, and that, like all natural objects, it passes through its regular stages of birth, vigor, decay, and death, in one order of progress.

[2] The uniformity of Nature is a most effective argument in this direction. Light travels everywhere through the universe at the same rate. The elements of star, planet, and the earth are the same. The sun, which may be considered as the mother of the earth, is composed of the same materials. The laws of gravitation rule so absolutely that the satellite of Sirius was not discovered until after it was observed that an unknown influence affected the star. 'The uniformity of law and matter is proof that there must be through the universe organizations similar to those of our system. We see the result of these laws in the world we inhabit, and we cannot doubt that the same powers and the same materials have produced organizations similar to these of the earth in millions of other places, though we can only philosophically suppose their existence, not practically prove it.' — W. MEYER.

what part of the sky is an inferior planet always seen? Define inferior and superior conjunction. Greatest elongation. Why is a planet at one time *evening*, and at another *morning*, star? What is a transit? Explain the retrograde motion of an inferior planet. (This motion, it will be remembered, was one that sorely puzzled the ancients.) Describe the phases of an inferior planet. Why does an inferior planet have phases? Define gibbous.

76, 77. Explain the opposition and conjunction of a superior planet. Explain its retrograde motion. Must a superior planet always be seen in the same part of the sky as the sun? Define quadrature. Can an inferior planet be in quadrature? Which retrogrades more, a near or a distant planet?

78, 79. Define a sidereal and a synodic revolution of an inferior and a superior planet, and tell what you can about each. In what case would there be no difference between a sidereal and a synodic revolution? Why is a planet invisible when in conjunction? When is a planet evening, and when morning star?

MERCURY. — Definition and sign? Are there any known planets interior to the orbit of Mercury? Describe the appearance of Mercury, and where seen. What was the opinion of the ancients? Of the astrologers? Of chemists? Why is it difficult to see this planet? When can we see it best? What is the peculiarity of its orbit? What is Mercury's greatest elongation from the sun? Why does this vary? What is Mercury's distance from the sun? What is its velocity?

81. What is the length of its day? Of its year? Has Mercury librations? What is the difference between its sidereal and synodic revolutions? What is its distance from the earth?

82, 83. Show why its greatest and least distances differ so much. What is its diameter? Volume? Density? Force of gravity? How much would you weigh on Mercury if weighed in a spring balance? (Mercury's force of surface gravity as compared with that of the earth is about $\frac{1}{3}$.) Describe its seasons. What is the temperature? The appearance of the sun? Has Mercury any moon? What is the appearance of the planet through a telescope? What do these phases prove? Has Mercury any atmosphere? What do recent observations reveal?

VENUS. — Definition and sign? Ancient names? Appearance to us? Can Venus be seen by day? Illustrate.

85. Describe the orbit of Venus.[1] What is the distance of Venus from the sun? Velocity? Length of the year? Day? Difference between the sidereal and synodic revolutions? Distance from the earth? How near may Venus approach us? How does her apparent size vary?

86, 87. When is Venus the brightest? What is her diameter? Volume? Density? Force of gravity? (The force of gravity on the surface of Venus is 0.8 that of the earth.) Describe the seasons upon Venus. Describe the telescopic appearance of Venus. Who discovered the phases of Venus? What was the effect of this discovery?

88. What proof have we that Venus possesses a dense atmosphere? How may the 'phosphorescence' of her dark hemisphere be explained? Has Venus a moon? What markings have been seen by recent observers?

EARTH. — Sign? What is the appearance of the earth from the other planets? Do we, then, live on a star? Is it probable that the earth was always dark and dull as it now seems to us?[2] How does the size of the earth compare with that of the other planets? What is the shape of the earth? What is its exact diameter? (See Table in the Appendix.) Circumference? Density? Weight?

91. What comparison may be made to illustrate its inequalities? How do you prove the rotundity of the earth?

92. Why can we see further from the top of a hill than from its base? Why is the horizon a circle? Give some illustrations of apparent motion. Is it, then, natural for us to *transfer* motion? Under what conditions do you think this occurs?

93. Explain the cause of the rising and setting of the sun and stars. Who first explained these phenomena in this manner? What do you say of its simplicity? What is the cause of day and night?

[1] Venus is the only planet mentioned by Homer —

> Οἷος δ' ἀστὴρ εἶσι μετ' ἄστρασι νυκτὸς ἀμολγῷ
> Ἕσπερος ὃς κάλλιστος ἐν οὐρανῷ ἵσταται ἀστήρ. — *Iliad*, xxii. 317.

[2] Probably not. The earth was doubtless once a glowing body, hot like the sun. Its crust is only the ashes and cinders of that fearful conflagration. The rocks are all burnt bodies. The atmosphere is only the gas left over after the fuel was all consumed. Every organic object has been rescued by plants and the sunbeam from the grasp of oxygen.

94. Do all places on the earth revolve with equal velocity? Illustrate. At what rate do we move? Why do we not perceive our motion?

95. What would be the effect if the earth were to stop its rotation? Is there any danger of this catastrophe? How is the length of the day increasing? Is the amount appreciable?

96, 97. Draw the figure, and show how the stars move daily along unequal paths, and with unequal velocities. Describe the appearance of the stars at the north pole. At the equator. At the south pole. Describe the path of the earth about the sun.

98, 99. Define eccentricity. What is the amount of the eccentricity of the earth's orbit? Is this invariable? Do we see the same stars at different seasons of the year? Why not? If we should watch from 6 P.M. to 6 A.M., what portion of the sphere would we see?

101. What do we mean by the yearly motion of the sun among the stars? How can we see it? What is the cause? What is the ecliptic? Why so called? What are the equinoxes? What do you understand when you see in the almanac the statement, 'the earth is in Aries?' 'The sun is in Sagittarius?' etc. How many apparent motions has the sun? Name them, and give the cause and effects of each. Has the sun any real motions?

102. Describe the apparent motion of the sun, north and south. How is it that the sun in summer shines on the north side of some houses both at rising and setting, but in winter never does? Define the obliquity of the ecliptic. The parallelism of the earth's axis. What do you say of its permanence? Why will a top stand while spinning, though it falls as soon as it ceases spinning?

103. Show how the rays of the sun strike the various parts of the earth at different angles at the same time. Show how the angles vary at different times. Is the sun really hotter in summer than in winter? Why does it seem to be? Why is summer warmer than winter? What effect upon the temperature has the difference in the length of the summer and the winter day?

104–106. Explain the cause of equal day and night at the equinoxes. Why are our days and nights of unequal length at all other times? Why does the length vary at different seasons of the year? How do the seasons, etc., in the north temperate zone compare with those in the south temperate zone? Describe the yearly path of the earth about the sun — (1), at the summer solstice; (2), at the autumnal equinox; (3), at the winter solstice; (4), at the vernal equinox; (5), the yearly path finished back to the starting point. Is the division of the earth's surface into zones an artificial or a natural distinction? Who invented it?

107, 108. How much nearer are we to the sun in winter than in summer? Why is it not warmer in winter? How is it in the south temperate zone? When do the extremes of heat and cold occur? Why do they not occur exactly at the solstices? Why is summer longer than winter? Does the earth move with the same velocity in all parts of its orbit? Describe the curious appearance of the sun at the north pole. In Greenland, at what part of the year will the midnight sun be seen due north? What is the length of the days and nights at the equator?

109. Describe the results if the axis of the earth were perpendicular to the ecliptic. If the equator were perpendicular to the ecliptic. Define the precession of the equinoxes. Who discovered this fact? At what rate does this movement proceed?

110, 111. What time will be required for the equinoxes to make an entire revolution? What are the results of precession? What star was formerly the polar star?

112–114. Explain the cause of precession. How does the spinning of a top illustrate this subject? In what way is the force which acts on a spinning top opposite to that which produces precession?

115. What is nutation? What is the cause of the nodding motion? How does the moon's influence compare with that of the sun? What is the effect of nutation? What is the real path of the north pole through the heavens?

116. Is the obliquity of the ecliptic invariable? What is the period of this oscillation? What causes combine to produce the nodding motion we have described? Why are the tropics located where they are? Is their position on the earth permanent? What effect does the variation in the obliquity have on the latitude of the stars? What is meant by the line of apsides of the earth's orbit? Is its position permanent?[1]

[1] The line of equinoxes of the earth's orbit, as we have seen, has a slow *left-handed retrograde motion* of 50¼″ each year, called the precession of the equinoxes; and the line of apsides has a still slower *right-handed direct*

117. At what season of the year is the earth now in perihelion? When was it in perihelion in the autumn? When in the winter? When will perihelion occur in the spring? When in summer? When will the cycle be completed? What provision is there for permanence in the midst of these changes?

118, 119. What is refraction? Its effect? Upon what principle of optics is this based? How does refraction vary? Are the sun and moon ever where they seem to be?

120. Is the real day longer or shorter than the apparent one? Describe the apparent deformation of the sun and moon near the horizon. Explain. Why are not these bodies apparently deformed in the same way when they are high in the heavens? Why do they appear smaller in the latter case? (See page 128.) What causes the hazy appearance of the heavenly bodies near the horizon?

121. What is the cause of twilight? How long does it last? Is it the same at all seasons of the year? In all parts of the earth? Where is it the longest? Shortest? State the cause of this variation.

122. What is diffused light? Is there really any sky in the heavens? What is the cause of the appearance?

123. What is aberration of light? Illustrate this phenomenon. State two reasons why we never see the sun where it really is.

124. What is the general effect of aberration? Define parallax. Illustrate.

125, 126. Define true and apparent place. How does parallax vary? What is the practical importance of this subject? Define horizontal parallax. What is the sun's horizontal parallax? What is annual parallax?

THE MOON.—Signs? Describe the moon's orbit. What is the moon's distance from the earth? Illustrate. What is the difference between her sidereal and synodic revolutions?

127. What is the real path of the moon? How often does the moon turn on her axis? What is the moon's diameter? Volume? How does her apparent size vary? Why does she appear larger than she really is?

motion of 11″.8; and in consequence of the motion of both these lines, the angle formed by them changes through about 62″ each year, so as to complete an entire revolution in about 21,000 years.

128. Why does the crescent moon appear larger than the dark body of the moon? When ought the moon to appear the largest? Do all persons think the moon to be of the same apparent size?

129. Explain the three librations of the moon. How does moonlight compare with sunlight? Is there any heat in moonlight?

130. Has the moon any atmosphere? What proof have we of this? (*Ans.* 1. We see but slight, if any, appearance of twilight on the moon. 2. When the moon passes between us and a star, it does not refract the light of a star, so that the atmosphere cannot be sufficient to support more than $\frac{1}{15}$ of an inch of the mercurial column.) How does the earth appear from the moon? What is the earth shine? How is it caused? What is it called in England?

131, 132. Describe the path of the moon around the earth, and the consequent phases. Why is new moon seen in the west and full moon in the east? Why can we sometimes see the moon in the west after the sun rises, and in the east before the sun sets? What is the length of a lunar month?[1]

133, 134. What do we mean by the moon's running high or low? What is the cause of this variation? Is it of any use? What is harvest moon? What is the cause?[2]

135–137. Explain the cause of 'Dry Moon' and 'Wet Moon.' What are nodes? How much is the moon's orbit inclined to the ecliptic? What is an occultation? What use does it subserve? Describe the seasons, heat, etc., on the moon.

[1] 'The moon's sidereal period is not constant, and a comparison of modern with ancient observations shows that it has undergone an acceleration since the period of the Chaldean observations of eclipses made B.C. 720. Several explanations have been given by Laplace and others, of the supposed cause of the acceleration of the moon's mean motion; but it is highly probable that it is a *pseudo-phenomenon*, that owes its origin to a real lengthening of the time of rotation of the earth (which is the unit of astronomical time), caused by the friction of the sea and atmosphere.'

[2] It will aid in understanding the cause of harvest moon, if one gets clearly in mind the fact that the moon when full is always in the opposite part of the heavens from the sun. At the time of the autumnal equinox, *i.e.* when the sun is at the autumnal equinox (or in Libra, note, p. 101), the moon must be at the vernal equinox (or in Aries). The least retardation of the moon, which occurs at this time, happens, therefore, in September.

138–141. Describe the telescopic appearance of the moon. Are the mountains the light or the dark portions? What can you say about them? The gray plains? The rills? The craters? What are the peculiar features of the lunar landscapes? Are the lunar volcanoes extinct? What aid has photography rendered to astronomy? Why?

142. ECLIPSES. — When can an eclipse of the sun occur? Show how a solar eclipse may be total, partial, or annular. Define umbra. Penumbra. Central eclipse. State the general principles of a solar eclipse. What eclipses of the sun are visible for a half century in the United States? What eclipses have the longest duration of totality? What curious phenomena attend a total eclipse?[1] What are Baily's Beads? What is the corona? How does the corona vary in appearance from time to time? Describe the effect of a total eclipse. What is the Saros? Is it now of any value? What is the Metonic Cycle? Explain its use. What is the Golden Number? What is the Golden Number of the present year? What is the cause of a lunar eclipse? Why are lunar eclipses seen oftener than solar ones? How were total eclipses formerly regarded? What uses have observations of lunar eclipses?

152. THE TIDES.[2] — Define ebb. Flow. How often does the tide happen? Explain the cause. Why does the tide occur about

[1] Sir Norman Lockyer, describing the beginning of a total eclipse, 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.' — Gillis, in his observations upon the eclipse of 1859, as witnessed by him in Peru, remarks: 'At 1.54, the moment of totality, the attendants, catching sight of the corona, dropped on their knees, and shouted, "La Gloria! La Gloria!"'

[2] As the tidal wave does not move so rapidly as the earth does, the water has an apparent backward motion. It has been suggested that this (as well as the friction of the atmosphere) *acts as a brake* on the earth's diurnal revolution. It has been shown that the moon's true place can be best calculated if we suppose that the sidereal day is shortening at the rate of $\frac{135}{10000}$ of a second in 2400 years. (See page 95.)

fifty minutes later each day? Why is there a tide on the side opposite the moon? The sun is much larger than the moon; why does it not produce the larger tide? What effect has the friction of the tides produced upon the earth? What theory upon this topic has Sir Robert Ball advanced? What is meant by the differential effect of the moon? Why is not the tide felt out at sea? What is spring tide? Neap tide? Why does the tide differ so much in various localities? Tell about the height of the tides at different points. Why is there practically no tide on a lake? Is the tidal wave a forward movement of the water?

156. MARS. — Definition and sign? Describe the appearance of this planet. When is it brightest? What is its distance from the sun? Velocity? Day? Year? Distance from the earth? What is the peculiarity of its orbit? What is the diameter of Mars? Its volume and density as compared with the earth? How far would a stone fall on its surface the first second? Who discovered its moons? What is the peculiarity of these tiny globes? What are the peculiar telescopic features of Mars? What is the cause of its ruddy color? What are the canals and oases thought by some astronomers to be? Also the polar caps? What happened for the first time in 1894? Can we watch the change of the seasons of Mars?

161. SMALL PLANETS (ASTEROIDS).[1] — Give Bode's law. Tell when the first of these planets was discovered. How many are now known? Are they probably all discovered? Describe some of these 'pocket planets.' Which one is the largest? What is the average size? Do all lie within the zodiac? What is their origin? (*Ans.* According to the nebular hypothesis, the ring of matter broke up into numberless small bodies, instead of aggregating into

[1] 'It may surprise some persons to learn that the total mass of the two or three hundred small planets which have been discovered between the orbits of Mars and Jupiter is sufficient only to make a globe a little over 400 miles in diameter. In other words, if our globe were divided into 8000 equal parts, one of these parts would equal in bulk and in weight the total of all these asteroids. Or, cut the earth through the equator, then take a section of about three fourths of a mile in thickness, and it would furnish material for all these small planets, and something remaining. It would seem that the solar system could not be much damaged if some of these small planets should drop out of their courses, and join some of the larger ones.'

one large planet.) Give some of the names and signs. What is the nearest planet? When discovered, and by whom? Why is it important? What is its least distance from the earth? How often does this occur? How large is Eros?

164. JUPITER. — Definition and sign? Describe his appearance. Describe his orbit. What is his distance from the sun? Velocity? Day? Year? Distance from the earth? Diameter? Volume? Density? Centrifugal force? Force of gravity? Figure? Describe his seasons. Upon what does the change of seasons in any planet depend? What must be the appearance of the Jovian sky? Describe the telescopic features of Jupiter. Are Jupiter's moons visible to the naked eye? What are their names? What is their size? What space do they occupy? How large a telescope is required to show the fifth satellite? Is it closer to Jupiter than the other satellites? What markings are thought to have been seen on the major satellites? How rapidly do they turn round on their axes? Describe the eclipses of Jupiter's moons. Define immersion, emersion, and transit. How rapidly do the satellites revolve? What can you say of the frequency of eclipses on Jupiter? Is satellite IV eclipsed at every revolution? Describe the belts. Why are they parallel to Jupiter's equator? How was the velocity of light discovered? Does Jupiter emit light? How has the great red spot been explained? Is it probable that a solid crust has formed over this planet? In what way is Jupiter reproducing the earth's history?

172. SATURN. — Definition and sign? Describe Saturn's appearance in the heavens. How rapidly does this planet move through the sky? What is its distance from the sun? What is the peculiarity of its orbit? What is its velocity? Year? Day? Distance from the earth? Diameter? Volume? Density? Force of gravity? Describe its seasons. Has it any atmosphere? Who discovered the rings of Saturn? Describe them. Which are the bright rings? Which is the dusky ring? Are they stationary? Explain their phases. Of what are they composed? How is this theory of their composition demonstrated? Does Saturn emit light? Describe Saturn's belts. Describe Saturn's moons. The scenery on Saturn.

179. URANUS. — Definition and sign? How was this planet discovered? Tell of its previous observation by Le Monnier. Is

Uranus visible to the naked eye? What is its distance from the sun? Year? Diameter? Density? Describe its seasons. Telescopic features. Satellites. Peculiarity of its moons. What are their sizes?

180. NEPTUNE. — Definition and sign? What is the appearance of this planet in the sky? Give an account of the wonderful discovery of Neptune. What is its distance from the sun? Year? Velocity? Diameter? Volume? Density? Do we know anything of its seasons? Why not? What is the appearance of its heavens? What are the telescopic features of Neptune? Has Neptune any moon? What advantage have the Neptunian astronomers, if there be any?

183. METEORS AND SHOOTING STARS. — Define a meteorite. A shooting star. A meteor. Give some account of the fall of meteorites. What elements are found in meteorites? How can a meteorite be distinguished? How is the structure of iron meteorites revealed? Give an account of wonderful meteors. Of shooting stars. Describe the showers of 1799 and 1833.[1] The shower of 1866. At what intervals did these showers occur? Why was not the shower of 1866 seen in this country? (*Ans.* Our side of the earth was not turned toward the meteors.) Can meteors be photographed? How? Were any Leonids seen in 1898? Why are they called Leonids? When are they next expected to be seen in large numbers? Can they do any harm to the earth? What is the average number of meteors and shooting stars daily? Why do we not see more of them? In what months are they most

[1] A southern planter, describing the effect of the star shower of 1833, says: '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 toward the earth: east, west, north, and south, it was the same.'

abundant?[1] Describe the origin of meteors and shooting stars. What is their velocity? What causes the light? The explosion often heard? What is the theory of meteoric rings? What is their shape? How do these streams of meteors account for the showers at regular intervals? What is the period of the November ring? Why is the August shower so uniform, while the November one is periodic?[2] What is the relation between meteors and

[1] It has been noticed from very early times that the night of the 10th of August (Saint Laurence's Day) is especially favorable for the occurrence of shooting stars; and in Catholic Ireland these stars, on the 10th of August, are always called the 'tears of Saint Laurence the Martyr,' who was put to death by being broiled upon a gridiron.

[2] The fact that the November meteors are collected in a shoal, instead of being distributed uniformly through the orbit, gives color to the idea that this stream has not been long a member of the solar system. 'In 1867 Leverrier stated his belief that the November meteors form the remains of some comet that had been recently introduced into the solar system by the attraction of one of the large outer planets. He found that the year A.D. 126 would give a position to the planet Uranus capable of producing such an effect, by converting the parabolic path of a comet into the path now described by the November meteors. In the year A.D. 137 the changed path of the comet for the first time came near the earth in her orbit round the sun, since which year the petrified comet or shower of stones has completed 52 entire revolutions, the last of which terminated on the 13th of November, 1866. Theophanes of Byzantium relates that in November, A.D. 472, the sky at Constantinople appeared to be on fire with flying meteors. This corresponded with the tenth revolution of the November meteors. — Condé, in his history of the dominion of the Arabs, speaking of the year A.D. 902, states that in the month of October (13th), on the night of the death of King Ibrahim Ben Ahmed, an immense number of falling stars were seen to spread themselves over the face of the sky like rain, and that the year in question was thenceforth called the "Year of Stars." This year corresponded to the twenty-third revolution of the November meteors. — A similar shower of stars took place on the 17th of October, A.D. 934. — On the 14th of October, A.D. 1002, a remarkable shower of shooting stars is noted by the Arab astronomers and historians, corresponding with the completion of the twenty-sixth revolution of the November meteors. — It is related in the annals of Cairo that on the 19th of October, A.D. 1202, the stars appeared like waves upon the sky, toward the east and west; they flew about like grasshoppers, and were dispersed from left to right. This shower corresponded with the thirty-second revolution of the November meteors. — On the 22d of October, A.D. 1366, a shower of stars was noted, corresponding with the thirty-seventh revolution of the Novem-

comets? What do you mean by the radiant point? What is the height of meteors? Weight?

194. COMETS. — How were comets looked upon by the ancients? Illustrate. Define the term *comet*. What is the tail?[1] The nucleus? The head? The coma? Does each comet necessarily possess all these parts? How would a mere round, fleecy mass be known to be a comet? What mistake did Herschel make in looking, as he supposed, at one of this kind (p. 179)? Where do comets appear? In what direction do they move? How does a comet look when first seen? Describe the approach of a comet to the sun. Upon what does the time of greatest brilliancy depend? What do you say of the number of the comets? What was Kep-

ber meteors. — A similar phenomenon (forty-second revolution) was observed on the 25th of October, A.D. 1533. — The forty-seventh revolution was noted on the 9th of November, A.D. 1698. — The fiftieth revolution, observed by Humboldt and Bonpland, on the 12th of November, A.D. 1799, as already remarked, first led modern astronomers to speculate on the true nature of these remarkable periodic phenomena. The early observations of this meteoric shower were dated on the 12th of October, and during 52 revolutions the intersection of its orbit with that of the earth has moved on to the 14th of November. Adams has shown this movement of nodes to be a consequence of the attractions of the superior planets, and has finally demonstrated the truth of the cometary origin of the November meteors.' — HOUGHTON.

[1] 'Comets are almost always accompanied by tails, which are placed in the line joining the sun and comet, and on the side opposite to the sun. Exceptions to this rule, though rare, sometimes occur. For example, the tail of the comet of 1577 deviated 21° from the line joining the sun and the comet, and the tail of the comet of 1680 diverged 5° from the same line. Comets have been occasionally observed with two tails, one in the usual position, and the other in nearly an opposite direction, or toward the sun. The angle between the two tails, when such a phenomenon has been observed, has always been very considerable, varying from 140° to 170°. This rare phenomenon of two tails is supposed to be connected with certain rapid changes which the gaseous substance of the comet is observed to undergo on approaching the sun. There are many instances on record in which the tails of comets were observed to stretch through 100° of the celestial sphere, and the apparent length of the tail is known to undergo most rapid changes. We shall mention only one case as an example of this phenomenon. The comet of 1618 presented to the Danish astronomer, Longomontanus, a tail 104° in length, while it had been measured by Kepler a few days previous, and ascertained to be only 70° long.'

ler's remark? Why do we not see them oftener? Describe the orbits of comets. Which class has been calculated? Which classes never return? Describe the difficulty of calculating a comet's orbit. Name the periods of some comets. What has been the distance of some noted comets from the sun? Velocity? What do you say of the density of a comet? Illustrate. Is there any danger of our running against a comet? Do comets shine by their own or by reflected light? Tell what you can of their variation in form and dimensions. What chemical elements are found in comets? By what instrument? Name and characterize the classes or types of tails of comets. Give some account of the comets of 1811, 1835, and 1843. For what is Biela's comet noted? (*Ans.* 'A very remarkable phenomenon attended the perihelion passage of this comet in the latter end of 1845. It became divided into two comets, which did not again unite, but traveled along together in similar orbits. This unique phenomenon was noticed for the first time in America on the 29th of December. The greatest distance observed between these two fragments of Biela's comet, before their final disappearance, was about *two thirds* of the moon's distance from the earth.') For what is Encke's comet noted? Is the idea of a resisting medium supported by later observations? What is its period? Give some description of Donati's comet. The comet of 1882. Discovery of comets by photography. When will the next bright comet come?

206. ZODIACAL LIGHT. — Where can this be seen? What is its appearance? Where is it brightest? What is its origin? What is the gegenschein? When best seen? To what is it thought to be due?

III. THE SIDEREAL SYSTEM

213. Tell something of the appearance of the heavens at Neptune's distance from the sun — our starting point. Which star is nearest the earth? What is its parallax? Its distance? How long would it take light to reach the nearest star? How would the earth's orbit appear at that distance? Our sun? How long does it take for the light of the smaller stars to reach the earth? What is meant by the term *light year?* How long a distance is it? Express the distance of Vega in light years. What can you say of the motion of the fixed stars? Illustrate. What proof have we

that the fixed stars are suns?[1] Describe the motion of the solar system. Toward what star? Is the center known? How many stars can we see with the naked eye? With a telescope? Have all the stars been discovered? What is the cause of the twinkling of the stars? What stars twinkle most? What ones least? Do we know anything of the magnitude of the stars? Name the points of difference between a planet and a fixed star. What do you mean by a star of the first magnitude? How many are there? Of the second magnitude? How many sizes can one see with the naked eye? What is the cause of the difference in the brightness? How are the stars named? What are star catalogues? Star charts? Describe Argelander's charts. How are such charts made at the present day? With what advantage? Describe the international stellar survey. Describe the division of the stars into constellations. Is there any real likeness to the mythological figures? Name any figure which seems to you well founded. Are the boundaries distinct? Who invented the system? State the possible meaning of the signs of the zodiac and their origin. Explain why the signs and the constellations of the zodiac do not agree. What causes the appearance of the constellations? Would they appear as they now do, if we should go out into space among them? Are the present forms permanent? State the value of the stars in practical life. What were the views of the ancients with regard to the stars? Describe the division of the stars into three zones.

224. The Constellations. — The questions on these are uniform: (1) *description*, (2) *principal stars*, (3) *mythological history*. Therefore, they need not be repeated with each constellation. What are the pointers? Does Polaris mark the exact position of

[1] 'Sirius shines at least 200 times as brightly as our sun would shine if set beside it. Assuming its surface to be equally brilliant, this would imply, in comparison with our sun, a diameter 14 times and a volume 3000 times as great. Its luster, however, seems higher than the sun's, but, even making allowance for that, we must still consider this giant sun to be at least 1000 times as large as our own orb. Recent evidence tends to show that its rate of recession from us is diminishing, so that we may expect this to change into a motion of approach. Here is a hint that Sirius is traveling in a mighty orbit with movements carrying it alternately from and toward us.' — Proctor.

the north pole? How many times a day is Polaris on the meridian of any place? Explain how this applies in navigation or surveying. State how the amount of the variation from the true north will change through the ages. What star will become the pole star in 12,000 years? What curious facts are stated concerning the pyramids? What do you say of the distance of Polaris? How may latitude be calculated by means of Polaris? What stars never set in our sky? What stars never rise?[1] Will the Big Dipper always appear as now? Name three bright stars near the first meridian. (*Ans.* α Andromedæ, γ Pegasi, and β Cassiopeiæ.) How many degrees of longitude correspond to an hour of time? At what rate is Sirius coming toward the earth? How has this motion been discovered? (See page 275.)

250. DOUBLE STARS. — Does any star appear double to the naked

[1] All stars whose north polar distance is less than the latitude of any place in the northern hemisphere will never set at that place, and all stars whose south polar distance is less than the latitude will never rise. The Greeks and the Romans were familiar with the fact that certain stars never descend below the horizon. The following quotations are interesting: —

'Immunemque æquoris Arcton.'

OVID, *Metam.* xiii. 293.

'Arctos
Æquoris expertes.' *Ib.* 726-7.

Ἄρκτον θ' ἣν καὶ ἄμαξαν ἐπίκλησιν καλέουσιν,
Ἥτ' αὐτοῦ στρέφεται, καί τ' Ὠρίωνα δοκεύει,
Οἴη δ' ἄμμορός ἐστι λοέτρων Ὠκεανοῖο.

Iliad, xviii. 487–9, and *Odyssey*, v. 273–5.

Ἄρκτοι κυανέου πεφυλαγμένοι Ὠκεανοῖο.

ARATUS, *Phænom.* 48.

'Arctos oceani metuentes æquore tingui.'

VERGIL, *Georg.* i. 246.

In order to understand the meaning of the expressions πέφυλαγμένοι Ὠκεανοῖο and *æquoris expertes*, as used by a Greek or Latin, we should remember that the north polar distance of η Ursæ Majoris is 39° 56′ 48″; and since the latitude of Athens is 37° 58′, and that of Naples 40° 50′, an inhabitant of the former city would see this star descend below the northern horizon for a small portion of its course; and an inhabitant of Naples would see it sink down almost to the horizon, so as to move along and just above its northern edge.

eye? How many have been found by the use of the telescope? What is an optically double star? Are all double stars of this class? Describe the revolution of a binary system. What other combinations have been discovered? What are their periods? How has the spectroscope assisted in these discoveries? Describe how these systems exist in space. What elements of the system are found by the spectroscope? What binary star was first discovered in this manner? What is its period and mass? What is the most rapidly moving one? Describe the orbits of ordinary binaries. Mass. Are these companion stars as close to each other as they seem?

252. Name some prominent colored stars. What is the probable effect in a system having colored suns?

253. What are variable stars? Describe the changes of Algol. Of Mira. What is the cause? How many variable stars are now known? How are star clusters peculiar in this respect? What is the shortest known period of a variable star? What is its period? Can it be seen from the United States?

254. What are temporary stars? Describe the one seen in Cassiopeia. The one in Corona Borealis, in 1866. What new star appeared in 1876? In 1885? In 1892? Describe its discovery. Give its history. What is it now? How have other new stars been discovered? In what part of the heavens are most of the temporary stars seen? What are lost stars? Can you give any explanation of this phenomenon? Of what did the star of 1866 consist? Are these stars destroyed? Is the process of creation now complete?

257. What are star clusters? Name several. Is such grouping a mere optical effect? Are they probably as closely compacted as they seem to be?

258. What are nebulæ? How do they differ from clusters? Is it possible that all nebulæ will be resolved into clusters? What has spectrum analysis proved some of the nebulæ to be? Where are they most abundant? What can you say about their distances? What is the general belief concerning nebulæ? Into how many classes, for convenience, are they divided? What do recent photographs of the great nebula in Andromeda reveal? Describe and illustrate the elliptic nebulæ. What is said of the distance of the great nebula in Andromeda? The number of stars it contains? Describe the annular nebulæ. What is said of the ring nebula in Lyra? Describe the spiral nebula in Canes Venatici. Describe

the planetary nebulæ. What is said of the number and size of these 'island universes'? Describe the fantastic appearance of the irregular nebulæ. What are nebulous stars? What is their structure? What are variable nebulæ? Give instances. What is said of double nebulæ? Is anything definite known with regard to them?

265. What are the Magellanic clouds? Describe the Milky Way. What can you say of the number of stars in the Galaxy? Are the stars uniformly distributed? State the latest views regarding the form of the visible universe. Where is the sun supposed to be located in it? What relation has the Milky Way to it? Is our sun thought to be a star of great relative importance?

267. Give an account of the nebular hypothesis. What is said of Saturn's rings? May they ultimately disappear? What peculiarity is shown by the earth-moon system? What was effected by tidal reaction? Apply this theory to the evolution of stellar systems. How do they differ from the planetary system? How are double stars thought to have been formed?

270. What is spectrum analysis? Name the three kinds of spectra. What colored rays will a gas absorb?[1] Describe the

[1] The power that gases possess of cutting out the particular lines which belong to the color that each emits has been beautifully illustrated by Newcomb. He says: 'Suppose nature should loan us an immense collection of many millions of gold pieces, out of which we were to select those which would serve us for money, and return her the remainder. The English rummage through the pile, and pick out all the pieces which are of the proper weight for sovereigns and half-sovereigns; the French pick out those which will make five, ten, twenty, or fifty franc pieces; the Americans the one, five, ten, and twenty dollar pieces, and so on. After all the suitable pieces are thus selected, let the remaining mass be spread out on the ground according to the respective weights of the pieces, the smallest pieces being placed in a row, the next in weight in an adjoining row, and so on. We shall then find a number of rows missing; one which the French have taken out for five-franc pieces; close to it another which the Americans have taken for dollars; afterwards a row which have gone for half-sovereigns, and so on. By thus arranging the pieces, one would be able to tell what nations had culled over the pile, if he only knew of what weight each one made its coins. The gaps in the places where the sovereigns and half-sovereigns belonged would indicate the English, that in the dollars and eagles the Americans, and so on. If, now, we reflect how utterly hopeless it would appear, from the mere examination of the

spectroscope. What are the Fraunhofer lines? What is the reversing layer? How is its existence proved? What is the nature of its spectrum? What is known of the constitution of the sun? What proof have we that iron exists in the sun? What elements have been found in the sun? How can we verify the sun's rotation by means of the spectroscope? What proof have we that the stars are suns? Describe the five classes or types of stellar spectra. How do we ascertain the motions of stars toward or from us? What stars are examples of motion from the sun? Of motion toward the sun? What is the astronomer's name for such motions? What has been discovered with regard to the constitution of the nebulæ? What important elements are known to exist in nebulæ? How is the relation of the Orion nebula to stars in that constellation? How remote is it? What is its motion? How has the proper motion of the stars been shown? Describe the sun and its protuberances. Their velocities. How does the spectroheliograph aid in the study of these objects? What is the relation of the sun's corona to them?

277. TIME. — What two methods of measuring time? What is a sidereal day? What are sidereal clocks? Tell how they are used. Why do astronomers use sidereal time? What is a transit instrument? How is it used? What is a chronograph? A photo-chronograph? What is a solar day? What causes the difference between a sidereal and a solar day? To how much time is a degree of space equal? Which is taken as the unit, the solar or the sidereal day? How long is a solar day? A sidereal day? A solar day equals how many sidereal hours? A sidereal day equals how many solar hours? Describe mean solar time. What is apparent noon? Mean noon? The equation of time? When is this greatest?

miscellaneous pile of pieces which had been left, to ascertain what people had been selecting coins from it, and how easy the problem would appear when once some genius should make the proposed arrangement of the pieces in rows, we shall see in what the fundamental idea of spectrum analysis consists. The formation of the spectrum is the separation and arrangement of the light which comes from an object on the same system by which we have supposed the gold pieces to be arranged. The gaps we see in the spectrum tell the tale of the atmosphere through which the light has passed, as in the case of the coins they would tell what nations had sorted over the pile.' — *Popular Astronomy*, p. 228.

When least? When do mean and apparent time coincide? What is local time? Why inconvenient? When was its use abandoned? Explain the system of standard time now in use in the United States. Give the relation of the four great time zones to one another and to Greenwich. Can a watch keep apparent time? How may apparent time be kept? How can it be changed into mean time? Tell how to erect a noon mark. When will a sidereal and a mean-time clock coincide? A mean-time clock and the sundial? How did the ancients measure time before the invention of clocks and watches?[1] State the two reasons why the solar days are of unequal length. What is the civil day? Who invented the present division? Describe the customs of various nations. What is the

[1] 'The ancients used clepsydræ and sundials to measure time. The clepsydra, in its simplest form, resembled the hourglass, water being used instead of sand, and the flow of time being measured by the flow of the water. After the era of Archimedes, clepsydræ of the most elaborate construction were common; but while they were in use, the days, both winter and summer, were divided into twelve hours from sunrise to sunset, and consequently the hours in winter were shorter than the hours in summer; the clepsydra, therefore, was almost useless except for measuring intervals of time, unless different ones were employed at different seasons of the year. The sundial was a great improvement upon the clepsydra; but at night and in cloudy weather it could not be used, of course, and the rising, culmination, and setting of the various constellations were the only means available for roughly telling the time during the night. Indeed, Euripides, who lived B.C. 480–407, makes the chorus in one of his tragedies ask the time in this form:—

What is the star now passing?

and the answer is:—

The Pleiades show themselves in the east;
The Eagle soars in the summit of heaven.

It is also on record that as late as A.D. 1108, the sacristan of the Abbey of Cluny consulted the stars when he wished to know if the time had arrived to summon the monks to their midnight prayers; and in other cases, a monk remained awake, and, to measure the lapse of time, repeated certain psalms, experience having taught him in the day, by the aid of the sundial, how many psalms could be said in an hour. When the proper number of psalms had been said, the monks were awakened.' — Sir Norman Lockyer.

origin of the names of the days?[1] Where does the day change? Why is a change necessary? What is meant by the expression 'dropping the day'? What is the sidereal year? What is the mean solar year? What causes the difference? What is the anomalistic year? How did the ancients find the length of the year? What error did they make? What was the result? Give an account of the Julian calendar. The Gregorian calendar. What is the meaning of the terms O.S. and N.S.?[2] What country now uses O.S.? When was the change adopted in England?[3] How was it received? How could a child be eight years old before a return of its birthday? When do the Jews begin their year? Why does our year begin January 1st? Show how the earth is our timepiece.

CELESTIAL MEASUREMENTS.—These problems are to be used throughout the study. They require no questions but the formal statement of the problem requiring solution.

[1] It is said that the Egyptians named the seven days from the seven celestial bodies then known. The order was continued by the Romans. Tuesday they called *Dies Martis*; Wednesday, *Dies Mercurii*; Thursday, *Dies Jovis*; Friday, *Dies Veneris*. In the Saxon mythology, Tiu, Woden, Thor, and Friga are equivalent to Mars, Mercury, Jupiter, and Venus. Hence we see the origin of our English names.

[2] '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 birthday in that year; hence, he was 20 years old on the 22nd of February, 1753, new style. Because anniversaries are always determined according to the civil calendar, the birthday of Washington is properly celebrated on the 22nd of February, and not on the 23rd, as some have contended, on account of the day dropped in the year 1800.' —PECK'S *Astronomy*, p. 216.

[3] 'In England, from the 14th century till the change of style in 1752, the legal and ecclesiastical year began at March 25, though it was not uncommon in writing to reckon it from January 1. After the change was adopted in 1752, events which had occurred in January, February, and before March 25, of the old legal year, would, according to the new arrangement, be reckoned in the next subsequent year. Thus the revolution of 1688 occurred in February of that legal year, or, as we should now say, in February, 1689; and it was at one time customary to write the date thus: February, 168$\frac{8}{9}$.' —APPLETON'S *Cyclopædia*.

GUIDE TO THE CONSTELLATIONS

Following is a description of the appearance of the heavens on or about the first day of each month in the year.

January (7 P.M.). — *In the North*, Cassiopeia and Perseus are above Polaris, Cepheus and Draco west, Ursa Minor is below, and Ursa Major below and to the east. *In the East*, Cancer is just rising, Canis Minor (Procyon) has just risen. *Along the Ecliptic*, Gemini is well up, then Taurus, Aries — reaching to the meridian, next Pisces; Aquarius (letter Y) and Capricornus are just setting. *In the Southeast*, Orion and the Hare are well up. *In the South*, Cetus swims his huge bulk far to the east and west. *In the Southwest* is Piscis Australis (Fomalhaut). *North of the Ecliptic*, the Triangles are nearly in the zenith, Perseus is just east, below is Auriga, Andromeda lies just west of the meridian, and Pegasus is midway; Delphinus (the Dolphin, Job's Coffin), Aquila (Altair), and Lyra (Vega) are fast sinking to the western horizon; while, along the Milky Way, blazes the brilliant cross of Cygnus.

February (7 P.M.). — *In the North*, Ursa Major lies east of Polaris, Ursa Minor and Draco are below, Cepheus is west, Cassiopeia above and to the west. *In the East*, Regulus and Cor Hydræ are just rising. *Along the Ecliptic*, Leo (Regulus, the Sickle) just rising, Cancer well up, Gemini midway, Taurus on the meridian, Aries (the scalene triangle) past, Pisces next, and, lastly, Aquarius just setting. *In the Southeast*, Canis Minor, Canis Major (Sirius), and Orion are conspicuous. *In the Southwest*, Cetus covers nearly the whole sky. *North of the Ecliptic*, Perseus is on the meridian, while Auriga is a little east of it; west of Perseus is Andromeda, while the Great Square of Pegasus is fast approaching the horizon. *In the Northwest*, Cygnus is setting.

March (7 P.M.). — *In the North*, Ursa Major lies east of Polaris, Draco and Ursa Minor are below, Cepheus is below and to the west, and Cassiopeia west. *In the East*, Cor Caroli is well up, toward the northeast, and Coma Berenices is rising. *Along the Ecliptic*, Leo is fully risen, next Cancer, Gemini reaches to the meridian, Taurus is past, Aries midway, and, lastly, Pisces is just beginning to set. *In the Southeast*, Cor Hydræ, Canis Minor, and Canis Major are conspicuous. *In the South*, Orion blazes brilliantly. *In the Southwest*, Cetus is hiding below the horizon. *North of the Ecliptic*, Auriga is in the zenith; west are Perseus and Andromeda, while Pegasus is just beginning to sink out of sight.

April (7 P.M.). — *In the North*, Ursa Major is above and to the east of Polaris; opposite and to the west is Perseus, Draco below and to the east, Cepheus below and to the west, Cassiopeia west. *In the East*, Boötes (Arcturus) is not quite fully risen. *Along the Ecliptic*, Virgo (Spica) is rising, Leo midway, Cancer reaches to the meridian, Gemini is past, next Taurus, then Aries, and, lastly, Pisces just setting. *In the Southeast* is the Crater (the Cup); Hydra stretches its long neck to the meridian. *In the South*, Canis Minor. *In the Southwest*, Sirius and Orion; the Egyptian X (p. 239) can now be seen. *North of the Ecliptic*, and in the northeast, are Coma Berenices and Cor Caroli; above Gemini and Taurus is Auriga, while Andromeda is just setting in the northwest.

May (8 P.M.). — *In the North*, Ursa Major is above Polaris, Ursa Minor and Draco are east, Cepheus and Cassiopeia below, and Perseus is west. *In the East*, Lyra is rising, and Hercules is just up. *Along the Ecliptic*, Libra is just rising, Virgo is midway, Leo is on the meridian, Cancer is past, next Gemini, and lastly Taurus just setting. *In the South*, stretching east and west of the meridian, is Hydra, with the Crater and Corvus a little east. *In the Southwest* are Cor Hydræ, Canis Major, and Canis Minor, while Orion is just setting in the west. *North of the Ecliptic*, in the east, above Hercules, are Corona Borealis (The Northern Crown), Boötes (Arcturus), Coma Berenices, and Cor Caroli, which stretch nearly to the meridian. *In the Northwest*, above Taurus and Perseus, is Auriga.

June (8 P.M.). — *In the North*, Ursa Major is above Polaris, Draco and Ursa Minor are east, Cepheus is below and east, and Cassiopeia directly below. *In the East,* Cygnus (the Cross) and Aquila are rising, Lyra and Taurus Poniatowskii are well up. *Along the Ecliptic,* Scorpio is rising, Libra is midway, Virgo on the meridian, Leo past, Cancer midway, Gemini next, and Taurus just setting. *In the South* are Corvus and the Crater a little past the meridian. *In the Southwest* is Cor Hydræ, and in the west Canis Minor is nearing the horizon. *North of the Ecliptic,* in the east, above Scorpio, is Hercules; then Corona and Boötes, and, near the meridian, Cor Caroli and Coma Berenices. *In the Northwest* is Auriga, just coming to the horizon.

July (9 P.M.). — *In the North,* Draco and Ursa Minor are above Polaris, Ursa Major is west, Cepheus east, and Cassiopeia below to the east. *In the East,* the Dolphin (Job's Coffin) is now well up, Cygnus is almost midway to the meridian, and Lyra is still higher. *Along the Ecliptic,* Capricornus is rising, Sagittarius (the Archer) is next, Scorpio, with its long tail swinging along the horizon, is directly south, Libra is past the meridian, Virgo midway, and Leo has almost reached the horizon. *In the Southwest,* the Crater is setting, and Corvus is just above. *North of the Ecliptic,* above Scorpio and east of the meridian, are Serpentarius, Hercules, and Taurus Poniatowskii; Corona is almost on the meridian, to the west of which lie Boötes, Cor Caroli, and Coma Berenices.

August (9 P.M.). — *In the North,* Draco and Ursa Minor are above Polaris, Cepheus is above and to the east, Cassiopeia east, and Ursa Major west. *In the Northeast,* Perseus is just rising, while south of it, Andromeda and Pegasus are fairly up. *Along the Ecliptic,* Aquarius is risen, next Capricornus, Sagittarius reaches to the meridian, Scorpio is just past, Libra next, and Virgo (Spica) just touches the horizon. *North of the Ecliptic,* Taurus Poniatowskii is on and Lyra is just east of the meridian; the Swan and Dolphin are east of Lyra, Serpentarius and Hercules are above Scorpio, and just west of the meridian; thence west are Corona and Boötes, while far in the northwest are Coma Berenices and Cor Caroli.

September (8 P.M.). — Draco is above and to the west of Polaris, Cepheus above and to the east, Cassiopeia east, Ursa Major is below and to the west. *In the Northeast,* Perseus is just rising.

In the East, Andromeda is fairly up, Pegasus is nearly midway to the meridian. *Along the Ecliptic*, Pisces is just rising, next Aquarius, Capricornus in the southeast, Sagittarius on the meridian in the south, next Scorpio in the southwest, Libra, and, lastly, Virgo just setting. *North of the Ecliptic*, Lyra is on the meridian, Cygnus, the Dolphin, and Aquila are just to the east; while to the west are Taurus Poniatowskii and Serpentarius; north of these latter are Hercules, Corona, Boötes, Cor Caroli, and Coma Berenices.

October (7 P.M.). — *In the North*, Cepheus and Draco are above Polaris, Ursa Minor is west, Cassiopeia east, and Ursa Major below and west. *In the Northeast*, Perseus is fairly risen. *In the East*, Andromeda is nearly midway to the zenith. *Along the Ecliptic*, Aries is just rising, Pisces well up, Aquarius and Capricornus are in the southeast, Sagittarius is in the south, Scorpio far down in the southwest, and Libra just setting. *North of the Ecliptic*, Cygnus and Aquila are on the meridian; the Dolphin is just east of it, and far south; Lyra is west of the meridian; Taurus Poniatowskii is lower down and to the south; Serpentarius is just above Scorpio; next, in line with Scorpio and Polaris, is Hercules; Corona and Boötes are toward the northwest, where Coma Berenices is just setting.

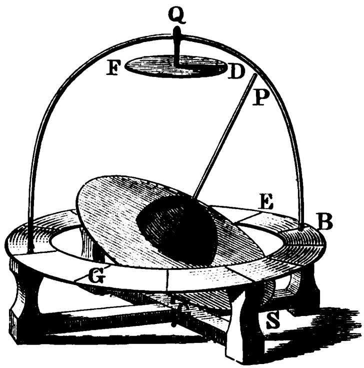
November (7 P.M.). — *In the North*, Ursa Major is below Polaris, Ursa Minor and Draco are to the west, Cepheus is above, and Cassiopeia above and to the east. *In the Northeast*, Auriga is just rising, and Perseus is above, nearly midway to the meridian. *Along the Ecliptic*, Taurus is just rising, next are Aries and Pisces; Aquarius is on the meridian, south; then Capricornus, and lastly Sagittarius, in the southwest. *North of the Ecliptic*, Pegasus and Andromeda lie east of the meridian, the Swan, Dolphin, Eagle, Taurus Poniatowskii, and Lyra west. *In the Northwest* are Hercules and Corona.

December (7 P.M.). — *In the North*, Cassiopeia is above Polaris, Cepheus above and to the west, Perseus above and to the east, Draco west, and Ursa Major below. *In the Northeast*, below Perseus, is Auriga. *In the East*, Orion is rising. *Along the Ecliptic*, Gemini is just rising, Taurus is nearly midway, next Aries, Pisces is on the meridian, then Aquarius, and lastly Capricornus, far in the southwest. *In the South*, east of the meridian, is Cetus, and west is Fomalhaut. *North of the Ecliptic*, Andromeda is nearly on the meridian, and Pegasus west of it; Cygnus, the Dolphin, Lyra, and Aquila are about midway, while Taurus Poniatowskii is just sinking to the horizon. *In the Northwest*, Hercules is just setting.

NOTE. — It should be borne in mind that a month makes a variation of about two hours (30°) in the rise of a star; hence, in the foregoing Guide, the January Sky of 9 P.M. would be about the same as the February Sky of 7 P.M.; the January Sky of 11 P.M. would be about the same as the March Sky of 7 P.M., etc. In this way the Guide may be used for any hour in the night. The pupil will see that in the Guide the prominent figures and stars in each constellation are sometimes given in parentheses. Examples: the 'Y' in Aquarius, the 'scalene triangle' in Aries, 'Job's Coffin' in the Dolphin, 'Procyon' in Canis Minor, etc. These aid in identifying the constellation.

APPARATUS

To illustrate Precession of the Equinoxes,[1] make the simple apparatus shown in the cut. It represents the figure on page 111, and the explanation of that figure and several subsequent ones applies to it. The ingenuity of pupil and teacher will devise methods of explaining by means of this instrument many otherwise abstruse points under this difficult subject. The following are suggestive merely: —



Model to illustrate Precession

(1) *To show motion of earth's axis around pole of Ecliptic.* — Move P, axis of earth's plate, around DF, whose circumference roughly represents the little circle described by the pole of the earth (see figure on page 115).

(2) *To show change of Polar Star.* — The pupil can readily see that the north pole of the heavens will, at different times, lie adjacent to different stars located around this circle, — Thuban, Polaris, Vega.

(3) *To show why the polar distance of Polaris will gradually diminish and then increase* (page 227). — Polaris lies at a little distance from this circle (edge of plate), and the pole is gradually ap-

[1] The above apparatus can be made by any ingenious pupil. The plates are cut out of tin; the standard may be made with the knife or a scroll saw; the earth is half of a little wooden ball balanced on the wire pin C; and the semicircle, poles, etc., are of wire. The different parts may be soldered, or fastened together with tacks.

proaching the star, but will pass it and then recede further from it, until, many thousand years hence, Lyra, being 5° from this circle, will become the polar constellation, and Vega the polar star.

(4) *To show Precession of Equinoxes.* — Pass axis of earth around small circle. Note the position of the equinoxes before moving, and their gradual change of position along the ecliptic.

(5) *To show cause of Precession.* — Apply explanation of the figure on page 112.

(6) *To show necessity for new stellar maps occasionally,* or careful reductions to previous standards. With the changes of equinoxes there is also a change of the equinoctial system (pages 35–37).

(7) *To illustrate the figure on page* 114. — Remove the wire semicircle, and, inclining the axis of the earth, spin the wire between the thumb and finger like a top. The equinoxes will pass around the ecliptic as they did when the axis was carried around in the previous experiments.

Letting GBE represent the plane of the ecliptic, and GE the line of the equinoxes, we can use this apparatus to illustrate the seasons, etc. (page 102). Also, by placing a lamp near S, the phenomena of day and night, long summer days, short winter days, etc. (pages 103, etc.), can easily be explained.

LIST OF INTERESTING OBJECTS VISIBLE WITH ORDINARY TELESCOPES

Constellation and Nature of Object	Object	R.A. 1900	Decl. 1900	Magnitudes of Doubles	Distance of Doubles	Remarks
		h. m.	° ′		″	
Andromeda, Double Star	Gamma	1 58	+41 51	2.2, 5, 6	10	Triple. Beautiful object. Different colors.
Andromeda, Nebula	Messier 31	0 38	+40 43	....	......	One of the grandest known. Visible to naked eye.
Andromeda, Nebula	M. 32	0 38	+40 19	....	......	In same field with above; small, bright.
Aquarius, Double Star	Zeta	22 24	− 0 32	4 4.5	3	Binary, long period. Fine object.
Aquarius, Cluster	M. 2	21 28.	− 1 17	....	......	Globular. Stars of 15th magnitude.
Argo Navis, Cluster	....	7 32	−14 16	....	......	Fine cluster. Visible to naked eye.
Argo Navis, Cluster	M. 46	7 37	−14 29	....	......	Stars of 10th magnitude.
Aries, Double Star	Gamma	1 48	+18 48	4.5 5	8	First double star discovered. Fine object.
Boötes, Double Star	Epsilon	14 41	+27 30	3 7	3	Fine pair. Difficult. Companion, blue.
Boötes, Double Star	Xi	14 47	+19 31	4.5 6.5	4	Fine pair. Binary. Period 128 years.
Cancer, Double Star	Zeta	8 6	+17 58	6, 7, 7.5	5, 1.3	Triple star, probably in one system.
Cancer, Cluster	M. 44	8 34	+20 20	....	......	Easily resolvable. Fine object. Præsepe.
Canes Venatici, Double Star	Cor Caroli	12 51	+38 52	2.5 6.5	20	Fine pair. Easy.
Canes Venatici, Cluster	....	13 38	+28 53	....	......	Resolvable into 1000 stars by large telescopes.
Canes Venatici, Nebula	M. 3	13 26	+47 42	....	......	Double. Lord Rosse's wonderful spiral.
Canes Venatici, Nebula	M. 63	13 11	+42 34	....	......	Bright; very elongated; many nebulæ near.
Cepheus, Double Star	Beta	21 27	+70 7	3 8	13	
Cepheus, Double Star	Delta	22 25	+57 54	4.5 7	41	
Cepheus, Nebulous Star	....	21 2	+67 38	....	......	Faint star in center of a faint, large, round nebula.
Cepheus, Variable Star	U	0 53	+81 20	....	......	From 7th to 9th magnitude in 2 d. 11 h. 49 m. 38 s.
Cetus, Variable Star	Mira	2 14	− 3 26	....	......	From 2d to 10th magnitude in 331.6 days. Irregular.
Cetus, Variable Star	R	2 21	− 0 38	....	......	From 8th to 13th magnitude in 167 days.
Cetus, Nebula	....	0 43	−25 51	....	......	Very bright; very elongated; very large.

LIST OF INTERESTING OBJECTS, ETC. — *Continued*

Constellation and Nature of Object	Object	R.A. 1900	Decl. 1900	Magnitudes of Doubles	Distance of Doubles	Remarks
		h. m.	° ′		″	
Coma Berenices, Double Star.	24	12 30	+18 56	5 7	20	Orange and purple.
Coma Berenices, Double Star.	....	12 15	+27 42	7 7	8.5	
Coma Berenices, Variable Star	R	11 59	+19 20	....	......	From 7th to 13th magnitude in 361.8 days.
Coma Berenices, Cluster......	M. 53	13 8	+18 42	....	......	Mass of stars of 11th to 15th magnitude.
Coma Berenices, Nebula......	M. 64	12 52	+22 14	....	......	Large, bright. Many in this constellation.
Cygnus, Double Star..........	Beta	19 27	+27 45	3 5	34	Yellow and blue. Very fine pair.
Cygnus, Double Star..........	61	21 2	+38 13	5.5 6	20	Second nearest star to us. Binary.
Cygnus, Double Star..........	....	20 4	+35 7	7 9	5.5	
Cygnus, Double Star..........	....	20 58	+37 10	8 8	4.5	
Cygnus, Variable Star........	R	19 34	+49 58	....	......	From 6th to 14th magnitude in 425.7 days.
Cygnus, Variable Star........	S	20 3	+57 42	....	......	From 9th to 14th magnitude in 322.8 days.
Delphinus, Double Star.......	Gamma	20 42	+15 46	5 6	11	Beautiful pair. Binary.
Delphinus, Double Star.......	....	20 26	+10 55	7 8	14	Quadruple in larger telescopes.
Delphinus, Double Star.......	....	20 41	+15 32	7 8	5	
Delphinus, Variable Star.....	R	20 10	+ 8 47	....	......	From 8th to 13th magnitude in 285.5 days.
Delphinus, Variable Star.....	T	20 41	+16 2	....	......	From 8th to 13th magnitude in 331.2 days.
Delphinus, Nebula............	....	20 29	+ 7 4	....	......	Bright. Resolvable.
Draco, Double Star...........	Mu	17 3	+54 36	4 4.5	2.5	Binary. Period, 600 years. (?) Interesting pair.
Draco, Double Star...........	40	18 9	+79 59	5.5 6	20	
Draco, Double Star...........	....	14 37	+58 32	7 8	7.5	
Draco, Nebula................	....	15 4	+56 9	....	......	Oval. Very bright. Resolvable.
Gemini, Double Star..........	Castor	7 28	+32 7	2 3	6	Finest double star known. Easy.
Gemini, Double Star..........	....	7 27	+23 7	6.5 8.5	12	
Gemini, Double Star..........	....	7 4	+22 29	7.5 7.5	8.5	Fine pair.
Gemini, Variable Star........	R	7 1	+22 52	....	......	From 7th to 13th magnitude in 370.2 days.
Gemini, Variable Star........	T	7 43	+23 59	....	......	From 8th to 13th magnitude in 288.1 days.
Gemini, Nebula...............	M. 35	6 3	+24 21	....	......	Cluster of minute stars.

LIST OF INTERESTING OBJECTS, ETC. — *Continued*

Constellation and Nature of Object	Object	R.A. 1900	Decl. 1900	Magnitudes of Doubles	Distance of Doubles	Remarks
		h. m.	° ′		″	
Hercules, Double Star........	Alpha	17 10	+14 31	3.5 5.5	4.5	Interesting pair. Orange and green.
Hercules, Double Star........	Rho	17 20	+37 15	4 5.5	3.5	Binary.
Hercules, Double Star........	95	17 57	+21 37	5.5 6	6	Fine pair. Yellow and blue.
Hercules, Double Star........	100	18 4	+26 5	7 7	14	A neat double.
Hercules, Variable Star.......	R	16 2	+18 38	....	......	From 8th to 13th magnitude in 317.7 days.
Hercules, Variable Star.......	T	18 5	+31 0	....	......	From 7th to 13th magnitude in 164.85 days.
Hercules, Cluster............	M. 13	16 38	+36 39	....	......	Many thousand stars. Wonderful object.
Hercules, Cluster............	M. 92	17 14	+43 15	....	......	Very bright. Easily resolved.
Hydra, Double Star	Epsilon	8 42	+ 6 49	3.5 8	3.5	Binary. Yellow and blue.
Hydra, Double Star	....	8 31	+ 6 58	6 7	10.5	Fine pair.
Hydra, Double Star	....	8 40	− 2 14	7 8	5	Fine pair.
Hydra, Variable Star.........	R	13 24	−22 46	....	......	From 4th to 10th magnitude in 425.15 days.
Hydra, Variable Star.........	S	8 48	+ 3 27	....	......	From 8th to 12th magnitude in 257.0 days.
Leo, Double Star.............	Gamma	10 14	+20 21	2 4	3.3	Binary. Period, over 400 years.
Leo, Double Star.............	54	10 50	+25 17	4.5 7	6.5	Binary.
Leo, Variable Star............	R	9 42	+11 54	....	......	From 5th to 10th magnitude in 312.8 days.
Leo, Nebula..................	M. 65, 66	11 14	+13 38	....	......	Two in one field.
Lyra, Quadruple Star	ε — 1 and 2	18 41	+39 34	5 5.5	{ 3.3 } { 2.5 }	Binaries. Finest object of the kind in the heavens.
Lyra, Nebula.................	M. 57	18 50	+32 54	....	......	Annular. Remarkable object.
Monoceros, Triple Star	11	6 24	− 6 58	5, 5, 6	7, 10	Most beautiful triple visible from this [latitude.
Ophiuchus, Double Star	A	17 9	−26 27	4 6	. 5	Binary.
Ophiuchus, Double Star	70	18 0	+ 2 32	4.5 6	3	Binary. Period, 88.4 years. [tude.
Ophiuchus, Cluster...........	M. 12	16 42	− 1 46	....	......	Resolvable cluster, 10th to 16th magni-
Ophiuchus, Cluster...........	M. 10	16 52	− 3 57	....	......	Resolvable cluster, 11th to 15th magn.
Ophiuchus, Variable Star.....	U	17 11	+ 1 19	....	......	From 6th to 7th magn. in 20h. 7m. 42.5s.

LIST OF INTERESTING OBJECTS, ETC. — *Concluded*

Constellation and Nature of Object	Object	R. A. 1900	Decl. 1900	Magnitudes of Doubles	Distance of Doubles	Remarks
		h. m.	° ′		″	
Orion, Triple Star	Zeta	5 36	− 1 59	3, 6.5, 10	2.5, 57	
Orion, Triple Star	Iota	5 30	− 5 58	3.5, 8.5, 11	12, 50	Beautiful object.
Orion, Triple Star	Sigma	5 34	− 2 39	4, 9, 7	12, 42	Beautiful object.
Orion, Double Star	....	4 55	+ 3 28	6 7	21	
Orion, Nebula	M. 42	5 30	− 5 27	....	......	Greatest marvel in the heavens.
Perseus, Variable Star	β — Algol	3 2	+40 34	....	......	From 2.3 to 3.5 magnitude. Period, 2 d. 20 h. 48 m. 55.4 s.
Sagittarius, Nebula	M. 22	18 30	−23 59	....	......	Cluster of stars of 11th magnitude.
Sagittarius, Nebula	M. 25	18 26	−19 8	....	......	Coarse cluster.
Sagittarius, Nebula	M. 8	17 57	−24 23	....	......	Visible to naked eye.
Scorpio, Double Star	Beta	16 0	−19 32	3 5.5	14	
Scorpio, Triple Star	Xi	15 59	−11 6	4.5, 5, 7.5	1, 7	Binary.
Scorpio, Variable Star	T	16 11	−22 44	....	......	From 7th to 12th magnitude, irregular.
Scorpio, Nebula	M. 80	16 11	−22 45	....	......	The above variable is in the middle of the nebula.
Ursa Major, Double Star	Zeta	13 20	+55 27	2 4	15	Interesting object for small telescopes.
Ursa Major, Double Star	....	11 34	+45 40	6 8	10	Yellowish white and ash.
Ursa Major, Variable Star	R	10 38	+69 18	....	......	From 6th to 13th magnitude in 302.1 days.
Ursa Major, Nebula	M. 81	9 47	+69 32	....	......	Bright. Resembles a comet. M. 82 near.
Virgo, Double Star	Gamma	12 37	− 0 54	4 4	5	Binary. Period, 194 years.
Virgo, Variable Star	R	12 33	+ 7 32	....	......	From 7th to 11th magnitude in 145.5 days.
Virgo, Variable Star	S	13 28	− 6 41	....	......	From 5.7 to 12.5 magnitude in 376.4 days.
Virgo, Nebula	M. 86	12 21	+13 30	....	......	Resolvable; one of 7 in one field.
Vulpecula, Nebula	M. 27	19 55	+22 27	....	......	The celebrated dumb-bell nebula.

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