# ASTRONOMY

FOR

# SCHOOLS AND GENERAL READERS.

BY

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PHILADELPHIA:
J. B. LIPPINCOTT & CO.

1882

# PREFACE.

Astronomy is not studied in the lower and intermediate schools of the United States as much as its importance and interest demand. Its phenomena are so striking, so well calculated to awaken thought, and so much objects of common notice, that an intelligent appreciation of their causes and relations is greatly to be desired.

This book is believed to be written so that any person of ordinary education and intelligence can understand it. No knowledge of mathematics beyond arithmetic is necessary, except that in a few cases trigonometrical solutions of important problems have been given in foot-notes for the benefit of those who understand such methods. Special effort has been made to render clear the abstruse points in the science,—with what success can be judged from the explanations of the Transit of Venus, the Precession of the Equinoxes, the Tides, etc. Particular care has been taken to distinguish between theories and established facts, even when the former seem to be highly probable; while mere speculations are altogether excluded. The illustrations have been carefully chosen. They are believed to be better and more numerous than are usually found in books of this character, and it is hoped that they will render considerable help in making the subject clear and interesting.

The most original feature of the work is the direction everywhere given for observations with the naked eye and with small telescopes. As illustrations of this may be mentioned the methods of observing meteors, variable stars, and the phenomena of Jupiter's satellites. This plan of setting students at practical work has been so successful in chemistry, botany, and other sciences, that it seems to be quite time to use it in astronomy. It may be that many of the readers of this little book will be surprised at the large amount of interesting and valuable observation that can be made with the aid of a very small glass, and even with the unassisted eye.

While primarily designed as an elementary text-book, its authors hope that it may be found adapted to general reading. Much care has been taken to make its information entirely reliable and in accord with the best methods and views of the present time.

Acknowledgments are due to Prof. E. S. Holden, of Washburn Observatory, and to the well-known instrument-makers, Fauth & Co., of Washington, and Browning, of London, for kindly furnishing electrotypes of some of the illustrations.

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*Aids.*—A celestial globe, twelve inches, or thereabouts, in diameter, is most useful in illustrating and explaining many astronomical phenomena, and in finding the constellations and principal stars. Be sure that the globe has a horizontal ring about the middle. A Planisphere is a tolerable substitute for a globe, and much cheaper. A Star Lantern is also very convenient. A good star-map is important. A telescope of any size, or even a good spy-glass or pair of opera-glasses, will add much interest to the study.

*Methods of Instruction.*—Each teacher has his own method of conducting recitations, but the authors' experience leads them to prefer the *topical method*, and whenever possible they would have the student learn the topics in their order, so as to get a complete and connected knowledge of the subject. The headings of the paragraphs and the arrangement of the topics will facilitate this. Reviews here, as elsewhere, will be found to be very valuable. Distances, dimensions, etc., as given in round numbers, should be learned and made perfectly familiar by frequent repetition. Particular attention ought to be paid to the questions and suggested problems in the foot-notes. This will test the pupil's knowledge and make it more thorough. A teacher should never be content until his class understands each point thoroughly; and it must not be forgotten that no one can explain clearly to a class what he does not clearly understand himself. It is hoped that every teacher who essays to teach this subject will acquaint himself thoroughly with it by making use of standard works upon astronomy; and he may rest assured that no knowledge that he can acquire will be more interesting, or more valuable everywhere and anywhere, than this.

*Practical Work.*— Above all things, the teacher must not neglect the practical work. Let him take his class out under the clear sky and point out the constellations, principal stars, and planets. Let him make himself, and lead his students to make, the observations described in the following pages. He will be surprised at the interest awakened, and at the valuable results. A common household almanac will be of great aid here. There is much more in an almanac than most people see.

Any suggestions or corrections will be very acceptable to the authors.

# INTRODUCTION.

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## History of Astronomy.

1. *Early History.*—Astronomy, the science of the heavenly bodies, is probably the oldest of all the sciences. So old is it that there is no trustworthy account of its origin; indeed, almost every famous nation of antiquity claimed the honor of originating it. Nor is it hard to see why this science should have been cultivated so early. The first men had no books to occupy their time, hence they observed nature. The most striking occurrence was the succession of day and night, the one lighted up by the brilliant sun, the other dark, or feebly illuminated by the wonderful stars and the curiously changing moon. These changes were a very natural division of time, the only ones they had. As men knew not the true God, they naturally turned to the heavens for objects of worship, and this led to careful study and observation of the heavenly bodies by priests and other ministers of religion. Besides, the occupations and modes of living of our earliest ancestors were most favorable to the study of astronomy. As hunters, shepherds, and farmers, their lives were spent in the open air, by night as well as by day. In travelling over the thinly-peopled earth, and the sea as

well, the stars were their guides. It is not surprising, then, that these men, with no instruments, no books, no schools, knew much about astronomy. They seem, in fact, to have known more about the appearance and phenomena of the heavens than we generally do.

2. *Astronomy of the Chaldeans.*—According to the Greek historians, the Chaldeans were the first astronomers. These people lived along the Euphrates River in Asia, in and about the city of Babylon. They kept careful records of the movements and phenomena of the heavenly bodies. By these records they discovered that the eclipses of the sun and moon are almost exactly repeated every eighteen years, and thus successfully predicted eclipses. But of the real causes of eclipses, or of the nature, distance, or real motions of the heavenly bodies, these ancient astronomers knew nothing.

3. *Astronomy among other Ancient Nations.*—The Egyptians, like the Chaldeans, studied astronomy in very ancient times. Some writers contend that their famous pyramids are so built as to show great astronomical knowledge, but very little is certainly known about this matter, or about their advancement in astronomy. It seems to be proved that the Chinese had a knowledge of astronomy very early,—more than four thousand years ago, according to their own claim; but the evidence of this extreme age of the science among them is doubtful. Their records relate that about that date Ho and Hi were the two royal astronomers, whose duty it was to predict all eclipses, but that, giving themselves up to the pursuit of pleasure, they neglected their duties, and an eclipse of the sun occurred without being predicted. The whole nation was thus exposed to the

anger of their gods, because of the omission of the religious ceremonies always performed upon such occasions. The unfortunate astronomers were immediately put to death. It is certain, however, that the Chinese made reliable astronomical observations, some of which are of use to us, at least two thousand five hundred years ago.

The Hindoos also claim to have been the first to study astronomy. They have proved their claim to an extensive knowledge of the subject, but whether they borrowed this knowledge from the neighboring nations, or gained it by observation, is uncertain.

4. *Greek Astronomy.*—Astronomy was a favorite science with the ancient Greeks. But, as was the case with a great part of their science, their astronomy was imagined rather than observed. Some of their astronomers advanced surprisingly correct theories of the heavenly bodies, but seem to have made little effort to prove them. Certain of their earliest philosophers taught that the earth is a sphere, a belief not original with Columbus, as some people think, but one taught in Greece two thousand years before Columbus was born. Later some of the Greeks taught that the sun is the centre of the system of planets to which the earth belongs, and that all revolve about the sun; others taught that day and night are caused by the revolution of the earth upon its axis. These great truths are the foundation of modern astronomy, but the Greek philosophers brought forth so little evidence in support of these guesses, and mingled so many absurdities with them, that they were not generally believed, and were soon forgotten. Notwithstanding their general habit of neglecting experiments for theories, the Greeks

achieved some substantial results. They made observations which were of use to succeeding astronomers, they greatly improved the reckoning of time, and determined the length of the year to be three hundred and sixty-five and one-fourth days, which is wonderfully near its exact length.[1]

5. *The Alexandrians.*—For a few hundred years before and after the Christian era,[2] the city of Alexandria in Egypt was famous for its learning. Its astronomers were the most skilful that had yet lived. They attempted to find the relative distances of the sun and moon from the earth. The method employed was a correct and very ingenious one, but from the imperfections of their observations their results were far from the truth. They determined the width of the torrid zone with great exactness, and found the circumference of the earth with surprising accuracy, using the method

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[1] The ancients found the length of the year by means of a gnomon (nō′mon). This was a pillar set up to cast a shadow, which was measured at noon every day. When the noonday sun was lowest down in the sky the shadow of the gnomon was longest, as a little reflection will show. This time of year is called the winter solstice, and marks the time when the sun is farthest south of the equator and is shining directly down upon the tropic of Capricorn; according to our reckoning, this is about the 21st of December. After that date the noonday shadow grows shorter, because the sun gets farther north every day. Now, if the day upon which the gnomon's shadow is shortest is found, and the days are carefully counted until the shortest shadow comes again, the length of the year is found. It is interesting to know that the obelisks of Egypt, one of which has lately been brought to New York and set up in the Park there, are thought to have been used as gnomons.

If the gnomon were *south* of the equator, would it make any change in this explanation? Could the *time of noon* be found by measuring the length of the shadow?

[2] What is meant by this?

which is still used as the very best one known. It will be described farther on in the book. Euclid,[1] who gave us the geometry which in substance is still universally used, lived in Alexandria during this period, and contributed to the advancement of astronomy.

6. *Hipparchus.*[2]—This was the greatest of the ancient astronomers, and well deserves his title, "Father of Astronomy." He lived upon the island of Rhodes, in the Mediterranean Sea, about 150 B.C.[3] Hipparchus determined the length of the year to within about four minutes of its true length. He discovered that the distance from the sun to the earth varies throughout the year, and he made several most important discoveries in the movements of the heavenly bodies. He made the first catalogue of the stars, fixing the position of over a thousand of them. This catalogue is one of the most valuable possessions of modern astronomy. Hipparchus invented the science of trigonometry, and first used latitude and longitude to determine the positions of places on the earth.

7. *Ptolemy*[4] *and his System.*—This most famous astronomer of antiquity lived at Alexandria about 130 A.D.[3] He made few observations himself, but collected the results of other men's work and wrote them down, together with some important investigations of his own, and it is to him that we owe almost all our knowledge of ancient astronomy. His great work upon astronomy, the "Almagest," still exists, and for fourteen hundred years it was the highest and the only authority upon

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[1] Euclid (yoo′klid) flourished about 300 B.C.

[2] Pronounced Hip-ar′kus.

[3] What is meant by this? How long ago were these times?

[4] Pronounced Tol′e-my.

the subject. The foundations of the Ptolemaic system are that *the earth is a sphere*, that *it is the centre of the universe*, and that *it is stationary, while all the heavenly bodies revolve about it every twenty-four hours.* That the earth is a sphere Ptolemy proved by the fact that at places west of the observer the sun rose and set *later*, and at places east, *earlier*;[1] and also because as one goes north the pole-star rises higher in the sky, while it sinks lower as he goes south. That the earth stands still while the sun and stars revolve about it, Ptolemy argued was simply common sense. And he took some pains to show the absurdity of the belief that these phenomena are caused by the turning of the earth upon its axis. Ptolemy's theory explains the apparent motions of the sun, moon, and stars pretty well, but the apparent motions of the planets[2] are so peculiar, as will be explained when these are treated of, that he was forced to conclude that these bodies do not move in circles about the earth, but in very complicated circular paths, composed of series of loops. This is the theory of the universe which was accepted everywhere without question until the sixteenth century.[3]

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[1] A little thought, aided perhaps by a diagram, will make this reasoning clear. At St. Louis the sun rises and sets an hour later than at Philadelphia; hence St. Louis time is an hour behind Philadelphia time. How would this affect travellers? How does it affect railroad-trains?

[2] A few of what are commonly called stars are planets, and are comparatively near to us. They resemble the earth in many respects. The others are properly called stars, and are suns, situated at immense distances from us. The word planet is derived from a Greek word, meaning a wanderer, because these bodies wander among the stars.

[3] The sixteenth century began at the beginning of the year 1501

8. *Copernicus*[1] *and his System.*—It has already been mentioned that some of the old Greek astronomers held and taught the true theory of the heavenly bodies, but, substantiated by no proofs and borne down by the great authority of Ptolemy, their teachings had long since been forgotten. And it was not until about 1500 A.D. that Copernicus, a Prussian mathematician and astronomer, revived and firmly established the essential truths of astronomy. He showed that the earth and planets revolve about the sun as a centre, and that the daily risings and settings of the heavenly bodies are caused by the turning of the earth upon its axis. Although his theories were not strictly original with him, and although he left them very incomplete, yet Copernicus has been honored greatly and justly for bringing forward and clearly stating the true principles of astronomy, at the same time showing good reasons for his belief; as well as for his courage in thus breaking away from the ignorance and superstition of his age. His work upon the subject was not published until just at the close of his life, and the first printed copy of it was put into his hands only a few hours before his death. In his honor our theory of astronomy is still called the Copernican System.

9. *Kepler.*[2]— This great mathematical astronomer followed Copernicus. His whole life was spent in laborious calculations. His name is most frequently mentioned in connection with three great laws, which regulate the paths, motions, and distances of the planets.

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and ended at the close of the year 1600. What century is this? When did it begin, and when will it close?

[1] Copernicus (ko-per′ni-kus), 1473–1543.

[2] Kep′ler, a German, 1571–1630.

These three laws (see page 36), which would scarcely fill a half of one of these pages, cost him seventeen years of hard work. When the third one was established, he said of the book containing it, "It may well wait a century for a reader, as God has waited six thousand years for an observer."

10. *Galileo.*[1]—This famous Italian first used the telescope in astronomy. The first telescope was made in Holland in 1608; a vague report of the invention reached Galileo the next year, and from this hint, after one night's reflection, he was able to construct one which magnified objects three times, and he finally made one which magnified thirty-two times. He discovered the moons of Jupiter, the spots upon the sun, and many other wonderful things. His brilliant discoveries convinced the world of the truth of the Copernican theory, but brought on him the condemnation of the Church for teaching heresies, and the closing years of his life were saddened by its persecutions. Natural philosophy is as greatly indebted to this remarkable man as astronomy.

11. *Newton.*[2]—Upon the very day on which Galileo died, Sir Isaac Newton was born in England. While Newton did not *discover* the law of gravitation, as is sometimes stated, yet he first proved that the force which brings the apple to the earth binds the planets and sun into one system.[3] This establishment of the

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[1] Galileo (Gal-i-lee′o), 1564–1642.

[2] New′ton, 1642–1727.

[3] The well-known story that while driven into the country by the Plague in London, Newton noticed an apple falling from a tree, and that this suggested the idea that the motions of the planets might be controlled by the same force, is worth remembering. This discovery

fact that gravity is the force which controls the motions of the heavenly bodies was of the greatest importance: a large part of the science of astronomy depends upon it.[1] Newton, like Kepler, was a mathematical astronomer, not an observer. He discovered and proved many other important facts in astronomy, besides making many and valuable discoveries in natural philosophy and other sciences. He also occupied important positions under the English government. Sir Isaac Newton was probably the greatest scientist that the world has yet seen. His great work is called the "Principia." La Place,[2] the only man who could have disputed Newton's pre-eminence as a mathematical astronomer, pronounced this work the greatest production of the human intellect.

12. *Modern Astronomy.*—Since Newton a host of eminent astronomers and mathematicians have given their lives to the advancement of our science. Every generation and every civilized country has furnished its share. As it was the earliest begun, so it is the farthest advanced of the sciences. Its strides seem to be growing longer rather than shorter. Our own generation and our living astronomers are inferior to none of their predecessors in ability or in the value of their discoveries. And there is every reason to expect these discoveries to go on with increased rapidity. In the

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*was* made by Newton while he was absent from London on account of the Plague, but the rest of the story is not supported by sufficient evidence; it is not at all improbable, however.

[1] It may not be amiss to remark that, while the laws and effects of gravity are well known, the cause of this force has never been discovered.

[2] La Place (Lä-pläss′), a great French mathematician and astronomer, 1749–1827.

astronomical work of the last generation our own country has done its full share. Our astronomers and observatories have no superiors. Our contributions to the world's store of knowledge have been greater in this direction than in any other. The history of the important discoveries in astronomy made since Newton's day would fill a much larger book than this. We can only give these discoveries in their proper places in a general account of the subject.

## General View of the Heavens.

13. *Introductory.*—If a person will carefully watch the heavens, he will see much that will tend to excite his curiosity. What are all the glittering lights? How far are they away? Why do they seem to move around him in a circle every day? Why do some of them change their position among the others? Many such questions as these will come up, and the best method of arriving at a correct answer is first to observe carefully all that can be seen. The ancients did this much more faithfully than we do, and the various generations of men have accumulated a great number of facts and laws of which we can now have the benefit. It is the object of a book on astronomy to explain these points so that an observer can better comprehend the causes of what he sees. But careful watching must accompany the study if the phenomena are to be fully understood.

14. *The Heavens by Day.*—But what can the unaided eye see? In the daytime there is usually only the sun, and this presents the same general appearance every

day. We will find that continual changes are taking place on his surface, but these changes are not visible to the eye. His position in the heavens is, however, perceptibly changing. Every one is familiar with the motion which occurs each day,—his rising in the east, reaching the highest point at noon, and setting in the west. A careful observer will notice, besides this, a change of place at different seasons of the year. He is in the south every day at noon, but in the summer he is higher up in the sky than in the winter. It will be noticed, too, that he does not rise and set in the same place through the year. If the point of setting be noted every evening, beginning with the first of the year, it will be found to be moving towards the north as the winter progresses. This will go on till the middle of summer, when the place of setting will be far to the north of the west. Then it will slowly change back again towards the south through the fall and early winter. So with the *time* of rising and setting: it will be noticed that the farther to the north the sun rises, the earlier in the day it will rise and the later it will set.[1]

15. *Horizon and Zenith.*—The circle where the earth and sky appear to meet is called the *horizon*. On the ocean it is a perfect circle, but on land it is broken up with the irregularities of the surface. When the sun rises it passes above this circle, and when it sets it sinks

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[1] Let the student carefully note, by reference to a tree or some distant object, the point in the horizon where the sun rises or sets, at intervals of a week or two, and this change of place will be readily manifest. He must be careful to occupy the same point of observation at the different times. Let him also with a watch observe the exact time, and thus notice the gradual change.

below it. The point in the sky directly over the head of the observer is called the *zenith.*[1]

16. *The Heavens by Night.*—In the night there is much more to attract attention in the sky. The moon seems to follow nearly in the path of the sun. If carefully observed, she will be seen to change her place among the stars, being each night a little farther to the east than the preceding. The changes in her appearance from crescent-shaped to full, and from full to crescent-shaped, are also striking. There will be certain nights each month when she cannot be seen; after this a glimpse of her can be obtained in the west just after sunset; she will then be crescent-shaped, and her horns will point directly away from the sun. She will then grow in size for about two weeks, all the time appearing farther and farther away from the sun at sunset, till when quite full she will rise in the east just as the sun is setting in the west. Then she will go through the changes in a reverse order for two weeks more.

It will also be noticed that certain of the brighter stars appear, like the moon, to change their places among the others. The ancients called these *planets*, or "wandering stars." Those that can readily be seen by the naked eye are *Venus*, *Mars*, *Jupiter*, and *Saturn.*

But the great majority of the stars preserve exactly their relative positions. They appear night after night looking precisely the same. A given star will always

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[1] Towards what point will a plumb-line, extended upwards, point? Does the zenith change with a change of position on the earth? Is the sun ever seen in the zenith in the northern hemisphere? On which side of the zenith is the sun at noon? In what time of year does the sun pass nearest the zenith?

rise in the same point in the horizon, though not at the same time; it will always follow in the same path throughout the year, and set in the same place in the west.

But it will be noticed that the paths which different stars describe are very different. If we look in a northerly direction towards a point nearly half-way from the horizon to the zenith, we shall see a star of medium brightness which does not change place at all; it is the *pole-star*, or *Polaris*. Around this star all the northern heavens seem to revolve in circles. If these northern or *circumpolar stars* be watched, such as are between the pole-star and the horizon will move towards the east; such as are on the east of the pole will ascend; such as are above will move westward; and such as are to the west of the pole will descend. Those stars situated a little farther from the pole than the northern horizon is will just dip below it and remain set but a short time. Those that rise in the east will be visible just twelve hours and set in the west; they will not, however, pass through the zenith, but south of it, always remaining the same distance from the pole-star. Still farther to the south the stars will be but a short time above the horizon, passing over from southeast to southwest.[1]

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[1] In order to obtain a correct idea of this diurnal motion, the student should watch stars in different parts of the heavens at intervals of a few hours, so as to notice the paths they are describing. It is also advisable to set a globe so that the axis about which it revolves will point nearly to the pole-star. The horizontal ring encircling the globe will then represent the horizon. By turning the globe on its axis, it will be seen that the part around the pole will not pass below the horizon, and the various circles of latitude will represent the paths of stars in different parts of the sky. Some portions around

17. *Diurnal Motion.*—This general motion of the sun, moon, planets, and stars, which carries them apparently around the earth every twenty-four hours, is called the *diurnal motion.* The heavens appear to us to be the concave surface of a sphere, called the *celestial sphere.* The celestial sphere and all the heavenly bodies revolve about the earth every day, while the sun, moon, and planets have a separate motion of their own, which causes them to change their places among the stars.

18. *Cause of Diurnal Motion.*—A quiet motion often gives the impression of rest. A sailing vessel will glide along through still water so quietly that a person on board can easily conceive that he is at rest and surrounding objects are in motion in the opposite direction. Now the earth is turning on its axis from *west to east* with a perfectly noiseless and smooth motion. The effect produced on us is that all the heavenly bodies are passing over from *east to west.* The apparent diurnal motion of the heavens is therefore due to a real motion of the earth. Instead of the sun, moon, and stars rising above the horizon, the eastern horizon is really falling away from them. Instead of their setting, the western horizon is rising to obscure them. The reason that they appear to climb the sky is because the portion of the earth on which we are is turning more directly under them; and the reason that they sink is because we are revolving away from them. All the effects of diurnal motion above described are readily explained by the rotation of the earth on its axis, this axis pointing nearly towards the pole-star.

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the south pole will not pass above the horizon. There are some very brilliant southern stars that we never see in this latitude.

In some explanations it is easier to consider that the sun moves about the earth, as it seems to do. When we speak in this way, it must be remembered that we refer to the *apparent* and not the real motion.[1]

19. *Celestial Measures.*—The heavenly bodies being apparently on the inner surface of a sphere, the line joining their positions on this sphere is an arc of a circle. Hence we do not measure distances in the heavens by miles or other linear units, but by circular measure. Every circle is divided into three hundred and sixty degrees (°), each degree into sixty minutes (′), and each minute into sixty seconds (″). The distance from the zenith to the horizon is a quarter of a circle, or ninety degrees. It is well for the student to have a correct idea of the size of small measures in the heavens. The following will aid in obtaining it. There are two stars which continually point to the pole-star. They are two of the seven which form what is often called the *Dipper*, revolving continually about the pole-star and just touching the northern horizon. These two "pointers" are just

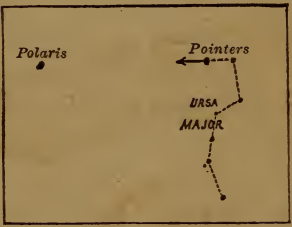

FIG. 1.

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[1] In the summer of 1881 there was a bright comet, the tail of which pointed nearly to Polaris. It partook of the diurnal motion of the heavens, and being near the pole-star was seen all night. When in the northwest in the evening, its tail pointed upwards and to the right. When it got around to the northeast in the morning, the tail pointed upwards and to the left. Many people who saw it in both of these positions, not understanding about the diurnal motion, thought there were two comets. Let the student think of this matter till he sees how it was that the comet thus changed the direction of its tail with reference to the horizon.

about five degrees apart. The diameter of the sun and that of the full moon are each about half a degree or thirty minutes long. If two stars are nearer together than three or four minutes, they will appear as one to the eye.[1]

20. *The Heavens at the Equator and at the Poles.*—As the observer changes his position on the earth, the appearance of the heavens will also change. If he move eastward or westward, his horizon will move the same way, and the time of rising and setting of the stars will vary. If the movement be eastward, the same stars will pursue the same course through the sky, but they will rise earlier and set earlier; if westward, the reverse will be the case. If, however, the observer move towards the north or south, the whole aspect of the heavens will change.

The reason that the pole-star does not seem to move is because the axis about which the earth revolves points almost directly towards it.[2] There is no change of the horizon with reference to it. To an observer at the equator the pole-star would be at the horizon, be-

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[1] The following additional measurements will assist in estimating distances. The stars may be found on a map or globe, or some one knowing them may point them out in the heavens. The extreme stars of the three in the belt of Orion are about three degrees apart; Castor and Pollux about four degrees. Near Vega is a faint star, which by a good eye can be seen to be made up of two stars. They are three and a half minutes apart. The height of the pole-star above the horizon is about equal to the latitude of the place. In the Middle States this is nearly forty degrees.

[2] The axis of the earth does not point directly towards the pole-star, but about one and a half degrees from it. The pole-star, therefore, describes a small circle about the pole of the heavens, though, roughly speaking, it may be said to correspond with it.

cause the axis of the earth is pointing in that direction. If a globe be set with its axis horizontal, it will show the motion of the heavenly bodies to a person at the equator. The stars that rise in the east will pass directly overhead and set in the west; every star will be just twelve hours above the horizon; those around the poles will describe small circles, those farther away larger; there will be no stars that never rise, and none that never set.

As the person moves towards the north pole, the pole-star will rise above the horizon, its height being equal to the latitude of the person;[1] that is, if the observer is at latitude 40°, as at Philadelphia, the pole-star will be forty degrees above the horizon. When the observer reaches the pole, the pole-star will be in his zenith; the heavens seem to move as in the case of a globe with its axis vertical; only one-half the stars will be ever visible; those in the horizon will con-

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[1] The elevation of the pole-star may be shown to be equal to the latitude by the aid of Fig. 2.

Let BAC be a meridian of the earth, P the north pole, and E the point where the meridian cuts the equator. The axis of the earth, OP, will cut the celestial sphere at a point, P′, very near the pole-star. Let A be the position of the observer on the earth. Then the arc EA, or the angle EOA, is the latitude of the place of the observer, and BOP is the elevation of the pole of the heavens above the horizon. We wish to prove that EOA = BOP.

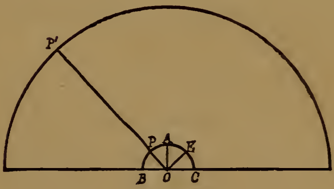

Fig. 2.

BOA is a right angle, and also POE, because the equator is ninety degrees from the pole. Hence BOA = POE. Taking from these equals the angle POA, we have BOP = AOE, which is what we wished to prove.

tinually skirt around the horizon; none will ever rise, and none set.

The same changes would be noticed if the observer moved southward from the equator, except that there is no star to mark the position of the south pole.

## Usefulness of Astronomy.

21. Astronomy, besides being a very grand and interesting science, has great practical usefulness.

Every day there is telegraphed over the country from the Washington and other observatories the accurate time of noon; this is determined by astronomical observations, without which it would be almost impossible to keep our clocks and watches correct.

Every captain of a vessel when he starts out on a long voyage takes with him a *chronometer*[1] which has been previously tested at an observatory, and a *nautical almanac*,[2] in which the positions of the sun, moon, and principal stars are given with great accuracy. With these and some simple observations he is able to tell his position on the ocean and thus to direct his movements.

The basis of our calendar is astronomical. The lengths of the year, month, and day are governed by phenomena of the heavenly bodies, and are determined by observations of them. Our common almanacs are calculated from the nautical almanacs, which are issued from the national observatories.

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[1] A clock swinging in rings, so that the motion of the vessel will not affect it.

[2] This will be further explained on page 169.

All the maps of the surface of the earth are dependent for their accuracy on astronomical observations; the methods of finding latitude and longitude are largely astronomical.

Astronomy is also a great help to chemistry, to geology, to meteorology, and to other sciences.

Hence we see that it is one of the very practical sciences; and it will probably be found that some of its researches, which do not now seem to be of any use to man, will in the future be in some way closely related to his welfare.

It will be of use to students also, if they study it rightly, to teach habits of observation, to strengthen their powers of thought, and to give correct ideas of the method by which the Creator of the universe works.

# PART I.

## THE SOLAR SYSTEM.

## CHAPTER I.

### GENERAL VIEW OF THE SOLAR SYSTEM.

22. *Parts of the Solar System.*—The group of bodies to which the earth belongs is called the solar system. It consists of the sun, the planets, their satellites or moons, the comets, and meteoroids.[1] The earth is one of the planets, and the moon one of the satellites. These bodies are closely connected with one another, and, comparatively speaking, are close together. The sun is very much the largest and most important member of the system: hence the name solar[2] system. The stars are all situated at immense distances from us, and, aside from their light, exert little or no influence upon us.

23. *Arrangement of the Solar System.*—The sun is the centre of the solar system, and about it all of the other

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[1] "Shooting stars" are meteoroids which have come into our atmosphere.

[2] Solar, from Latin *sol*, the sun.

3*

members revolve. The time that it takes one of these bodies to revolve about the sun is called its year. If an observer could be at the sun and watch the other members of the solar system, they would revolve about him in apparent circles, just as we see the moon revolving about the earth. But from one of the planets these motions do not seem so simple, and it was a long time before men found out that the earth and the rest of these bodies revolve about the sun.

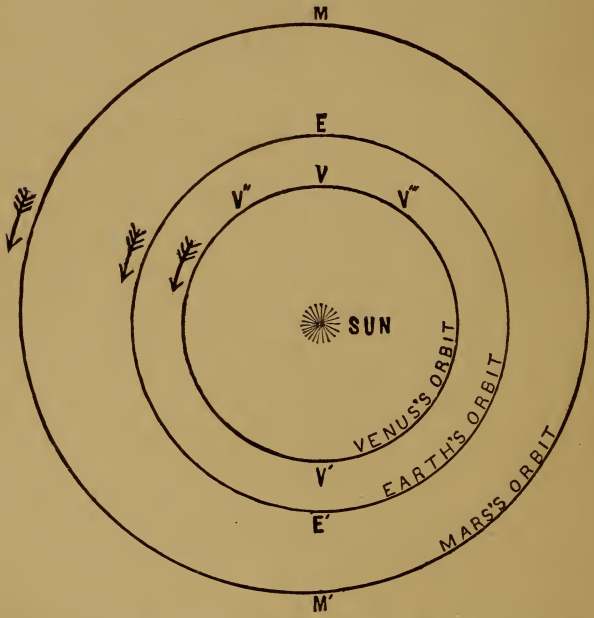

FIG. 3.—THE ORBITS OF MARS, THE EARTH, AND VENUS. One inch = 100,000,000 miles. The arrows show the direction in which the planets move, as seen from the north side of their orbits.

The path in which a body moves about the sun is called its orbit. Fig. 3 shows the orbits of the earth and the planets next to it on either side, Mars and

Venus. Those planets whose orbits are inside of the earth's orbit, as Venus, are called *inferior planets*, because they are nearer to the sun. Those outside are called *superior* planets.

24. *Positions and Apparent Motions.*—When a heavenly body is on the side of the earth *opposite* to the sun, it is said to be in *opposition;* thus, if Mars is at M, with the earth at E, Mars is in opposition. When a heavenly body and the sun are on the *same* side of the earth, the body is in *conjunction;* thus, if Mars is at M′,[1] with the earth at E, Mars is in conjunction. It is evident from the figure that an inferior planet has two conjunctions. With the earth at E, Venus at V is in *inferior conjunction*, but at V′ is in *superior conjunction.* If in going between the earth and the sun Venus should happen to pass directly across the face of the sun, it would be called a *transit.*[2] This rarely happens; the inferior planets usually cross a little below or above the sun. A superior planet may be seen at any height in the heavens; it may be in opposition to the sun, when it would rise about the time the sun sets, and would shine all night. An inferior planet can never be in opposition to the sun, but in revolving about the sun seems to us to pass back and forth, from one side of the sun to the other, as Fig. 3 shows is the case with Venus. An inferior planet, then, is never far from the sun; it is only seen a little while after sunset or before sunrise. When Venus is at V″ or V‴, with the earth at E, it seems to be farthest from the sun; it is then said to be at its *greatest elongation.* The planets all

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[1] M′ is read M prime; V′, V prime; V″, V second; V‴, V third, etc.

[2] Can a superior planet ever transit?

move about the sun in the same direction, from west to east. To an observer north of them (as anywhere in the United States north of Florida) they would seem to move from the right over to the left, or in a direction opposite to the motion of the hands of a clock.[1] Although the planets always move around the sun in the same direction, our position upon the earth makes them *seem* to move differently sometimes. With the earth at E, Venus seems, while moving from V″ to V‴, to move in the proper direction, from right to left, but while moving from V‴ to V″, across between us and the sun, it seems to move in the opposite direction. This is called its *retrograde* (backward) motion. A *superior* planet retrogrades when the earth passes between it and the sun. The earth leaves the planet behind, and it seems to move backward, just as fences and trees seem to move backward when we move past them in the cars. If we imagine ourselves at E in the figure, watching Venus move by us, or watching Mars as we move by him, these retrograde motions will be entirely clear.

25. *Shapes of the Orbits.*—The orbits of the planets are not circles, but ellipses. An ellipse is an oblong curve, so made that *the sum of the distances from any*

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[1] This motion must not be confounded with the apparent diurnal motion of the heavenly bodies. All of the planets and stars seem to move every night *from east to west*, which, as has been explained, is caused by the revolution of the earth upon its axis. But the motion here referred to is one which the planets have in the *opposite* direction *among* the stars, just as the moon moves to the east among the stars, although it rises and sets with them. The planets move more slowly than the moon, but if one of them be watched from night to night, its motion eastward among the stars may be seen. It is very important to have this matter perfectly clear.

*point of it to two fixed points is always the same.* Fig. 4 represents an ellipse. The sum of ES and EF is just equal to the sum of E′S and E′F.[1] If the ends of a string be fastened at two points (S and F) upon a table, so as to lie loosely between them, and a pencil held against the string so as to stretch it (as at E) be moved along, it will mark an ellipse. S and F are called the *foci* (fo′si). In the orbits of the planets the sun is always at one focus (fo′kus). If the foci are nearer to the centre C, the ellipse is nearer circular. The *eccentricity* of an ellipse is the distance CS divided by CP; it is usually expressed in a decimal fraction: the eccentricity in Fig. 4 is .8, or $\frac{4}{5}$.[2] The eccentricity of an ellipse shows whether it is nearly circular or more oblong. The orbits of the planets have very little eccentricity, as the table in Art. 27 shows. It must be remembered, then, that the elliptical shape of a planetary

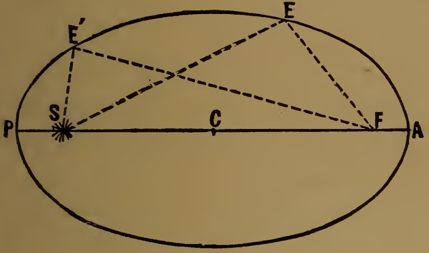

FIG. 4.—ELLIPSE.

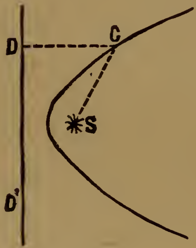

FIG. 5.—PARABOLA.

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[1] Measure the lines in the figure, and see if SE and EF taken together are equal to SE′ and E′F. Try the sum of the distances to any other point on the curve.

[2] Measure CS and CP, and see if CS is .8 (or $\frac{4}{5}$) of CP.

orbit, as shown in Fig. 4, is greatly exaggerated. An exact figure of a planet's orbit could not be distinguished by the eye from a circle. Fig. 3 shows the real shapes of the orbits of Mars, Earth, and Venus. If the sun and the other orbits be covered, no one of these can be distinguished from a circle. That point of a planet's orbit which is nearest to the sun is its *perihelion*;[1] the point which is farthest from the sun is its *aphelion*.[2] In Fig. 4, P is the perihelion, and A the aphelion. The difference between the distances of these two points from the sun may be very considerable, even if the orbit does seem to be almost a circle. In the case of the earth the difference is three millions of miles, and with most of the other planets the difference is greater. Some of the *comets* are thought to move not in ellipses, but in *parabolas*.[3] The two sides of this curve (Fig. 5) keep separating farther and farther forever. The parabola is not a closed curve like the circle and the ellipse.

26. *Characteristics of all the Planets.*—Next to the sun the planets are the most important parts of the solar system. They are alike in many points. Besides moving about the sun in the same direction in elliptical orbits, they all seem to revolve upon their axes in the same direction, giving them all day and night. Their paths all lie nearly in the same plane. They are all of the same shape. They all shine by reflected sunlight.

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[1] Perihēl′ion, from the Greek *peri*, near, and *helios*, the sun.

[2] Aphēl′ion, from the Greek *apo*, from, and *helios*, the sun.

[3] The parab′ola is so drawn that every point of the curve is equally distant from a fixed point and a fixed straight line. As in Fig. 5, CD and CS are equal; S is the *focus*, and DD′ the *directrix*.

## 27. *Statistics of the Sun and Planets.*

| Name. | Average dist. from the sun. | | Diameter in miles. | Length of year. | Length of day. | Mass (times the weight of the earth). | Density (times the weight of water). | Eccentricity of orbit. |
|---|---|---|---|---|---|---|---|---|
| | Millions of miles. | Times the earth's dist. | | | | | | |
| Sun........ ........ | ........ | ...... | 866,000 | ........ | 25 days. | 330,000 | 1½ | ........... |
| | | | | days. | | | | |
| Mercury ...... .. | 36 | ⅓ | 3000 | 88 | 24h. 5m.? | 1/15 | 6⅞ | 0.2056 |
| Venus............ | 67 | ⅔ | 7630 | 225 | 23h. 21m.? | ¾ | 4¾ | 0.0068 |
| Earth............ | 93 | 1 | 7918 | 365¼ | 23h. 56m. | 1 | 5½ | 0.0168 |
| Mars.............. | 142 | 1½ | 5000 | 687 | 24h. 37m. | ⅑ | 4⅙ | 0.0933 |
| | | | | years. | | | | |
| Planetoids... | 200<br>to<br>325 | 2<br>to<br>3½ | 20<br>to<br>300 (?) | 3<br>to<br>7 | unknown. | unknown. | unknown. | 0.02<br>to<br>0.38 |
| Jupiter.......... | 483 | 5 | 90,000 | 12 | 9h. 55m. | 312 | 1⅜ | 0.0483 |
| Saturn........... | 886 | 9½ | 73,000 | 29½ | 10h. 14m. | 93 | ¾ | 0.0560 |
| Uranus.......... | 1,782 | 19 | 33,500 | 84 | unknown. | 14½ | 1¼ | 0.0164 |
| Neptune......... | 2,790 | 30 | 37,000 | 164½ | unknown. | 17 | 1⅛ | 0.0090 |

This table is not to be committed, as the most important of these statistics will be given in round numbers in connection with the separate planets, but some of its striking facts should be noticed. The sun is by far the largest body in the solar system. His mass is seven hundred times that of all of the planets together. The planets are divided into three groups. Nearest the sun are four small planets, not differing very greatly in size; of these the earth is the largest. Next to these is a large number of very small planets, or planetoids. Then come four giant planets, which in several respects resemble one another. The four small planets are of heavy material; the sun and the four large planets are all about as light as water. The four small planets seem each to have a day about twenty-four hours long, while all of the large planets whose axial revolutions have been determined have days of only ten hours. Figs. 6 and 7 will assist in giving clear ideas of the sizes and distances of the planets. In Fig. 7 two of the planetoids are put between Mars and Jupiter. These planetoids are very small planets. They all come between Mars and Jupiter, and are close together. Little is known about them. The planetoids and the two farthest planets, Uranus and Neptune, were unknown to the ancients.

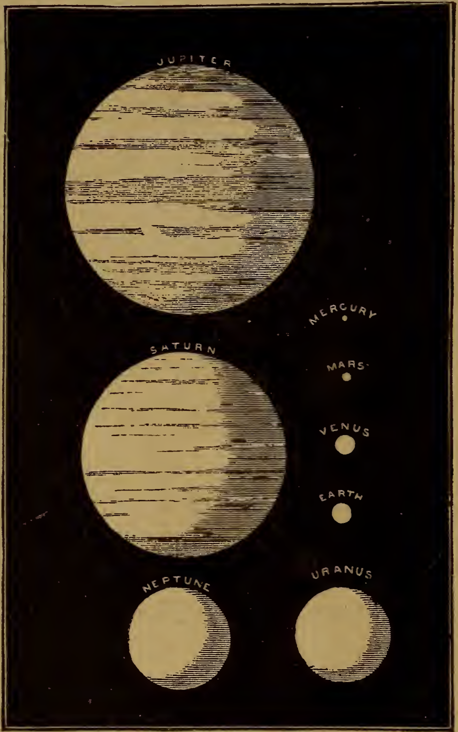

Fig. 6.—The Comparative Size of the Planets.

28. *Satellites.* — All of the principal planets except the two inner ones, Venus and Mercury, have one or more satellites. The earth has one satellite, the moon; and the satellites of the other planets are often called their moons. These satellites all revolve around their planets, just as the planets revolve about the sun, and are carried with them by the planets in their journey about the sun.

29. *Kepler's Laws.*—As has been said, Kepler discovered three important laws, by which the motion of all the planets and their satellites is controlled. These are:

I. *The planets move in ellipses, with the sun in one focus.*

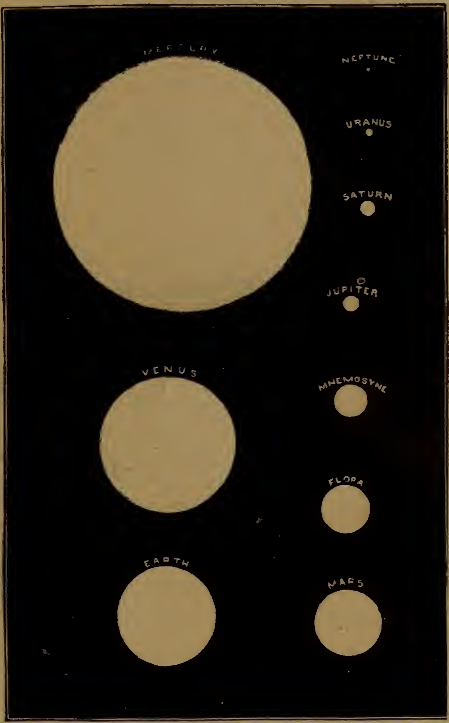

Fig. 7.—The Comparative Sizes of the Sun, as seen from the Different Planets.

Before the discovery of this law, astronomers had always assumed that the planets move in circles, and it must not be forgotten that these ellipses are almost circles. When it is at perihelion, or nearest the sun, a planet moves fastest; if it did not, the increased attraction of the sun would cause the planet to fall into it. This is between $P^2$ and $P^3$ in Fig. 8; but as the planet moves from $P^3$ to $P^4$, the sun's attraction, pulling it back, makes its motion slower and slower, until between $P^4$ and $P^5$ it is slowest of all. If this were not the case, the sun's attraction upon it here would be too weak to hold it in its place, and it would fly off into space. As it turns and passes through P and $P^1$, the sun's attraction pulls it forward and continually increases its velocity, so that at perihelion the planet's motion is swift enough to carry it past the sun without falling into it.

II. *The radius-vector of each planet sweeps over equal areas in equal times.*

The *radius-vector* is the line drawn from the sun to any point of the orbit, as SP, $SP^1$, $SP^2$, etc., in Fig. 8.

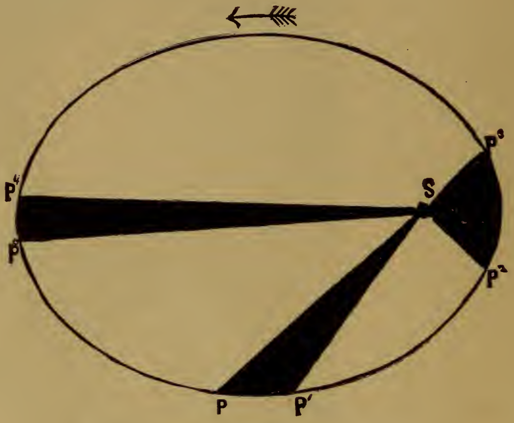

Fig. 8.—Illustrating Kepler's Second Law.

In this figure suppose that $PP^1$, $P^2P^3$, and $P^4P^5$ each represent the path of a planet for two weeks. Then the three shaded parts will be equal in area.

III. *The squares of the times of revolution of two planets are proportional to the cubes of their distances from the sun.*

To illustrate this law, let us compare the times and distances of Mercury and Mars, from the table on page 35, and by this law we shall have:

$$\underset{\left(\substack{\text{Mercury's}\\\text{period.}}\right)}{88^2} \ : \ \underset{\left(\substack{\text{Mars's}\\\text{period.}}\right)}{687^2} \ :: \ \underset{\left(\substack{\text{Mercury's}\\\text{distance.}}\right)}{36{,}000{,}000^3} \ : \ \underset{\left(\substack{\text{Mars's}\\\text{distance.}}\right)}{141{,}000{,}000^3}$$

If this be worked out, the product of the means will be found to be nearly equal to the product of the extremes.[1] The same proportion will be true for any other pair of planets. Observation has fixed the times of revolution of the planets very exactly, and when the distance of the earth from the sun is found,[2] the third law enables us to find the distance of any other planet from the sun by the proportion:

Square of earth's period : square of planet's period :: cube of earth's distance : cube of planet's distance.

Knowing the first three terms of this proportion, the last is found by arithmetic. This is the method used by astronomers to find the distances of the planets.

It also follows from this law that the planets near the sun move much faster than the distant ones. The table shows that Neptune is eighty times as far from the sun as Mercury, and its orbit is then eighty times as long. But it takes Neptune seven hundred times as long to complete its circuit. Mercury must move nearly nine times as fast as Neptune. Every planet moves faster than the planets outside of it. If it did not, it could not keep from being pulled in towards the sun by his greater attraction.

30. *Ecliptic.*—As has been said, the earth revolves about the sun once a year, but, as in all such cases, it seems to us that the earth is stationary, and that the sun moves about it. The *apparent* yearly path of the

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[1] The products will not be found to agree exactly, chiefly because the distances and times used above are not quite exact. If the exact distances and times were used, the agreement would be still a little imperfect, because the different planets influence the motions of one another slightly.

[2] The method of finding the distance from the earth to the sun will be explained in chapter iii.

sun among the stars is called the *ecliptic*.[1] The earth's axis is not perpendicular to the plane in which the sun moves, but is inclined to it. The angle between the ecliptic and the equator is 23½ degrees. Fig. 9 shows this leaning of the earth's axis. SS′ is the ecliptic.

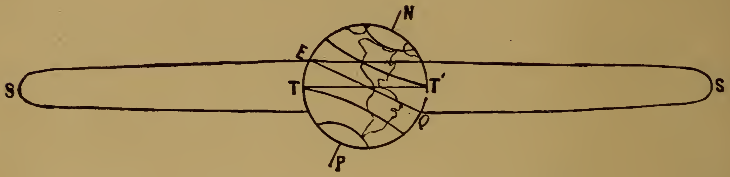

FIG. 9.—THE ECLIPTIC.

EQ is the equator. The plane of the ecliptic cuts the earth along TT. The angle EVT is the angle of 23½ degrees. When the sun is at S it is directly over T, which is 23½ degrees south of the equator. This is the *winter solstice*;[2] it comes on the 21st of December. This is the shortest day of the year, the sun being farthest south. As the sun moves around from S towards S′ it shines directly down upon the line TVT′, and is getting farther north, nearer the equator. On the 20th of March the sun is half-way from S to S′, and then shines directly down upon the equator at V. This is the *vernal equinox*,[3] or *spring equinox*. On the 21st of June

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[1] So named because eclipses can occur only when the moon is near this line.

[2] Sol′stice, from the Latin words *sol*, the sun, and *sto*, to stand, because the sun seems to stand still here a short time before turning to the north.

[3] E′qui-nox, from the Latin words *equus*, equal, and *nox*, night, because the nights and days are here equal. Vernal, from the Latin adjective *vernalis*, spring.

The dates of the solstices and equinoxes may vary a day, because 365 or 366 days do not make an exact year.

the sun is at S′, the *summer solstice*, and is now farthest north, being directly over T. Half-way from S′ to S, on September 22, the sun again crosses the equator, giving us the *autumnal equinox.*

The student must again carefully distinguish this motion of the sun among the stars from its apparent daily motion from east to west. If the stars could be seen in daytime, the sun would be seen to be slowly moving among them *towards the east*, just as the moon does at night; it is this path that is the ecliptic.

The ecliptic is divided into twelve equal arcs of 30 degrees each, called *signs.* They begin at the vernal equinox, and take their names from the names of twelve constellations, or groups of stars. Their names—which are all Latin—and symbols are these:

| | From the Vernal Equinox. |
|---|---|
| A′rĭ-ēs, ♈ (*the ram*) | 0° to 30° |
| Tau′rus, ♉ (*the bull*) | 30° to 60° |
| Gem′i-ni, ♊ (*the twins*) | 60° to 90° |
| Can′cer, ♋ (*the crab*) | 90° to 120° |
| Le′o, ♌ (*the lion*) | 120° to 150° |
| Vir′go, ♍ (*the virgin*) | 150° to 180° |
| Li′bra, ♎ (*the balance*) | 180° to 210° |
| Scor′pio, ♏ (*the scorpion*) | 210° to 240° |
| Sagitta′rius, ♐ (*the archer*) | 240° to 270° |
| Capricor′nus, ♑ (*the goat*) | 270° to 300° |
| Aqua′rius, ♒ (*the waterman*) | 300° to 330° |
| Pis′ces, ♓ (*the fishes*) | 330° to 360° |

The sun enters the sign Aries at the time of the vernal equinox, about March 20, and about a month later enters the second sign, Taurus, and so on through them all during the year. These signs and their symbols are in the first part of our common almanacs.

31. *The Celestial Equator.*—The celestial equator is a

great circle around the heavens, right above the equator on the earth. It cuts the ecliptic at the equinoxes, making an angle with it, of course, of 23½ degrees. If the equator were visible in the sky, it would appear as an arch, passing across our southern sky, cutting the horizon just east and west of us. The path of the sun on March 20, or September 22, is on the equator. In summer the sun's path is higher up in the sky than the equator; in winter it is lower.

Latitude and longitude are used to fix the position of places on the earth, and in the same way places in the sky are located; but, unfortunately, astronomers use other names than latitude and longitude to indicate corresponding distances. The distance of a star north or south of the equator is called its *declination*. Instead of the meridian of Greenwich or Washington to reckon longitude from, the meridian passing through the vernal equinox is used. And the distance that a star is *east* of the vernal equinox is its *right ascension*.[1] Both declination and right ascension, like latitude and longitude, are reckoned by degrees.

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[1] Declination, like latitude, is measured both north and south from the equator to the poles, but right ascension is measured around by the east only. So that a heavenly body may have any right ascension up to 360°.

What is the greatest possible declination that any point can have? where is that point? What is the dec. of the sun on June 21? on September 22? What is the dec. of your zenith? (See Fig. 2).

What is the R. A. (right ascension) of the sun on March 20? on June 21? on December 21? In which sign is the sun when his R. A. is 50°? when it is 140°? 250°? When the sun's R. A. is 110° is its dec. north or south? when its R. A. is 180°? when it is 300°? What is the sun's dec. when its R. A. is 90°? when 180°? when 270°? when 360°?

32. *The Zodiac.*—The zone of the heavens, extending about eight degrees on each side of the ecliptic, is called the *zo'diac.* It too is divided into twelve signs, which have the same names and order as the signs of the ecliptic. These signs roughly coincide with twelve constellations, or groups of stars, and it was to these constellations that the ancients gave the names Aries, Taurus, etc. When these names were given, the sun entered the constellation Aries at the time of the vernal equinox, and the signs of the ecliptic, through which the sun moves, coincided with the constellations marking the signs of the zodiac. But the vernal equinox, the point where the sun crosses the equator in the spring, moves very slowly backward, so that now the sun comes to the vernal equinox about a month before it enters the constellation Aries. The sun, therefore, is in the *sign* Aries while it is in the *constellation* Pisces, and in the *sign* Taurus while in the *constellation* Aries, etc. The signs of the ecliptic are about *one place ahead* of the corresponding signs and constellations of the zodiac.

Although the planets all move about the sun in the same direction, yet their orbits do not lie in the same plane. But the angles which the planes of the orbits make with each other are all small, and the planets are always found within the zodiac. Their paths are apparently circles, cutting the ecliptic at two points 180 degrees apart. These points are called *nodes.* Since the planets are always so close to the ecliptic, whenever they can be seen they show us just about where the ecliptic lies in the sky.

# CHAPTER II.

## THE SUN. ⊙

**Distance from the Earth, 93,000,000 Miles.[1] Diameter, 866,000 Miles. Axial Rotation, 25 Days. Specific Gravity, 1.5.**

33. *The Sun's Parallax.*—In finding the distance from the sun to the earth, astronomers have generally tried to determine first the sun's *parallax*.[2] The parallax of a heavenly body is the angle that the earth's radius would make if seen from that body. And so the sun's parallax is the angle that the earth's radius of nearly four thousand miles would make, or, more properly speaking, would *subtend*, if looked at from the sun.

Fig. 10.—The Sun's Parallax (greatly exaggerated).

Fig. 10 will make this clear. E is the centre of the earth, and AE is the earth's radius. Then, if S repre-

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[1] In *kilometres*, now so frequently used for scientific measurements, the sun's distance is between 149 and 150 millions. A kilometre is nearly two-thirds of a mile.

[2] Par′al-lax, from a Greek word spelled almost exactly the same way, and having the same meaning.

sents the sun, the angle ASE is the sun's parallax.[1] An accurate measurement of the sun's parallax is exceedingly difficult, but so great is its importance that many efforts have been made to determine it. Some of the most successful methods will be explained later in the book, Arts. 56, 57. It is a very small angle; the best measurement so far makes it 8.81″.[2] The angle at S in Fig. 10 is greatly exaggerated; it is almost three thousand times as large as the real angle. To represent it exactly in a figure is of course impossible. It is the angle which a foot-rule would subtend at a distance of four and a half miles.

34. *Distance and Size of the Sun.*—Since the earth's radius is known very exactly (Art. 65), when we know the angle that it subtends at the sun, it is an easy problem in trigonometry to calculate the distance of the sun,[3] which will be found to be a little less than 93,000,000 miles. This distance has been aptly called the yard-stick of the universe. Our measurements of the distances and dimensions of all the other planets,

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[1] Properly speaking, this is the *horizontal parallax*,—that is, the angle subtended by the radius running to our feet *when the sun is on the horizon.* It is easily seen that if the sun were above its position in Fig. 10, the angle ASE would be smaller. And if the sun were directly above A, this angle would be zero.

[2] A few of our readers may need to be reminded that this is 8.81 seconds, and is angular measure. It must not be confounded with seconds of time, which are never indicated by these two strokes ″, but always by s, or sec.

[3] The following proportion will make this clear to those who understand trigonometry. Using the triangle in Fig. 10, in which A is a right angle and ASE is the parallax, we have:

Sin parallax : sin 90° : : earth's radius : dist. from sun to earth;

or, sin 8.81″ : sin 90° : : 3959 : required distance.

and even of the distances of the fixed stars, depend upon it. If the distance to the sun is determined more accurately, all these distances and dimensions as given in this book should be proportionately changed. On this account these figures will be found to differ in different astronomies.

By measuring the apparent angular diameter[1] of the sun, and knowing its distance from us, another simple trigonometrical solution gives us its diameter,[2] which is about 109 times the earth's diameter. And since the volumes of spheres are as the cubes of their diameters, the sun's volume is $109^3$, or about 1,300,000 times that of the earth. But the density of the sun is only about one-fourth of the earth's density, so that while it would take 1,300,000 worlds as large as ours to make one as *large* as the sun, yet it would only take one-fourth of this number, or about 325,000, to make one as *heavy* as the sun. The force of gravity upon the sun is much greater than upon the earth, and, as the weight of a body depends upon gravity, anything would weigh nearly twenty-eight times as much upon the sun as upon the earth. A man who weighs one hundred and fifty pounds here would weigh more than two tons upon the sun, and would be crushed to death by his own weight.

### THE SUN AND HIS SURROUNDINGS.

35. *The Sun's Outer Atmosphere.*—If it were possible

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[1] The angular diameter of the sun is the angle which its diameter subtends as seen from the earth.

[2] If a right-angled triangle be drawn, having the line from the centre of the earth to the centre of the sun as its hypothenuse, and its right angle at the surface of the sun (because the line along which the edge of the sun is seen is a tangent), we have:

Sin 90° : sin of half of sun's angle : : 93,000,000 : sun's radius.

to visit the sun, one would first enter the *corona*,[1] a very light atmosphere extending several hundred thousands of miles on all sides. It is never seen except during a total eclipse, and then is a bright cloud-like circle of light surrounding the darkened sun. A great part of the corona is made up of streamers of light extending from the sun in various directions. Sometimes these streamers stretch away in two opposite directions only; often they project in four directions, giving the corona a four-sided appearance. At the eclipse of 1878 these streamers were noticed by some observers to extend as far as 9,000,000 of miles from the sun. The corona is never twice of the same shape, and even during the same eclipse its shape appears very different to different observers.[2] Fig. 11 represents a sketch of the corona as seen by Prof. Stone[3] during the eclipse of 1878.

The spectroscope (Art. 254) shows that the corona is composed mostly of hydrogen, which is the lightest known gas upon the earth, and some unknown gas or vapor even lighter than hydrogen, while the rays or streamers seem to be great streams of particles lighted up by the sun, just as the sun's rays shine

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[1] Cor-ō′na, Latin *corona*, a crown.

[2] This is remarkable. Different observers of the same eclipse, even when sitting side by side, make totally different drawings of the same corona. This is probably because one observer's attention is attracted mainly or even only by those features of the corona which strike him as most prominent,—perhaps the great *length* or *breadth* of certain streamers. Another might notice particularly, and therefore draw only, the brighter parts of the corona. And owing to the short time that the eclipse lasts and to the excitement of the observers, probably none of them will notice all the parts of the corona.

[3] Ormond Stone, 1847—, director of the Cincinnati Observatory.

through a window and light up the particles of dust along their path through a room. What kind of matter these particles are made of, and how they are thrown out into the different-shaped masses in which we see them, no one knows. The particles cannot be solid, as the particles of dust in a room are, but must be wholly or partly vaporized by the intense heat of the sun.

FIG. 11.—THE CORONA AS SEEN IN 1878.

36. *The Sun's Lower Atmosphere.*—The lower part of the sun's atmosphere, which rests directly upon the sun itself, is called the *chromosphere.*[1] It is a sheet of flame several thousands of miles deep surrounding the sun. *The spectroscope shows that the chromosphere is made up of the burning vapors of iron, lead, sodium, and some*

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[1] Chrō′mo-sphere, from the Greek *chrōma*, color, and sphere. It is this layer of burning vapors that causes the dark lines in the sun's spectrum, as is explained in Art. 253.

*twenty or more other substances which we find upon the earth.* Besides these, there are several substances burning in the chromosphere which have never been found upon the earth. This discovery of the substances which compose the chromosphere is one of the most remarkable of modern times. It was made by Prof. G. R. Kirchoff (kirk'hof), of Germany, in 1859. The chromosphere cannot be seen with the naked eye, nor with an ordinary telescope, except during a total eclipse of the sun. But by having a spectroscope attached to a telescope (Art. 254), and directing it to the edge of the sun, the chromosphere can be observed on any clear day.

37. *The Solar Prominences.*—Terrible storms are constantly raging in the chromosphere. From every part of the sun's surface great masses of the burning vapors are frequently hurled up to a height which not uncommonly reaches 100,000 miles. Prof. Young, in 1880,

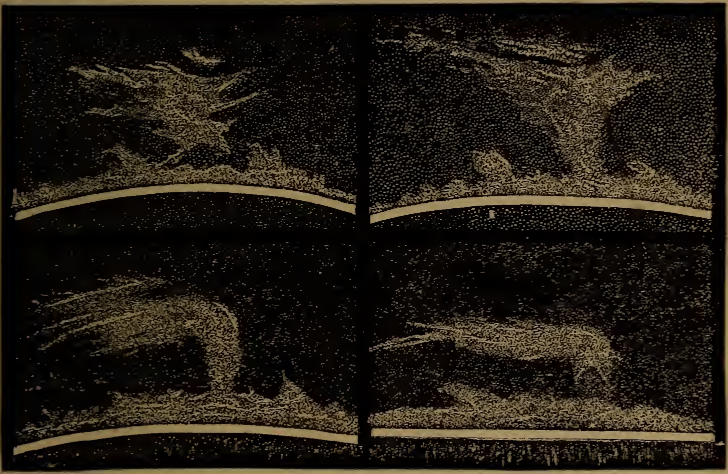

Fig. 12.—Changes in a Sun Prominence during ten Minutes, Observed by Professor Young, October. 7, 1869.

saw one thrown up to the enormous height of 350,000 miles. These are the red prominences seen during total eclipses of the sun, and now, with the aid of the spectroscope, watched every day. These masses are frequently thrown up with a velocity of 100 miles, and sometimes even 200 miles, *per second.* They are largely composed of burning or glowing hydrogen, but sometimes, near the base, of the burning vapors of the metals and heavy elements which make up the sun. They must be caused by great eruptions or explosions in the sun or the chromosphere. Fig. 12 shows the sudden changes in one of these prominences, as seen by Prof. Young[1] in 1869. Others of the prominences remain unchanged in form and position for days. These may be great masses of clouds thrown up by an explosion, which remain floating in the sun's atmosphere.

38. *The Surface and Interior of the Sun.*—Below the corona and chromosphere we come to the surface of the sun itself, the only part of it ever seen by most people, called by astronomers the *photosphere.*[2] This is now generally believed to be a *shell of clouds* surrounding the unseen mass of the sun beneath. Every one knows that the clouds about the earth are made up of tiny drops of water, that clouds are in fact precisely like fogs, except that they are floating high up in the air. The clouds which make up the sun's surface are not composed of water, but of tiny drops of fiery-hot melted iron, lead, and other substances that constitute the chromosphere.

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[1] Charles A. Young, 1834—, Professor of Astronomy at Princeton, New Jersey.

[2] Phō′to-sphere, from Greek *phōs*, light, and sphere.

Within the photosphere is the body of the sun, and, strange as it may seem, it is now generally believed that this is a great ball of gas; in fact, an enormous bubble. The great pressure makes this gas denser than water, so that it is not light and thin like the air around us, but probably as thick as tar or jelly. This gas is no doubt composed of the vapors of the various substances which make up the chromosphere. These are all kept in the condition of vapor by the intense heat.

39. *Sun-spots.*—With a small telescope the only thing to be seen on the sun's surface is a greater or less number of dark spots. The shapes of these are very various and irregular. The central part of a spot, called the *nucleus*, or *umbra*,[1] is black, while around the

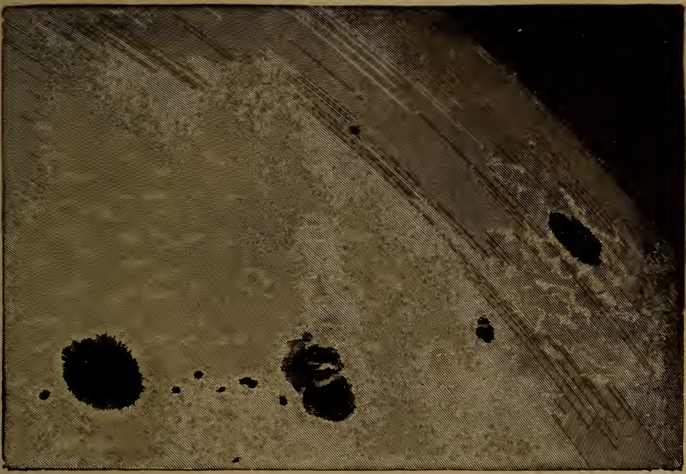

FIG. 13.—SUN-SPOTS AND FACULÆ. (From Young's The Sun.)

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[1] Um′bra, Latin *umbra*, a shadow.

edge is a lighter, grayish border, the *penumbra*.[1] Fig. 14, a drawing of a sun-spot seen through a large telescope in 1860, shows very clearly the features of a sun-spot. Here filaments of the penumbra stretch entirely across the umbra; but this is unusual. These spots are of all sizes, from those just visible in large telescopes to occasional monstrous ones 100,000 miles in diameter. They are very commonly found in groups, and are not distributed over the whole surface of the sun, but are confined to two zones, one on each side of the equator. These zones begin about 10° from the equator, and end about 35° from it. Close to the sun's equator spots are rarely seen, and close to the poles, never. As the sun turns upon its axis, the spots are carried along with it, and so pass across the sun's disk in twelve or fourteen days, and it is by the motion of the spots that we can tell that the sun rotates, and determine the time of its rotation. Besides being thus carried around by the sun, the spots have some motion of their own over the sun's surface. Careful observations have shown also that the spots in different latitudes have different rates of rotation. Spots on the equator revolve in twenty-five days, those farthest from the equator in twenty-six or twenty-seven days. This remarkable fact has made it very difficult to decide what the period of the sun's rotation really is, but, as Prof. Young says, "the probability is that the sun, not being solid, has really no exact period of rotation, but different portions of its surface and of its internal mass move at different rates, and to some extent independently of each other."

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[1] Pe-num′bra, Latin *pene*, almost, and *umbra*, shadow.

FIG. 14.—A GROUP OF SUN-SPOTS. (From Young's The Sun.)

40. *Phenomena and Cause of Sun-spots.*—The spots are certainly great cavities in the surface of the sun, the bottom of the cavity forming the umbra, and the sides

FIG. 15.—THE CHANGES IN THE APPEARANCE OF A SUN-SPOT AS IT IS CARRIED ACROSS THE SUN'S DISK BY THE ROTATION OF THE SUN. (From Newcomb's Popular Astronomy.)

the penumbra. This is shown by the appearance of a spot as it is first brought into view by the revolution of the sun. This may be seen in Fig. 15. When the spot is first seen on the edge of the sun, the penumbra and side of the umbra nearest to us would be hidden, but as the sun turned the whole spot would presently be seen. In going off the sun, the other side is hidden first. That the sun's spots are cavities is also conclusively proved by the fact that when just upon the edge of the sun they have sometimes been seen to be *notches.* The umbra is not entirely dark, but only so much darker than the brilliant surface of the photosphere as to look dark when compared with it. The highest artificial light that can be made, except the electric light, seems absolutely black compared with the sun's light. Spots may last for months, or only for hours. They appear and disappear with great rapidity, and frequently change their size and appearance greatly from day to day. A large spot frequently breaks up into small ones, and a group of small ones as frequently combine to make a large one.

The cause of the sun-spots is another of the mysteries of this wonderful body. As has been said, they are certainly great hollows or cavities, and may be caused by great whirlwinds, just as we see whirlpools formed in water. And there is evidence that these cavities are filled with gases and vapors, which obstruct the light from below, and so cause the dark parts of the spot; that they are places where the gases, which have been forced up in the prominences, and cooled in the upper layers of the atmosphere, are again drawn down into the sun.

41. *How to Observe the Sun-spots.*—When the spots are very large, they can be seen by the naked eye, looking, of course, through smoked or colored glass; but this is uncommon. With any good spy-glass they can generally be seen. If they are observed directly through a spy-glass or a telescope, the eye-piece must

always be covered with a dark glass. Several astronomers have lost their eyesight by looking at the sun through a telescope without using the colored shade. Unless a small glass, or very low magnifying power, is used, one must not expect to see the whole sun at once; the instrument must be moved gently over the surface to scan it all. It may be well, too, to remind the young observer that an astronomical telescope always inverts the object seen: what seems in the telescope to be the lower part of the sun is really the upper part, what seems to be the right side is the left side. But a spy-glass does not invert the object.[1]

A better way to observe the sun-spots is to throw the sun's image upon a screen with the spy-glass or telescope. For this a room having a window towards the sun must be chosen, and it must be darkened with shutters or curtains. The instrument is then pointed through a hole in the shutter or curtain at the sun, just as if it was to be observed in the ordinary way. But instead of looking at the sun, place a screen or piece of white paper perpendicular to the telescope and a short distance, say a foot, from the eye-piece, when a brilliant image of the sun will be seen upon the screen. The instrument ought to be upon a stand, or supported by some fixture attached to the window or shutter, and may be directed to the sun by glancing along the top of the tube. When the image is once thrown upon the screen, it can easily be kept there by gently moving the telescope as the image passes off. The instrument must be focused by moving the eye-piece in or out until the picture is most distinct. The whole of the sun will not generally be shown at once, but by moving

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[1] The cause of this is explained in Art. 244.

the instrument all the different parts of its surface may be thrown upon the screen and examined. No dark glass is needed to cover the eye-piece, and the sun's image with its spots may be seen by a number of persons at once. The image may be made as large as is wished by moving the screen farther off, or throwing the picture upon the opposite wall, but the smaller images will be most brilliant. By this method all the phenomena and changes of the spots may be carefully studied, their motions and changes noted, and their outlines drawn upon the screen itself. If an astronomical telescope is used, the observer will not forget that the motions of the spots are just opposite to their apparent motions from day to day upon his screen, and to give them their correct positions his drawings must be turned upside down. The general motion of the spots is from east to west, or, when looking at the sun, from left to right, but not directly across; the direction of the motion shows that the sun's axis is *inclined* to the plane of the earth's orbit. No heavenly body can be observed or studied with more interest by the owner of a spy-glass or small telescope than the sun. Accurate and complete records of sun-spots, accompanied if possible by drawings, would be valuable contributions to science, and many important discoveries have been made in this field with small instruments.

42. *Periodicity of the Spots.*—Long observations have proved the curious fact that sun-spots are most abundant about every eleven years. In 1848, 1860, and 1870 they were most numerous, while in 1856, 1867, and 1878 they were fewest. In 1882 and 1883 they may be expected to be abundant; then it is probable that they will diminish in size and frequency until

1889, increasing again until the next maximum in 1893. No satisfactory cause of this periodicity has been discovered. Observation has also shown a connection between the sun-spots and magnetic disturbances upon the earth. When sun-spots are most abundant, magnetic storms are most frequent; that is, compass-needles are turned from their proper direction, strong magnetic currents take possession of the telegraph wires, interfere with the sending of messages, and even set telegraph-offices on fire. These magnetic storms may be noticed over the whole earth, and are sometimes accompanied by unusual displays of the aurora, or northern lights. Like the sun-spots, these phenomena are periodical, and their periods coincide with the sun-spot periods. The cause of this coincidence is unknown, but there is probably an electrical connection between the sun and the earth. All of these phenomena are well worth observing and noting down. Such observations may lead to valuable results.

43. *Other Markings on the Sun.*—Seen through a good telescope, the whole bright surface of the sun is mottled, being covered apparently by bodies which from their shape and appearance have been called *rice-grains.* "Perhaps the most familiar idea of this appearance will be presented by saying that the sun looks like a plate of rice-soup, the grains of rice, however, being really hundreds of miles in length."[1] Under very favorable circumstances these rice-grains have been seen to be made up of smaller granules.

About twenty years ago, Mr. Nasmyth, an English astronomer, announced the discovery that through a

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[1] Newcomb's Popular Astronomy, p. 237.

powerful telescope this mottled appearance of the sun was seen to be due to a mass of long narrow bodies intertwined into a complete net-work over the whole surface of the sun. These did not seem to him to be shaped like rice-grains, but like *willow-leaves*. These willow-leaves, as they were called, have not been seen by other observers, and their existence is doubtful. Fig. 14 was drawn by Mr. Nasmyth, and shows around the spot the appearance resembling willow-leaves that he thought he saw.

Bright streaks are often seen upon the sun, sometimes separate, and sometimes forming a net-work. These are called *faculæ*.[1] They are temporary ridges on the surface of the sun; this is proved by the fact that they have been seen to project above the edge of the sun. They are sometimes many thousands of miles long. They are abundant about the edges of the sun-spots, and, like the spots, they are constantly appearing, disappearing, and changing their forms. In years when sun-spots are few faculæ are few also. They seem to be heaped up by the great storms and other commotions on the sun, especially when a sun-spot is formed or disappears. The white cloud-like patches shown in Fig. 13 are the faculæ. The faculæ, as well as the rest of the sun, are made up of the rice-grains. These faculæ can be seen with a telescope of moderate size, and may be observed directly or thrown upon a screen as the sun-spots were. They should be looked for around spots which are near the edge of the sun. The mottled appearance of the sun may be seen in the same ways, but needs at least a good

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[1] Fac′u-læ, plural of Latin *facula*, a torch.

three-inch telescope[1] and careful observation. The separate rice-grains can be seen only through large telescopes.

44. *The Sun's Position and Importance in the Solar System.*—The sun is the centre of the solar system, and his mass is 700 times as great as that of all the other bodies in the system put together. On account of his overwhelming size, his great attraction controls the motions of all the planets, and keeps them in their orbits. Were this attractive force of the sun to cease, the whole system would at once go to pieces, the planets would fly off into boundless space, and all life upon the earth or elsewhere in the system would speedily be destroyed.

45. *The Sun's Light. Its Amount and Importance.*—The sun's light is the most intense light known to us. It is from three to four times as bright as the brightest electric light; and every other artificial light seems absolutely *black* when put in front of the sun. Several attempts have been made to measure the brightness of the sun's light. This can be done only by comparing its light with some other light. For instance, it has been found that the sun gives out 600,000 times as much light as the full moon, while the light of the full moon is about the same as that of a candle twelve feet away.

Of the importance of the sun's light it is scarcely necessary to speak. Without it we should have only starlight in addition to our artificial light; for the moon shines wholly by reflected sunlight. Besides its

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[1] The size of a telescope is generally designated by the diameter of its object-glass.

great importance in vision, sunlight is essential to vegetable life, and indirectly, therefore, if not directly, to all animal life.

46. *The Sun's Heat.—Its Amount and Importance.*—The amount of heat which the sun gives out is beyond all our conception. That which the *earth* receives every year would *boil* an ocean of *ice-water* covering the whole earth to a depth of 60 miles. Yet this is only $\frac{1}{2,300,000,000}$[1] of all that the sun sends out. As Proctor puts it, "In each *second* the sun gives out as much heat as would be given out by the burning of 11,600,000,000,000,000 tons of coal."

Without the sun's heat the temperature of the earth would be some hundreds of degrees below zero, a temperature at which it would be impossible for life to exist. But this is not all, for to the sun's heat almost all motions on the earth are due. All the winds, all the clouds and storms, and consequently all springs and rivers, are due to the sun's heat. All our wood and coal represent just so much of the sun's heat stored up in the past. And, since it is now known that one sort of force may be changed into another, the sun's heat must be considered the real cause of almost all the forces, of all the work, and of all the power in the world. The tides are perhaps the only exception, for they are due mainly to the moon's attraction. But it is the sun's heat alone that keeps the water in a liquid state, and thus allows it to form tides. Tyndall well says, "The natural philosopher of to-day may dwell amid conceptions which beggar those of Milton. Look at the integrated energies of our world,—the stored

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[1] How is this calculated?

power of our coal-fields; our winds and rivers; our fleets, armies, and guns. What are they? They are all generated by a portion of the sun's energy, which does not amount to $\frac{1}{2,300,000,000}$ of the whole. This is the entire fraction of the sun's force intercepted by the earth, and we convert but a small fraction of this fraction into mechanical energy. Multiplying all our powers by millions of millions, we do not reach the sun's expenditure. And still, notwithstanding this enormous drain, in the lapse of human history we are unable to detect a diminution of his store. Measured by our largest terrestrial standards, such a reservoir of power is infinite; but it is our privilege to rise above these standards, and to regard the sun himself as a mere speck in its finite extension, a mere drop in the universal sea."

47. *The Cause of the Sun's Heat.*—The amount of heat given off from the sun continually is so enormous that, as none of this comes back, it has been a great problem to account for this constant supply of heat. We know that if the whole sun were a mass of *solid coal*, it would burn out at its present rate in five thousand years; and yet the sun has lasted much longer than that, and, so far as we can notice, his heat is not diminishing a particle. Two theories have been advanced to account for this. One is the *meteoric theory*. As will be fully explained in chapter VIII, it is known that immense numbers of small bodies are revolving about the sun, and some of these must be continually falling into it, just as they fall upon the earth and give us our shooting-stars, but the number there must be vastly greater than here. Now, when one body strikes another, heat is always produced, as when a nail is struck with a

hammer. If the striking body moves very swiftly, the heat produced is very great. If a combustible body were to fall from the earth to the sun, its striking would produce 6000 times as much heat as the burning of the same body could. And so it has been thought that the sun's heat is kept up by the striking of these bodies, called meteors, upon its surface. But when astronomers came to realize the prodigious heat of the sun, they saw that although this cause helps, yet alone it could not be sufficient to supply the sun with heat. The other theory of the sun's heat is the *contraction theory.* It supposes that by its own attraction the sun is slowly contracting in bulk: this condensation or squeezing together would produce heat just as a body falling upon it would. It has been estimated that if the sun's diameter should shorten only four miles in one hundred years, as much heat would be produced as the sun gives out in that time. No such contraction has ever been noticed in the sun, but this is no reason why the theory may not be true, for if the shrinking has occurred, we could not possibly detect it yet. This is the only cause ever suggested that, so far as we now know, can be the true one; and, although it has not been proved, it is generally regarded by astronomers as the principal cause of the sun's heat.

48. *The Sun's Past and Future.*—There has been of late much speculation upon the probable length of time that the sun has existed, and when he will probably cease to give out heat. No matter what may be the source of the sun's heat, we are forced to conclude that, if natural laws alone operate, his heat must at last be exhausted. As the sun gradually cooled off, the earth would become colder and colder; and when all heat

from the sun ceased, the temperature of the earth would, as has been said, probably be hundreds of degrees below zero. Long before this time all life would of course perish from the earth. But in any event these conjectures need give us little immediate concern, for the rashest speculators place these events millions of years in the future.

# CHAPTER III.

## THE INFERIOR PLANETS.

49. *Suspected Vulcan.*—For some years certain astronomers have strongly suspected that *between* Mercury and the sun there is a planet, which they have named Vulcan.[1] The great French astronomer Le Verrier,[2] of whom we shall hear in connection with the discovery of Neptune, found certain irregularities in Mercury's motion, which he suggested might be caused by the attraction of such an inside planet. Observers have several times announced that they saw the planet crossing the sun's disk; but few, if any, such observations have been reported by skilled astronomers, and an unpractised observer might easily mistake a sun-spot for a planet. Besides, at the very times when some of these supposed observations were made, other and better observers were also watching the sun, and saw no planet. But the strongest evidence in favor of Vulcan's existence was given in 1878. During a total eclipse of the sun in that year, two American astronomers, Prof. Watson[3] and Mr. Swift,[4] claimed to have discovered *two or more* planets within Mercury's orbit.

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[1] Vul′can, the god of fire.

[2] Lĕ Vĕr′rĭ-ĕr, 1811–1877. A great French astronomer; the discoverer of the planet Neptune. See Art. 179.

[3] James C. Watson, Professor of Astronomy at Michigan University, and at University of Wisconsin, 1838–1880.

[4] Lewis Swift, Astronomer of Rochester, New York.

Notwithstanding Prof. Watson's great reputation, astronomers generally seem to think that he mistook small stars for planets. No one has been able to find these planets since, and the existence of Vulcan must be regarded as an unsettled question.

## MERCURY. ☿

**Distance from Sun, 36,000,000 Miles. Diameter, 3000 Miles. Length of Year, 3 Months. Length of Day, Uncertain. Specific Gravity, 7.**

50. *Relations to the Solar System, and Features.*—So far as is certainly known, Mercury[1] is the nearest planet to the sun. Seen from him the sun seems seven times as large as seen from the earth, and upon his surface one would get seven times as much light and heat as upon the earth. Mercury is the smallest of the eight principal planets; his volume is only $\frac{1}{19}$ of that of the earth.[2] But he is the densest of all the planets, being about as heavy as cast iron. The planet is so close to the sun that observation of it is very unsatisfactory. In the largest telescopes its surface is brilliant but entirely unmarked. No reliable evidence of any mountains, land, or seas has ever been given. The absence of such markings makes it impossible to determine with certainty the length of its day, but there is some evidence that this is a little more than twenty-four hours. Nor is it certainly known whether the planet has an atmosphere or not; but it is supposed to have a very dense one.

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[1] The Latin name of the god who acted as messenger for the other gods. The sign ☿ represents his rod. All of the principal planets except the earth are named for the Latin deities.

[2] How is this found?

51. *Motions and Phases.*—As Mercury is an inferior planet, while revolving about the sun it seems to us only to swing backward and forward past the sun (Art. 24), and is never more than 29° from it. When opposite the sun from the earth, it is obscured by the sun's brightness and cannot be seen. As soon as it is far enough from the sun to be visible, it is small and nearly round. At one side of the sun, or at its greatest elongation (Art. 24), as at E in Fig. 16, it is larger, but only half full. As it comes around between the sun and the earth it grows still larger, but is a crescent, growing narrower and narrower, until in passing between us and the sun it is lost in the sun's glare, unless it should happen to go directly across the sun, when it could be seen as a black spot on his face.[1] These varying phases are just like those of the moon, and prove that the planet shines by reflecting the sun's light. When on the opposite side of the sun, the half of the planet lighted up is turned towards us, and it is about *full.*

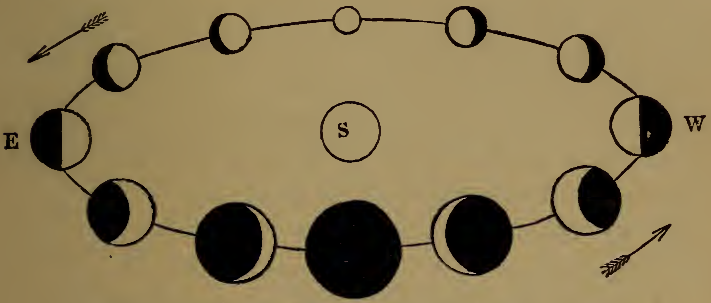

FIG. 16.—THE CHANGES IN MERCURY AS IT REVOLVES AROUND THE SUN.

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[1] How far are Mercury and the earth apart when they are on opposite sides of the sun? when on the same side?

When the planet is at one side of the sun, we see only *half* of the lighted hemisphere, and as it comes more and more between us and the sun, its bright side, always being the one towards the sun, is turned more and more away from us, while the dark hemisphere is turned more and more towards us, so that only a crescent of light can be seen, growing constantly narrower, until, if the planet *transits* the sun, its dark side is entirely towards us, and it is a round black spot.[1]

52. *Transits of Mercury.*—Every few years Mercury passes directly across the sun's disk. The transits are important in astronomical calculations, but are of little interest to observers. So small is the planet that the transit cannot be seen with the naked eye, but may be seen with a small telescope or a spy-glass. It is simply a small black spot on the face of the sun, crossing it in a few hours. During the next twenty years transits of Mercury will occur on the following dates:

May 9, 1891.
November 10, 1894.
November 4, 1901.

53. *How to observe Mercury.*—Mercury is always near the sun, and on that account is seldom seen except by astronomers. It can only be seen with the naked eye about the time of greatest elongation. It may then set one and one-half hours after the sun, or rise one and one-half hours before it, but the twilight and its

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[1] It is important that these phases and their cause should be clearly understood. If a careful reading of the explanation does not clear the matter up, a diagram, or a representation of Mercury's motion by moving any object around an imagined sun, and between that and an imagined earth, together with *a little study*, will make it clear. In which direction from Fig. 16 is the earth supposed to be?

nearness to the horizon interfere very much with its observation. The best times for evening observations of this planet during 1882 are about February 6, June 1, and September 28. For 1883 the dates will be eighteen days earlier than these, for 1884 about eighteen days earlier again, and so on. The dates may also be found in many of our common almanacs. For a week or more before and after these days the planet may be looked for.[1] If at these times a strange star be seen near the place on the horizon where the sun went down, one may be pretty certain that he has found the planet. It will not appear very bright, but will be as bright as any *fixed star* would appear in its position. The beginner must not be disappointed if he have difficulty in finding this planet, or even if he fail to find it. The great Copernicus never succeeded in finding it; but this was largely due to his northern latitude, where twilight lasts longer. To the naked eye the planet looks just like a star; with a small telescope the phases can be seen, which are its only inter-

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[1] In order that astronomical observation may be most successful, the body should be observed when at a considerable distance above the horizon; for any one may notice that even upon a very clear night stars close to the horizon cannot be seen well, if at all. This direction cannot, however, often be observed with Mercury. In general, moonless nights are the best for astronomical observation, although in the case of the bright planets the moon will interfere but little if it is not in their immediate neighborhood. Then, of course, the atmosphere and sky must be clear. The atmosphere, however, is occasionally quite deceptive. It will sometimes be very unfit for telescopic work, especially if high powers (Art. 247) be used on the telescope, when it seems to be perfectly clear; and nights which seem to be hazy may be found to be excellent for observation. The only way to determine the matter will be to bring out the telescope and try it.

esting features. When in its most favorable position for observation it is always about half full.

## VENUS. ♀

**Distance from Sun, 67,000,000 Miles. Diameter, 7600 Miles. Length of Year, 7½ Months. Length of Day, 23½ Hours. (?) Specific Gravity, 4¾.**

54. *Relations to the Solar System, and Description.*—Between the orbits of Mercury and the earth is Venus.[1] She comes nearer to us than any of the other planets, being sometimes only about 25,000,000 miles away;[2] but she gets twice as much light and heat as the earth.[3] Venus is almost the same size as the earth, her diameter being only three hundred miles less than the earth's. Notwithstanding her nearness, this planet is very difficult to observe. It is not certain that astronomers have ever seen any marks on her brilliant surface. Several observers have announced the discovery of some markings, and have inferred, from their motions, that the planet rotates in about twenty-three and one-half hours. But the best astronomers and the best telescopes of modern times can find no such marks. So that nothing is certainly known of Venus's surface or rotation. There is strong evidence of a dense atmosphere, and it would seem that this and its probable thick clouds reflect the sun's light so brightly that we never see the surface of the planet at all.

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[1] Venus, the goddess of beauty and love. Her sign is ♀, a mirror.

[2] How is this found? What is her greatest distance from the earth?

[3] The amount of light and heat that a planet receives from the sun depends upon the *square* of its distance. The earth is about 1½ times as far from the sun as Venus. The square of 1½ is 2¼, or about 2: therefore the earth receives one-half as much heat and light.

55. *Motions and Phases.*—As Venus is also an inferior planet, she swings from one side of the sun to the other, and passes through her phases just like Mercury, but on a larger scale. At her greatest elongation Venus is forty-seven degrees from the sun, and, owing to the great difference in her distances from us, her size varies much more than Mercury's.

Fig. 17 shows the appearance and comparative sizes of Venus when nearly between the earth and the sun, when at greatest elongation, and when on the opposite side of the sun.[1]

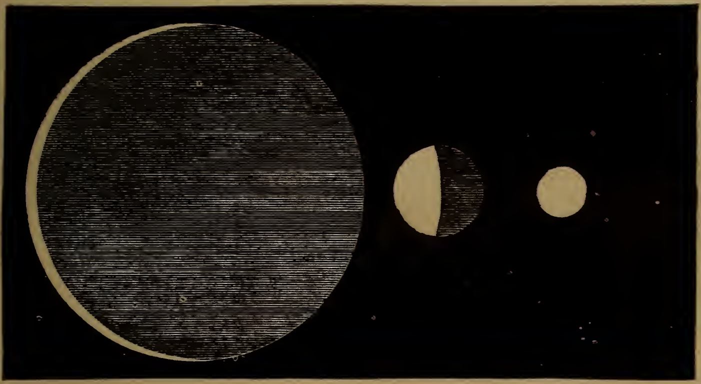

FIG. 17—THE APPEARANCE AND COMPARATIVE SIZES OF VENUS IN ITS DIFFERENT PHASES.

56. *Transits of Venus.*—These are much rarer phenomena than transits of Mercury, and have been considered to be of great importance, because they have hitherto been thought to afford the best opportunity of finding the distance from the sun to the earth. To find this, stations are chosen on opposite sides of the

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[1] The shaded parts of the figure are only intended to fill out the disks. The dark part of the *moon* can sometimes be seen, but not so with Venus.

earth, in the northern and southern hemispheres, as at N and S in Fig. 18. To the observer at N, Venus seems to cross the sun on the line HF; to the one at S, it crosses higher up, on CD. Each observer determines carefully where the planet seems to cross, and this gives the angular distance between A and B. This, with the distance from N to S, determined on the earth, and the *comparative* distances of the earth and Venus from the sun, which are found by Kepler's third law (Art. 29), will enable a person who has a knowledge of geometry and trigonometry to find the distance to the sun.[1] The real calculation of the dis-

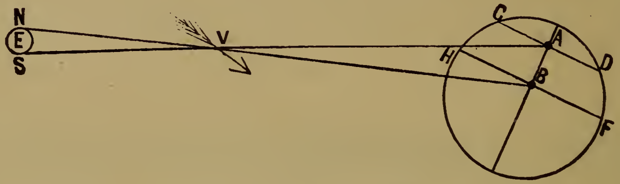

FIG. 18.—TRANSIT OF VENUS.

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[1] NVS and AVB may be taken to be similar isosceles triangles: therefore

$$NV : VB :: NS : AB.$$

But, by Kepler's third law,

$$NV : VB :: 1 : 2.61,$$

and therefore

$$1 : 2.61 :: NS : AB; \text{ or, } AB = 2.61NS.$$

Suppose that NS is the diameter of the earth, 7918 miles, and that AB has been found to be 46″. Then AB = 20,666 miles = 46″, and 1″ = 449 miles, which shows that 449 miles, seen at the distance between the earth and the sun, subtends an angle of 1″. The earth's radius, then, if seen from the sun, would subtend an angle of $\frac{7918}{449}$ seconds, or about 8.81″, which is the sun's *parallax* (Art. 33). Knowing the parallax and the earth's radius, the solution of a right-angled triangle (see foot-note on page 45) gives the distance in miles from the earth to the sun.

tance of the sun by this method is a very complicated problem.[1] The observations made during the transit of 1769 were not completely worked up for fifty years, and those made in 1874 have not been entirely computed yet. When the distance of the earth from the sun is found, the distances of all the other planets are easily found by Kepler's third law, and their diameters can then be found just as the sun's was found in Art. 34.

57. *The Duration of the Transit determined.*—The best method of finding the angular distance between the two paths across the sun (Fig. 19) is to measure at each station the exact *time* that it takes Venus to cross the sun. This is done by noting down the time when the planet first touches the edge of the sun, the *first external contact* (A in Fig. 19), and also just when it breaks away from the inside edge of the sun, the *first internal contact* (B). From these the time when the *centre* of the planet crosses the edge can be found. This is the beginning of the transit. In the same way, from the second internal and external contacts, the time when the transit ends is found. And since we know the angular distance that Venus passes over in an hour, multiplying this by the number of hours occupied in

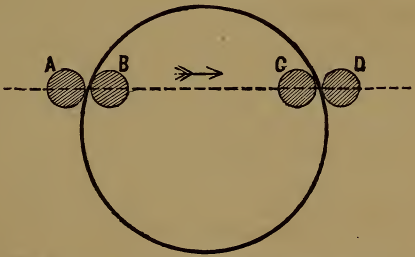

Fig. 19.—The Path of Venus across the Sun.

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[1] The simple conditions here supposed are never realized. Instead of two stations, there are many, and no two of them are actually at the extremities of a diameter. The earth does not stand still during the transit, but rotates on its axis and moves in its path around the sun.

the transit will give the lengths, and therefore the positions, of the two paths. From these their distance apart (AB in Fig. 19) is easily found.

In 1874 the paths were also determined by taking during the eclipse a number of photographs of the sun with Venus upon it. Upon these photographs themselves the paths were carefully measured.

58. *The Black Drop.*—At the two transits of the last century the observers were greatly perplexed at finding, when the moment of internal contact came and the planet should have separated itself from the inner edge of the sun, that it did not do so, but seemed to be attached to the edge of the sun for several seconds by a sort of neck. This ligament apparently connecting the planet with the edge of the sun is called the *black drop.* This made it very difficult to determine the exact time of internal contact. The black drop has been found to have been due mainly to the unsteadiness of the atmosphere and the imperfections of the telescopes then used. In 1874 it gave little or no trouble.

59. *The Early Transits.*—The first transit of Venus ever observed occurred in 1639. Jeremiah Horrox, a clergyman of the Church of England, and only eighteen years of age, calculated from the motions of the earth and Venus that there would be a transit of the planet on a certain Sunday in November. He arranged his telescope so as to throw the sun's image upon a screen, as explained in the directions given for observing sunspots (Art. 41). During the middle of the day he had to be at church, but, when he came back in the afternoon, to his great joy he found the image of the planet upon the screen. The next transit occurred in 1761. Astronomers now knew the importance of the event,

and preparations were made to observe it in various parts of the world; but the observations were not satisfactory. The next one came eight years later, in 1769. Astronomers were scattered over all those parts of the world from which it could be seen. The observations were thought to be satisfactory, and gave a distance of 95,000,000 of miles from the sun to the earth. This was universally accepted for many years, and may still be found in older text-books.

In connection with this transit occurred an incident which well illustrates the devotion of scientific men to their work. A French astronomer, Le Gentil, had been sent out to India eight years before to observe the previous transit there. Owing to the war between France and England, he was not allowed to land in British India. He saw the transit on shipboard, but the unsteadiness of the ship prevented him from making any valuable observations. Since he was there, he determined to wait eight years and observe the next one. He supported himself by business during these years, and made many scientific observations as well. "The long-looked-for morning of June 4, 1769, found him thoroughly prepared to make the observations for which he had waited eight long years. The sun shone out in a cloudless sky, as it had shone for a number of days previously. But just as it was time for the transit to begin, a sudden storm arose, and the sky became covered with clouds. When they cleared away, the transit was over. It was two weeks before the ill-fated astronomer could hold the pen which was to tell his friends in Paris the story of his disappointment."[1]

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[1] Newcomb's Popular Astronomy.

Another transit would not occur for over a hundred years.

A part of this transit was visible in the Eastern United States, and, under the management of Rittenhouse,[1] was observed at Norristown, Pa., Philadelphia, and Cape Henlopen. Although neglected at the time by the European astronomers, these observations were the most accurate that were made.

60. *The Transit of* 1874.—Before the next transit came, in 1874, astronomers were certain, from other methods of measurement, that a mistake had been made in 1769, and that the sun was not so far off as 95,000,000 of miles. This transit was expected to settle the matter, and very extensive preparations were made to observe it. The transit was to occur while it was night in the United States and over great part of Europe, so Asia and the South Pacific Ocean were the best places for seeing it. All of the foremost nations of the world sent out expeditions to observe it, at an expense altogether of $1,000,000. Our own government gave $150,000, and sent out eight different parties of observers.

Although the results of all the observations have not yet been completely worked out, yet those already found are unexpectedly discordant; and astronomers are now coming to the conclusion that, even with the best of instruments, in the hands of the best and most experienced observers, observations of the transits of Venus do *not* give us the best method of finding the distance to the sun, but that a method to be explained hereafter (Art. 239) is more reliable. The observations

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[1] David Rittenhouse, 1732–1796. A farmer's boy who made himself a great mathematician and astronomer. He used to calculate eclipses on his plough-handles. His life is interesting and instructive.

in 1882 will probably settle the question as to which is the best method of solving this important problem. Still, those results of the transit of 1874 which are apparently the most reliable confirm the belief that the old distance of 95,000,000 miles is too great.

61. *The Transit of* 1882.—The next transit of Venus will occur on December 6, 1882. It will be visible over the whole American continent except close to the north pole, and the best places in the northern hemisphere for its observation will be in the Eastern and Middle States. Should the day be favorable, it will be very carefully observed at our observatories. It will not be necessary to send out so many parties to observe it as were sent in 1874, nor is it likely that so much expense and trouble would be again incurred if it were necessary, since its observation is not now thought to be so important as it then was. The transit may be seen with the naked eye, looking, of course, through a piece of smoked or colored glass. The planet will appear to be a small round black spot on the surface of the sun. After 1882 there will not be another transit of Venus until the year 2004.

62. *How to observe Venus.*—When at her best, Venus is the brightest of all the planets, and much brighter than any of the fixed stars. She is never in the part of the sky opposite to the sun, and at night is only to be seen for a few hours after sunset or before sunrise. For about nine and one-half months she is seen after sunset, and is an evening star; for the next nine and one-half months she is seen before sunrise, and is a morning star. When she is to be seen in the evening, and when in the morning, are given in all almanacs. These facts will generally make it easy to recognize

Venus. She is not brightest at greatest elongation, but when a little nearer the earth than that. At this time Venus casts a shadow on a moonless night, and can be seen in the daytime with the naked eye, if one knows just where in the sky to look for her. The smallest telescope will show the phases of Venus, which are her most interesting features. Venus's rapid motions *among* the stars, both direct, that is, towards the east, and retrograde, towards the west, should be noted (Art. 24).

# CHAPTER IV.

## THE EARTH. ⊕

**Distance from the Sun, 93,000,000 Miles. Average Diameter, 7918 Miles. Length of Year, 365¼ Days. Length of Day, 24 Hours. Specific Gravity, 5½. One Satellite.**

63. *The Earth's Shape.*—The earth is the planet which comes next to Venus, and, like the rest of the planets, is round, or, more properly, spherical. The facts which led the ancients to believe that the earth was round have already been given (Art. 7), but other proofs of this fact are now known. One of the best known of these is that men have frequently travelled around it in almost every possible direction. This proves that it is *rounded*, but not that it is certainly a sphere.[1]

Another proof commonly given is that, when we watch a ship sailing away from the land, we notice that its hull is hidden first, then its lower sails, and last of all its highest sails. The water takes just the shape of the surface of the earth; and, since this gradual disappearance is noticed upon the water everywhere, and ships disappear just as fast in one direction as in another, the surface of the water at least must be round.[2]

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[1] Why not?

[2] The difference of level on the surface of still water is 8 inches in 1 mile. In 2 miles it is not twice 8 inches, but the *square of two* multiplied by 8 inches, 4 × 8, or 32 inches. In 3 miles it is 9 × 8, or 72 inches, and so on. If your eye were at the surface of the water,

A still stronger proof is given by the eclipses of the moon. As will be explained hereafter, the moon is eclipsed by getting into the *earth's shadow.* When the moon is passing into the shadow or coming out of it, the edge of the shadow as seen upon the moon is *always round.* Many hundreds of eclipses of the moon have been seen, and at these different times every side of the earth has been turned towards the moon. The earth must look round, then, from every side, and must be a sphere.[1] Another convincing proof of the spherical shape of the earth will be given when the method of finding the size of the earth is explained (Art. 65).

Notwithstanding the numerous and unanswerable proofs of the roundness of the earth, there still seem to be a few people who deny it. A few years since, Mr. John Hampden, of England, wrote a book to prove that the earth is flat. He afterwards offered to bet five hundred pounds (twenty-five hundred dollars) that he was right. The bet was taken, and to settle the question a part of an English canal, where there were two bridges six miles apart, was chosen. Halfway between the bridges a rod was put up. When a telescope was set up at one end of the six miles and pointed towards the bridge at the other end, the place on the rod which was just as far above the surface of the water as the bridges, was found to project several feet above the line of sight. The referee in the case decided that this proved the rotundity of the earth: so Mr. Hampden lost his money.

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how tall a ship's mast would be hidden by 10 miles of water? How far out at sea could a mountain 3 miles high be seen? (154+ miles.)

[1] What different shapes might the earth have and yet look round from *some* sides?

64. *Apparent Deviations from the Roundness of the Earth.*—One can hardly believe at first that the earth is round, when he thinks of the hills and mountains scattered so thickly over its surface. But, when compared with the great earth, these irregularities are insignificant. If on the surface of a globe one foot in diameter an elevation were constructed proportionate in size to the highest mountain on the earth, it would be less than $\frac{1}{100}$ of an inch high, and could not be seen at all one foot away. If the loftiest of the Himalayas or of the Andes is so trifling, we can see how insignificant the hills and even the mountains about us must be. If an exact model of the earth one foot in diameter were made, a foot away it would seem to be perfectly smooth and round. What appears to us to be the great roughness of its surface does not, then, at all destroy the roundness of the earth.

65. *Size of the Earth, how determined.*—Since the earth is a sphere, its circumference is a circle, and, like every other circle, contains three hundred and sixty degrees. So, if we can find the length of one of these degrees, multiplying that length by 360 will give the circumference of the earth.

In 1764–65, Mason and Dixon (who came over from England to mark the boundary between Pennsylvania and Maryland, still called Mason and Dixon's line), at a point in the southeastern part of Pennsylvania, carefully observed the height of a certain star above the northern horizon, then measured a straight line directly south until the star at the same time of day (why?) was one degree *nearer* the horizon than when they started (Art. 20). Then they knew that they had measured just one degree of the earth's circumference.[1] Parts of the earth's circumference have been measured with the utmost exactness many times in different parts of the earth. In other places the whole length of the line running north and south has not been measured upon the ground, as Mason and Dixon measured theirs, but the corners of a row of triangles extending from one end of the line to the other have been marked. Then, by measuring *one side* of the first triangle and *the angles* of all the triangles, the whole distance is calculated by trigonometry. This is a much more accurate way than to try to measure the whole distance, on account of the hills and mountains that would interfere with direct measurement. Very long lines have been measured in this way, and the number of degrees from one end to the other found by observing the stars. The average length of one degree of the earth's circumference has been found to be about 69 miles, and the whole circumference, then, is a little less than 25,000 miles. These measurements of the size of the earth also prove that it is a sphere.

66. *The Earth Flattened slightly at the Poles.*—In measuring these lines, it was found that a degree of a meridian near one of the poles of the earth is a little longer than a degree near the equator. This shows that the degree near the pole is part of a greater circle than the degree near the equator,[2] or that the earth is

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[1] Students who understand geometry should work out the proof of this.

[2] This may be hard to see ; if so, let the student draw a circle flattened above and below. He will see that where the equator bulges out there is a sharper curve than at the flattened parts. If the curvature of the upper or lower part be carried on around till it meets,

slightly flattened at the poles. The circumference of the earth which passes through the poles is not, then, a *perfect* circle, but is an ellipse; but it is so nearly a circle that, if it were accurately drawn, no one could distinguish it from a circle. The distance through the earth from north to south pole is twenty-six miles less than the diameter from one side of the equator to the other. This is much greater than the height of any mountain, and, as we shall learn hereafter, the bulging out of the earth's equator produces some important astronomical effects, but it would make no appreciable difference in the shape of a globe. If, then, an exact model of the earth of a moderate size were made, the sharpest eye could not see but that it was exactly round, a perfect sphere. From the circumference the earth's diameter is easily found by arithmetic. Its average length is 7918 miles.

67. *Weight and Density of the Earth.*—Many attempts have been made to determine the weight of the earth. The first was made in this way. As we all know, a plumb-line points directly down to the centre of the earth. But if the plumb-line be held near a mountain, the attraction of the mountain pulls it a little to one side. If the mountain were not there, the plumb-line would point to a certain place among the stars; but the attraction of the mountain makes it point to a different place. The difference between these two places in the sky shows how far the mountain pulls the plumb-line aside. The size of the mountain is then measured, and the average weight of the rocks that make

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or completes a circle, this circle will run outside of the middle parts of the flattened one.

up the mountain is found; these will give the weight of the mountain. Knowing this, and how much the mountain pulled the plumb-line from the earth's centre towards itself, the weight of the earth is calculated. Although this was the first method employed, it is not altogether reliable, because we cannot be certain that the weight of the mountain has been correctly found.

The best method of finding the weight of the earth is to measure the force with which a large lead ball attracts a small body to itself. The *weight* of the small body shows how much the *earth* attracts it, for the weight of any body is caused wholly by the earth's attraction. Then if the attracting force of the lead ball, the attracting force of the earth, and the weight of the lead ball be all known, the weight of the earth may be found.[1] This experiment has been repeated many hundreds of times with the greatest care, and as the result the weight of the earth is found to be about 6,000,000,000,000,000,000 tons. This shows that the specific gravity of the earth is about $5\frac{1}{2}$; that is, it is five and one-half times as heavy as a globe of water of the same size. The rocks and soil at the surface of the earth are not nearly so heavy as this, being generally only two or three times as heavy as water. The inside of the earth must, then,

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[1] To solve this the distances of the body from the centre of the earth and from the ball ought to be known. Calling these D and $d$, and denoting by M and $m$ the masses of the earth and ball respectively we have, from natural philosophy,—

$$\text{Attracting force of ball} : \text{attracting force of earth} :: \frac{m}{d^2} : \frac{M}{D^2}.$$

In this proportion everything is known but M, which may therefore be easily found.

be very much heavier than its surface. This is due to the condensation caused by gravitation.

68. *The Earth's Rotation on its Axis.*—The ancients generally believed that the earth stood still, and that the sun and stars revolved about it every day from east to west. But it is now known that these motions of the heavenly bodies are only apparent, and are caused by the rotation of the earth upon its axis from *west* to *east* once a day. One proof that the earth turns thus upon its axis is that all of the thousands of stars do thus seem to revolve about the earth in exactly the same time. The distances of the stars vary greatly, but all are at enormous distances from us, so that it is impossible to suppose that they all revolve about such enormous circles in so short a time, and in exactly the same time. The only possible explanation of their apparent motion is that the earth turns on its axis in the other direction.

Again, if the earth thus rotates upon its axis, the top of a tower must move through a larger circle in the same time, and hence move *faster*, than the foot of the tower. If a stone were dropped from the top of the tower upon the *eastern*[1] side, in falling through the air it would still keep the *forward* motion of the *top* of the tower. And, since the top moves faster than the bottom, the stone while falling would move faster eastward than the bottom, and would strike the ground a little way east of the foot of the tower. If the tower were at the equator, and 500 feet high, the stone would fall about two inches from its foot. This experiment has been tried many times from towers, and in the

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[1] Why not upon the western side?

shafts of deep mines, and from it we have another proof of the rotation of the earth.[1]

Until recently astronomers thought that the time of the rotation of the earth remained exactly the same from century to century, and that there was therefore no change in the length of the day. But it is now thought that the ocean tides, which move around the earth in the other direction, by their friction may be gradually making the rotation of the earth slower, and thus slowly lengthening the day. But as a day is, at the most, only $\frac{1}{66}$ of a second longer than it was 2500 years ago, we may consider the length of the day as practically invariable.

69. *Revolution of the Earth about the Sun.*—As has been said, the sun seems to move around the whole sky among the stars once a year. There is abundant evidence that this, too, is only apparent, and that it is the earth that really moves about the sun in this time.

70. *The Shape of the Earth's Orbit.*—If the apparent size of the sun is carefully measured with a telescope every day in the year, it will be found to be largest about the 1st of January, and to grow smaller every day until about the 1st of July, when it will be smallest; then it will daily grow larger until about the 1st of January again. As we cannot suppose the sun's size to change in this way, we are forced to conclude that the sun seems largest at the 1st of January because we are then nearest to it, and that as it seems to

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[1] The student may have heard of the man who proposed to travel from one place to another by going up in a balloon, and after waiting until the earth turned around under him, to come down. Why would his plan not succeed?

grow smaller from day to day, we must be going farther from it every day; about July 1, when it seems smallest, we must be farthest from it, just as a man seems smaller the farther off he is. If the earth's distance from the sun varies in this way, its path about the sun cannot be a circle with the sun in the centre. It is an ellipse, like the paths of the other planets. The measurements just referred to show that at the 1st of January the sun's diameter appears to be $\frac{1}{30}$ longer than at the 1st of July, so that the earth must be about $\frac{1}{30}$ nearer the sun on the former than on the latter day. As the average distance of the earth from the sun is 93,000,000 miles, we are more than 3,000,000 miles nearer the sun at the 1st of January than at the 1st of July.

71. *The Eccentricity of the Earth's Orbit—Its Effect upon Climate.*—Since the difference of greatest and least distances is $\frac{1}{30}$, one must be $\frac{1}{60}$ greater and the other $\frac{1}{60}$ less than the average distance. This $\frac{1}{60}$ is the eccentricity of the earth's orbit (Art. 25). It may seem strange that we should be nearest the sun in winter and farthest from it in summer, but we shall presently learn that summer and winter are due to other causes than distance from the sun. Although these differences of distance are small compared with the whole distance, and the sharpest eye could not distinguish the earth's orbit from a circle (Art. 25), yet they are really considerable, and the earth actually receives $\frac{1}{15}$ more heat[1] on the 1st of January than on the 1st of July. This makes our[2] winters slightly warmer and

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[1] For the method of finding this, see foot-note, p. 69.

[2] This refers to the northern hemisphere.

our summers slightly cooler than they would otherwise be. But, as will be explained presently, after some thousands of years this will be reversed, and we shall be farthest from the sun in winter, and nearest to it in summer.

72. *Precession of the Equinoxes.*—The student will remember that the sun in its apparent yearly revolution around the sky along the ecliptic crosses the celestial equator in two points called the equinoxes (Art. 30). If the equator were a visible line in the sky, it would seem to be a great circle among the stars, running entirely around the earth; half of it only could be seen at once. On March 20 the sun would be exactly on this line, crossing it from south to north; the place of crossing would be the *vernal equinox.* Day by day the sun would be seen moving to the east among the stars (if they could be seen at the same time as the sun), and also getting farther and farther above the line until June 21, when it would be 23½° above or north of the line. Then, as it moved on in its eastward course, it would draw nearer and nearer to the line again, crossing it from north to south on September 21, the autumnal equinox. For the rest of the year its path would be a similar curve *south* of the equator, coming back to cross the equator on March 20 again. *But this time the sun would cross the equator a little before it came to the place where it crossed a year before.* The equinox, or place where the sun crosses the equator, moves *backward* or westward every year. The same would happen at the other equinox in September; there, too, the sun would cross the equator before it got to the crossing-place of the year before. This moving backward of the places where the sun crosses the equator is

called the *precession*[1] *of the equinoxes.* This motion is extremely slow. It would take the vernal equinox about 26,000 years to move entirely around the equator once in this way. The sun crossing the equator only a very little way farther back every spring would cross it about 26,000 times before coming to its first crossing-place again.

If the earth were perfectly round there would be no such motion of the equinoxes: the sun would always cross the equator at the same places. But, as we saw in Art. 66, the earth is not quite a perfect sphere. It is flattened at the poles, or, which is the same thing, there is a bulging or protuberance about the equator. It is the attraction of this equatorial protuberance by the sun and moon that causes the precession of the equinoxes.

73. *Effects of the Precession of the Equinoxes.*—As has been said in Art. 31, the right ascension[2] of a heavenly body is the distance (in degrees) from the vernal equinox *eastward*, or forward to the body. And as the vernal equinox moves backward, the right ascensions of the stars must be growing greater. As the precession itself is so slow, this change is also slow, but after many years it becomes considerable, and it was by noticing this increase in the right ascensions of stars that Hipparchus (Art. 6) discovered the precession of the equinoxes more than two thousand years ago. The fact that the first sign of the ecliptic does not now coincide with the first constellation of the zodiac (Art. 32) is now explained. As there stated, when the con-

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[1] From Latin *præcedere*, to go before.

[2] What corresponds to right ascension upon the earth?

stellations were named, the vernal equinox was probably at the beginning of the first constellation, so that the signs of the ecliptic received the names of the constellation in which they lay. But since that time the equinox has moved nearly 30° backwards, and the first sign of the ecliptic coincides with the twelfth constellation.

Another effect of the precession of the equinoxes is to change slowly the direction in which the axis of the earth points. The backward motion of the equinoxes causes the north pole to move around in a circle once in 26,000 years.[1] Now the north end of the earth's axis points almost directly to what is called the north star, and it will continue to point almost towards it for many years to come. But the earth's axis has not always pointed towards this star, nor will it always

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[1] This motion of the earth's axis and the whole subject of the precession of the equinoxes constitute one of the most difficult points in astronomy. The following illustration may help to make it clear:

Take an apple to represent the earth. Call the stem the north pole, and mark a line around the middle of the apple for the equator. If this apple be floated in a bucket of water so that just half of it is above the water, with the stem leaning about 23½° from the perpendicular, the position of the earth is well represented. The surface of the water is the ecliptic, and where the apple's equator crosses the water-line are the equinoxes. If the apple be now twisted around so that the stem shall move in a circle, leaning in every direction, but always about 23½° from the perpendicular, half of the apple being always in the water, this revolution of the north pole is represented. And it will be seen that the surface of the water is continually crossing the apple's equator in new places as the apple turns. This represents the precession of the equinoxes.

This motion has also been compared to the motion of a top when it is "dying out." It then leans outward and slowly revolves. One such revolution of the top represents the 26,000 year revolution of the earth's axis.

do so in the future. And, as it moves slowly around in its journey of 26,000 years, it will point in turn to every star that lies in its circular path. So that future generations will have to use other stars for

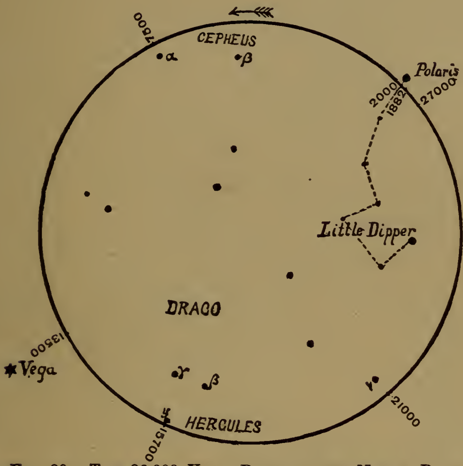

FIG. 20.—THE 26,000 YEAR PATH OF THE NORTH POLE AMONG THE STARS.

their north stars. Fig. 20 shows the path of the north pole among the stars as caused by the precession of the equinoxes. Some of the stars which generations in the far future will probably use as north stars, are marked.

74. *Nutation.*—If the attraction of the sun and moon upon the protuberance about the earth's equator were always the same, the precession of the equinoxes would cause the north pole to revolve in a perfect circle. But, on account of its own motions, the moon's attraction is always changing, growing greater and less alternately. This causes the pole to revolve in a *wavy* curve, and not in a perfect circle, as represented in

Fig. 20. The real path of the north pole in the sky is a circular, wavy line, crossing and recrossing the circle in Fig. 20. But these wavings are so small that they cannot be shown in the circle in Fig. 20. Yet they are of much importance in astronomy. It is this waving backward and forward that is called nutation.[1]

75. *The Seasons.*—When the sun is nearly overhead it gives us much more heat than when it is far down in the sky. This is proved every day. In the morning or in the evening the sun's rays are very slanting, and it is much cooler than at noon, when the sun shines much more directly down upon us.

Fig. 21 represents two rays of *equal breadth* striking the earth at noonday and at evening respectively. It is plain that the inclined or evening ray has to warm a much larger surface (BC) than the direct or noonday ray; and each spot cannot, therefore, receive so much heat.

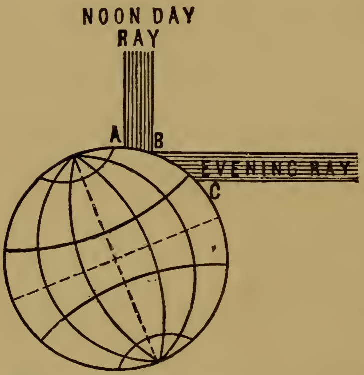

FIG. 21.—SUN'S RAYS STRIKING THE EARTH AT DIFFERENT INCLINATIONS.

The changing seasons are due to the same cause, the varying inclinations of the sun's rays. Fig. 22 represents the earth with its important circles drawn upon it. It will help to explain the seasons. On March 20 the sun is directly over the equator, exactly *in front* of the middle of the figure. And since the sun lights up just half of the

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[1] Nu-tā′tion, from Latin *nutatio*, nodding.

earth at one time, its light extends both to the north and south poles. If the figure be held up just in front of the eyes, and be supposed to rotate about the *axis* from left to right, or, much better, if a globe be held in this position and made to rotate, it will be seen that, since the sun is on the equator, it will rise directly east of us at six o'clock in the morning, and set directly west of us at six o'clock in the evening. Day and night will be equal all over the earth. (See Fig. 23.) Hence the name of this time of year, the *equinox*. This is the beginning of spring, so it is the *vernal* equinox. As the sun moves on in its yearly journey around the

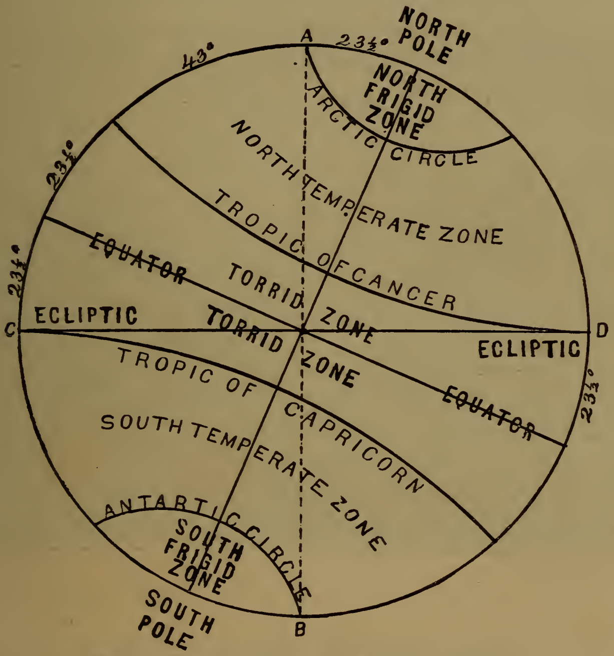

FIG. 22.—THE EARTH AND ITS IMPORTANT CIRCLES.

sky,[1] it is of course always directly over the line marked ECLIPTIC in the figure.

Moving from left to right, the sun in three months goes one-fourth way around its circular path, and on June 21 is to the *right* of the figure (22), directly beyond D. As the sun is now 23½° above the equator, it shines around 23½° beyond the north pole to A; but below the equator it shines only to B, 23½° short of the south pole. Right of AB is day, left of AB is night. As

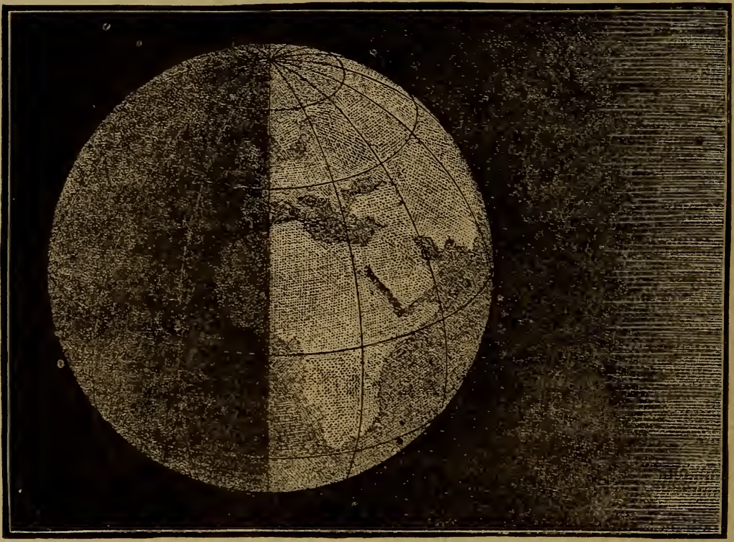

FIG. 23.—DAY AND NIGHT AT THE EQUINOXES.

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[1] It must not be forgotten that this apparent motion of the sun about the earth is really due to the earth's yearly motion about the sun, and that *this* causes the change of seasons. But the explanation is simpler if the sun be supposed to revolve about the earth. In the same way we commonly say, "The sun rises," or "The sun sets," although these things are really due to the rotation of the earth.

the earth rotates while the sun is here, the sun rises in the northeast and sets in the northwest, and we in the north temperate zone have our longest days and shortest nights. This is the beginning of *summer*,—the *summer solstice.* (See Fig. 24.)

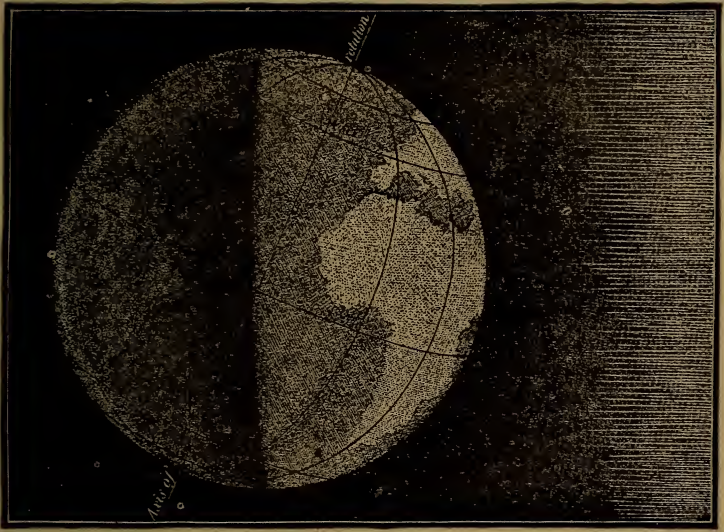

FIG. 24.—DAY AND NIGHT AT THE SUMMER SOLSTICE.

For the next three months the sun moves on around the earth, now of course *back* of the figure (22), and on September 22 is directly *behind* the middle of the figure and on the equator, making day and night again equal everywhere. This is the beginning of *autumn*,—the *autumnal equinox.* (See Fig. 23.)

In three months more the sun is directly to the *left* of C, 23½° south of the equator. Now the half of the earth to the left of AB is lighted up, while the half to the right is in darkness. The sun shines 23½° beyond the south pole, and not at all within 23½° of the north pole. Now, as the earth rotates, the sun rises in the southeast and sets in the southwest; our days are shortest and our nights longest. It is the *winter solstice*, —the beginning of *winter*. Another three months, and the sun comes to the vernal equinox again.

76. *The Seasons in the Southern Hemisphere.*—South of the equator the seasons are exactly opposite to ours. When the sun is nearest over our heads, and shines most directly down upon us, in the southern hemisphere it is lowest down in the sky, and its rays are most slanting. There the winter months are June, July, and August; the summer months, December, January, and February.

77. *Why the Days and Nights are Unequal.*—Figs. 22 and 24 show why, except at the equator, day and night are generally unequal. When the sun is to the right of D (Fig. 22), it shines upon *more* than half of each of the northern parallels of latitude (the tropic of Cancer, for instance); and therefore every place north of the equator, since it revolves every day through a circle of latitude, has sunlight for more than half of the twenty-four hours. It is evident, too, that the farther north one goes, the greater is the part of the circle in the sunlight, and therefore in summer the days grow longer and the nights shorter as we go north.[1] At the pole itself the sun shines for half the year, for from the vernal to the autumnal equinox the sun is north of the equator, and therefore less than 90° from the north pole, so that it must always shine upon the pole. At other places in the frigid zone the sun shines day

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[1] In Edinburgh, Scotland, on June 21, the sun rises about half-past three in the morning, and does not set until half-past eight in the evening, while twilight lasts all night.

after day without setting, the time being greater as the place is nearer to the pole. *South* of the equator the nights are longer than the days, and the south pole is having a six-months' night. Six months later the conditions are reversed. The people of the southern hemisphere have the long days and we the long nights.

78. *Duration of the Seasons.*—Astronomically, the seasons begin and end with the equinoxes and solstices. Spring begins March 20, and ends June 21;[1] summer begins June 21, and ends September 22; and so on through the year. Our almanacs agree with this division of the year; but popularly, in the United States, spring begins March 1, and summer June 1.[2]

If the number of days from the vernal to the autumnal equinox be counted, it is found to be seven more than the number from the autumnal to the vernal equinox. And if the time be counted more exactly, it is found that the sun is north of the equator about eight days longer than he is south of it. This is due to the fact that the sun is nearer to one end of the earth's orbit than to the other; and the earth moves through the larger end of its orbit in our spring and summer, taking a longer time to do it. In the southern hemisphere this is reversed. There spring and summer are eight days shorter than autumn and winter. This seems to make the temperature of the northern hemisphere milder than that of the southern. In time the precession of the equinoxes will reverse these conditions.

79. *Causes of Heat and Cold at Various Seasons.*—As

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[1] Remember that these may vary a day (see note on p. 40).

[2] In England, February, March, and April are commonly called the spring months, May, June, and July the summer months, and so on through the year.

has been shown, the sun shines most directly down upon us in summer, and most obliquely in winter. This would make our summers warmer than our winters. Besides, when the sun shines most obliquely upon us, the rays of heat pass through a greater thickness of air, which absorbs more of their heat, leaving less to reach the earth.[1] A third reason is that in summer the days are longer than in winter.

80. *Why the Greatest Heat and Cold occur after the Solstices.*—On June 21 the sun shines most directly down upon us, and also for the longest time; it may seem strange, then, that we have our hottest weather not at that time, but several weeks later. It is true that we are getting the most heat from the sun on June 21, but for several weeks after that day we receive more heat than we lose by radiation, and the weather grows hotter; just as a man who earns even a little more than he spends is constantly growing richer. About June 21 our savings of heat are the largest, for we then get most, but we are still saving some, though less and less every day, for several weeks, and are thus growing richer in heat until the latter part of July or the beginning of August. In the same way our coldest weather generally comes not at the winter solstice, but perhaps a month later. On December 21 we receive the least heat from the sun, but for some weeks afterwards we continue to lose more than we get, and are growing colder. For the same reason the hottest part of the day is not at noon, but some time in the afternoon.

81. *Geographical Zones.*—Fig. 22 also shows the well-known geographical zones. The torrid zone extends

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[1] Construct a figure showing this.

23½° on each side of the equator. Its boundaries are the lines where the sun turns back at the solstices. Its upper boundary is called the tropic of Cancer; the sun is directly over this line on the 21st of June. It then enters the fourth sign of the ecliptic, Cancer (Art. 30), from which the tropic is named; the sun now begins to go back towards the equator. Six months later it has gone entirely across the torrid zone to the tropic of Capricorn, which takes its name from that of the tenth sign of the ecliptic, which the sun now enters and begins its journey back towards the equator again. The torrid zone, then, is the part of the earth's surface which the sun some time in the year shines directly down upon. It is the hottest part of the earth's surface. In Art. 5, when the sun was supposed to be to the right of D, in Fig. 22, it was seen that the sunshine would extend 23½° beyond the north pole to A. As the earth rotates, the sun constantly shines over all the area within 23½° of the north pole. The circle which is everywhere 23½° from the north pole is the boundary line between the north frigid and the north temperate zones. It is the Arctic circle. At all points of this circle the sun would just escape setting on June 21. At the same time the sun does not shine within 23½° degrees of the south pole. This is the south frigid zone, and at the tropic of Capricorn on the 21st of June the sun does not rise.

Six months later the sun is at the winter solstice: now the sun does not rise in the north frigid zone, and does not set in the south frigid zone. Here, when they shine at all, the sun's rays are always very oblique, and these are the coldest portions of the earth's surface.

The temperate zones lie between the frigid and torrid zones. Here the sun is never directly overhead, yet it rises and sets every day during the year. Their name fitly describes the temperature of these zones.

82. *Effects of a Change in the Angle between the Equator and the Ecliptic.*—If the angle between the equator and the ecliptic should increase (see Fig. 22), the torrid and frigid zones would widen, while the temperate zones would grow narrower. The sun would rise higher in the sky in summer, and sink lower in winter. This would make our summers hotter and our winters colder. If the angle should decrease, the torrid and frigid zones would decrease also, but the temperate zones would widen.[1] The sun would not rise so high in the sky in summer or sink so low in winter. Our summers would be cooler, our winters warmer. If there were no angle between the two, the sun would always be directly over the equator, day and night would be equal everywhere through the whole year, and there would be no change of seasons. The equator of the planet Jupiter makes a very small angle with its orbit, so that there can be scarcely any change of seasons upon it, while on Mars the angle is somewhat greater than upon the earth, and there the changes are greater than here.

As a matter of fact, the angle between the earth's equator and the ecliptic *does* change slightly, but this change is very slow, and will never make much difference in the size of the angle, so that from this cause

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[1] How many degrees wide would the different zones be if the angle between the equator and the ecliptic were 15° ? 30° ? 40° ? 45° ?

there will never be any considerable change in our seasons.[1]

83. *Measures of Time.*—The three most natural divisions of time are the year, which is the time the earth takes to revolve about the sun; the month, which is based upon the time the moon takes to revolve about the earth; and the day, which is the time of the rotation of the earth upon its axis. We see, thus, that all our measures of time depend upon astronomy. The finding and keeping of correct time all over the earth is always done by astronomy, and is one of its most valuable uses.

84. *The Sidereal Day.*—From the time a star crosses our meridian[2] until it crosses it again is called a *sidereal*[3] *day.* This is the exact time in which the earth turns on its axis. As has been said, this time is practically invariable. It may be well to recall the fact that the word "day" is used in two senses. As opposed to night, it means the period of daylight, about twelve hours; but as used here and upon several pages following this, it includes both daylight and darkness, twenty-four hours.

85. *The Apparent Solar Day.*—If the sun, like a star,

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[1] The angle between the equator and the ecliptic is now decreasing about 45″ every hundred years. This will continue for many centuries; then it will grow greater again, and so vibrate backward and forward. The angle will never be as much as one and one-half degrees greater or less than at present, and will be thousands of years in making one such vibration.

[2] A star is said to be on our meridian when it is directly over the meridian of the earth passing through the place where we are. If the star's declination (Art. 31) is equal to our latitude, it is then exactly overhead; if not, it is directly north or south of us.

[3] Side′real, from Latin *sidus*, a star.

were always at the same place in the sky, a solar day would be just the same as a sidereal day. But we have learned that the sun moves entirely around the heavens every year; that is, it moves through 360° in 365 days, or about 1° every day, towards the east; this distance is about twice the sun's diameter, for the sun's diameter is about one-half of a degree. Now, the earth rotates on its axis in the same direction, and when its rotation has brought us around under the sun's place of the day before, the sun has moved one degree farther east, and the earth must turn that much farther to bring us under the sun again. Thus the time from noon to noon by the sun, which is the apparent solar day, is about four minutes longer than the sidereal day.[1]

86. *The Apparent Solar Days not Equal in Length.*—It has just been shown that the solar day is longer than the sidereal day, because the earth has to turn a little farther than a complete rotation to catch the sun. But these forward movements of the sun are not the same every day, so that the earth does not turn the same distance every day to catch the sun, and the solar days are therefore unequal. There are two reasons why the sun does not move the same distance forward every day.

87. *First Cause of Inequality in Solar Days.*—As shown in Art. 29, when the earth is in perihelion (Art. 25) it

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[1] As Proctor points out, this fact bears upon a curious error often found in our geographies and other text-books. It is commonly said that while the earth revolves about the sun once it rotates upon its axis 365¼ times. In fact, the earth rotates 366¼ times during the year, although there are but 365¼ days in the year. For the time of rotation is four minutes less than a day, as explained above, and therefore there is one more rotation than there are days.

moves more rapidly than in any other part of its orbit, while at aphelion it moves most slowly. Since the sun's apparent motion among the stars is really the earth's motion, about January 1, when the earth is at perihelion, the sun will move farther every day than usual. This will be further increased by the fact that because the sun is then nearest to us, it will seem to move still more rapidly. About the 1st of January, then, the solar days are longer than the average. And since about the 1st of July the sun really moves more slowly than usual, and from its great distance seems to move still more slowly, the days then are shorter than usual.

88. *Second Cause of Inequality in Solar Days.*—The ecliptic in which the sun moves is inclined to the equator, and when the sun is near the equinoxes its motion of a degree a day is on the *hypothenuse* of a right-angled triangle, but *our* eastern motion to overtake him is parallel to the equator, along the *base* of the triangle, and not so great. This would make the days about the equinoxes shorter than the average.

At the solstices the sun moves nearly in the tropics of Cancer and Capricorn, *parallel* to the equator. And as the sun moves through his regular daily distance along these *small* circles, it moves more than a degree along them each day. This makes the days about the solstices longer than the average.

89. *Mean Solar Day.*—On account of these constant changes in the length of the apparent solar day, it is not a good measure of time. But the average or mean of all the solar days in the year is taken as the standard day. This is the day which our clocks and watches keep, and which is divided into twenty-four hours, and these into minutes and seconds.

90. *The Equation of Time.*—Sun time is got from the sun either by a sun-dial, or by setting the clock at 12 when the sun is exactly on the meridian. From the two causes given in Arts. 87 and 88, sun time agrees with true or mean time only on four days of the year. These are

April 15, June 15, September 1, December 24.[1]

On the following intervening days, the difference between true time and sun time is greatest:

February 10, sun time 15 minutes slow.
May 14, " 4 " fast.
July 25, " 6 " slow.
November 2, " 16 " fast.[1]

The difference between true time and sun time is called *the equation of time.* Our common almanacs give the equation of time for every day of the year in a column on the page which gives the calendar of the month. In getting the time from a noon-mark or sun-dial, the time as thus found must be corrected as indicated in the almanac.[2] The times of sunset and sunrise as given in the almanac are in mean or true time at the latitude for which the almanac is calculated.[3] This time

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[1] These dates may vary slightly.

[2] If the column in the almanac is headed Sun Slow, the number of minutes must be *added* to sun time. If it is headed Sun Fast, they must be subtracted.

[3] According to the almanac, forenoon and afternoon are seldom of the same length. The time from sunrise until *apparent* noon (when the sun is on the meridian) is just the same as the time from apparent noon until sunset. But *mean* noon is understood in the almanac. If the sun is slow, he rises too late, and the forenoon is shorter than the afternoon. If fast, the sun rises early, and the forenoon is the longer.

will be exact only where the sun rises over a level surface.

91. *How Time is Found.*—Time is sometimes got from the sun as just mentioned, but it is generally and most accurately obtained by observations of the stars at astronomical observatories. By using a small telescope called a Transit (Art. 249), we can find out just when some well-known star crosses the meridian. The time when this ought to occur is given in the Nautical Almanac (see p. 169), and if the clock does not show the same time, we know how much too fast or too slow it is.

In many large cities time-balls are arranged so as to fall exactly at noon every day; and the correct time is sent by telegraph from various observatories along our principal railroads and to prominent jewellers every day. It would be a matter of great convenience if this system should be extended, and if all places lying near the meridian which passes through a suitable time-centre should use the time of that meridian instead of their local time.

92. *Civil and Astronomical Days.*—Civil or ordinary days begin and end at midnight, and are divided into two equal parts, each twelve hours long. The hours from midnight to noon are marked A.M., the first letters of the Latin words *ante meridiem*, "before noon." Thus, 5 A.M. means five o'clock in the morning. The hours from noon to midnight are marked P.M., the first letters of the Latin words *post meridiem*, "after noon."

The day used in astronomical work begins and ends at noon,[1] twelve hours later than the beginning and

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[1] Why is it most convenient for the civil day to begin at midnight? Why is it most convenient for the astronomical day to begin at noon?

ending of the same civil day.[1] This day is usually divided into twenty-four hours, which are numbered from 1 to 24. For many purposes an astronomer uses the sidereal day, which is about four minutes shorter than the mean solar day.

93. *The Week.*—This is not a natural astronomical division of time, although a very ancient one. The names of the seven days of the week were derived as follows: Sunday is the sun's day; Monday, the moon's day; Tuesday, Wednesday, Thursday, Friday, and Saturday are derived from the names of five old-English deities.

94. *The Month.*—The month is a very ancient division of time. At first it lasted from one new moon until the next, but this is about twenty-nine and one-half days, a number inconvenient in itself and not an exact divisor of the year. Presently the year was divided into twelve months differing somewhat in length. The present arrangement of the days in each month was made by Augustus, Emperor of Rome at the beginning of the Christian era. The names of the first six months of the year are derived from the names of six of the Roman deities, July and August are named for the Roman emperors Julius Cæsar and Augustus, and the last four months are named from the Latin words meaning seven, eight, nine, and ten, for when these

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[1] Thus, July 24, 9 A.M., civil time, would be July 23 d. 21 h., astronomical time; and July 24, 3 P.M., civil time, would be July 24 d. 3 h., astronomical time.

What astronomical times correspond to these civil times? April 5, 3 A.M.; May 10, 12 (noon); May 10, 12 (midnight).

What civil times correspond to these astronomical times? July 5 d. 6 h.; September 8 d. 14½ h.; March 3 d. 0 h.

names were given there were but ten months in the Roman year.

95. *The Year.*—The year which is always used is the time that it takes the sun to pass from the vernal equinox around to the vernal equinox again. This is 365 days, 5 hrs., 48 min., 46 sec.[1] These odd hours and minutes gave the ancients a great deal of trouble. Many devices were used by the different nations of antiquity to make the different seasons come at the same time year after year.

96. *The Julian Calendar.*—Julius Cæsar found the Roman calendar very much in error. Their winter months came in autumn, and the 1st of September came at the summer solstice. With the aid of an Egyptian astronomer he made the ordinary year to contain 365 days, but he added one more day to every fourth year, and also made the year begin with January 1. If the year were exactly 365 days and 6 hours long, this arrangement would be perfect. But because the odd hours and minutes are a little less than one-fourth of a day, the Julian years are a little too long, and the calendar fell back about 3 days every 400 years.[2]

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[1] This is called the *tropical* year, to distinguish it from the *sidereal* year, the time occupied by the sun in passing from a certain star around to that star again. The sidereal year is 21 minutes longer than the tropical year, and is, of course, the true year, or period of the earth's revolution about the sun. But the tropical year includes exactly the four seasons, and is, therefore, more convenient. The difference between the two is the result of the precession of the equinoxes (Art. 72).

[2] In the Julian calendar the year is supposed to be exactly 365¼ days long. This is too great, and if a certain portion of time is divided into these years there will be fewer years than there ought to be, and the count will fall behind; just as when the foot-rule is too long the measurement of a board will be too short.

97. *The Gregorian Calendar.*—In 1582, when Gregory XIII. was Pope, the calendar had fallen back 10 days. In that year the vernal equinox came on March 11, instead of March 21. As the time of Easter[1] and other festivals of the Catholic Church depends upon the vernal equinox, these festivals were gradually moving out of their proper months. To remedy this, the Pope introduced the *Gregorian Calendar.* This simply omitted three of the extra days every 400 years. The equinox was brought back to its place in the month by dropping 10 days out of the year 1582, the 5th of October being called the 15th. Catholic countries adopted the new calendar at once, but it was not adopted in England until 1752,[2] and in Russia the Old Style, as it is called, is still in use: so that now in Russia dates are 12 days earlier than elsewhere. The leap-years are determined by the following simple rule. *Every year, except the exact centuries, that is divisible by* 4 *is a leap-year. Every exact century that is divisible by* 400 *is a leap-year.* Thus, 1884, 1888, 1892, are leap-years, because they are divisible by 4; 1900 will not be a leap-year, because it is not divisible by 400, but 2000 will be a leap-year. This calendar loses only one day in about 4000 years.

98. *How to Find what Day of the Week a Given Day will be.*—A year of 365 days makes 52 weeks and 1

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[1] Easter is the Sunday following the first full moon that occurs after the vernal equinox.

[2] By this time the calendar was 11 days behind, for the year 1700 had intervened. By Act of Parliament in 1752 the day after September 2 was called September 14. There was great opposition to this change, especially among the lower classes. They thought that they had been robbed of 11 days, and ran after the members of Parliament who had secured the passage of the law, pelting them with stones and mud.

day; a leap-year makes 52 weeks and 2 days. Generally, then, a given day of the month comes one day later in the week each year, except when a 29th of February has come between; then it comes two days later. In 1882 the 4th of July is on Tuesday, in 1883 on Wednesday, but in 1884 on Friday.

99. *Latitude and Longitude.*—The latitude of any place is its distance in degrees north or south of the equator. The longitude of a place is its distance in degrees east or west of some fixed meridian.[1] The meridian of Greenwich[2] is used more than any other, although different nations use the meridians of their capitals also. The location of a place on the earth is always determined by its latitude and longitude. And it is absolutely essential that a ship-captain should find his latitude and longitude when at sea, in order to determine the course he must take to reach his destination and avoid dangers.

100. *How to Find the Latitude of a Place.*—With the proper astronomical instruments, properly mounted, as they are at observatories, it is easy to determine latitude. The angular distance of a star above the horizon when it crosses the meridian is measured. As the declination of the star is known, a simple arithmetical

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[1] What is the latitude of a place on the equator? On the tropic of Cancer? On the Arctic Circle? At the north pole? What is the longitude of the north pole, from any meridian? What is the greatest possible latitude of any place on the earth? The greatest possible longitude?

[2] Greenwich (pronounced grĭn′ij) is close to London, and is the seat of the Royal Observatory of England. American sailors reckon from the meridian of Greenwich, and the whole world ought to do it. It is mainly national pride that prevents it.

solution gives the latitude of the place.[1] At sea, the angular height of the sun above the water at noon is measured with a sextant (Art. 250), and from this the latitude of the ship is found in the same way.

101. *Longitude and Time.*—As the earth rotates once on its axis in 24 hours, every place on the earth must revolve around in a circle in that time. And as every circle contains 360°, in one hour every place on the earth rotates $\frac{1}{24}$ of 360°, or 15°.[2] This makes the sun rise 1 hour *later* for every 15° that a place is *west* of us, and 1 hour *earlier* for every 15° that a place is *east* of us. If the sun rises later upon places west of us, of course their *time* is later than ours,—that is, their clocks are behind or slower than ours. Places east of us have their time, and therefore their clocks, faster than ours. The difference of time is, of course, 1 hour for every 15° that one place is east or west of the other.[3]

102. *Longitude Found from the Difference of Time.*—

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[1] If the star is found to be 70° above the northern horizon, it must be 90° — 70°, or 20° farther north of the equator than our zenith, or than we are. Suppose a catalogue of stars gives the declination of this star as 60° N. Then, as we are 20° nearer the equator, our latitude must be 40° N. The declination of the sun for every day in the year is given in the Nautical Almanac, for the use of sailors.

[2] Does every part of the earth's surface move through the same *distance* in 24 hours? If there is any difference, which part of the earth's surface moves fastest as the earth rotates? Which slowest?

[3] A curious effect of this is that messages sent westward by telegraph seem to arrive at their destination before they are sent. The difference of time between England and New York is about five hours. After the morning papers come out in London, news from them are sometimes telegraphed to New York by one of the Atlantic cables and printed in our papers the same morning. When Pope Pius IX. died in 1878, our American afternoon papers which were printed at one o'clock announced that the Pope had died at three o'clock the same afternoon.

If one had a watch that kept perfect time, he could find the longitude of any place exactly. He need only set his watch just right at Greenwich, and carry it to the place whose longitude is wanted. The difference of time between his watch and a clock which gives the correct time of the place is the difference of *time* between this place and Greenwich. This multiplied by 15 gives the difference in *degrees*, or the longitude of the place. If the clock is faster than Greenwich time, the longitude of the place is east; if slower, the longitude is west.[1] It is impossible to make watches or clocks that will keep perfect time, but clocks are made which will vary very little. Those made to be carried are called *chronometers*, and are always carried by ships at sea. A ship's chronometer keeps Greenwich time[2] throughout the voyage, and the captain finds the correct time at his ship every clear day from observations of the sun with his sextant.[3] The difference between

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[1] Greenwich time is 5 hrs. 40 sec. faster than Philadelphia time. What is the longitude of Philadelphia? San Francisco time is 3 hrs. 9 min. slower than Philadelphia time. What is the longitude of San Francisco? The longitude of Pekin is 116° 27′ east: what is the difference of time between Pekin and Philadelphia? When it is noon at Pekin, what time is it at Philadelphia?

[2] The chronometer need not have Greenwich time, but the captain must know how much too fast or too slow it is. The amount which a chronometer gains or loses every day is called its *rate*, and is carefully determined before going to sea. Allowance is made for this in getting Greenwich time from the chronometer.

[3] Besides the height of the sun above the horizon (which is taken for this purpose about 8 or 9 A.M. or 3 or 4 P.M.), the captain needs his latitude (got as in Art. 100) and the sun's declination for that day (given in his Nautical Almanac). Knowing these, the time can be calculated by spherical trigonometry.

If the days are cloudy, but the nights clear, the moon or certain stars or planets may be used.

this and the chronometer's time when the observation was made gives him the ship's longitude. Thus knowing his latitude and longitude, the captain can find on his map just where his ship is.

103. *Longitude Found by Telegraph.*—When two places are connected by a telegraph-line, this can be used to find their difference of longitude in the best and most exact way. At the time of the passage of some star across the meridian of one place, a signal is sent over the wire to the other place. Since the electricity travels over the wire at the rate of about 8000 miles a second, unless the distance between the places is great, the signal reaches the second place at practically the same time it started. If the time when it arrives at the second place is observed, the difference of time between the two places, and hence the difference of longitude, is found. When the distance is great enough to make the time occupied by the passage of the electricity perceptible, a correction is easily made for that.

104. *Change of Days in going around the Earth.*—If a person travels towards the west, each of his days is longer than if he stays in one place. (Why?) And if he travels entirely around the earth in this direction, since each of his days has been longer, he has not had so many of them, and has had in fact one day less than his neighbors who stayed at home. If he has kept an account of his days, he will find his reckoning one day behind theirs: what he calls Tuesday they call Wednesday. If he goes around eastward, he will *gain* a day, and his Tuesday will be Monday at his home. It is necessary, then, to have some line where the day changes. The line now generally used is the one just opposite to the meridian of Greenwich, 180° from it

either way. It runs directly north and south, of course, through the Pacific Ocean, and nearly through Behring's Strait.[1] When voyagers from San Francisco to Asia cross this line, they skip a day. If, for instance, this meridian is crossed about noon on Monday, the rest of that day is called Tuesday. Coming back, a day is repeated: Monday noon would suddenly become Sunday noon, and the next morning, Monday morning over again.

105. *Refraction.*—When light passes from a *rare* transparent substance to a *dense* transparent one (as from air to water), its course is bent, and it becomes more nearly perpendicular to the surface of the dense substance.[2] But when the light is passing from the dense to the rare substance it is bent in the other direction, and becomes more slanting to the dense surface. This bending of the light is called *refraction.* When the end of a teaspoon or an oar is put under water, the part under water seems to be bent upward; because when the light from that part of the spoon or oar comes out from the water into the air it is bent down a little, and, as an

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[1] The reckoning in the islands of the Pacific Ocean does not in all cases depend upon their position with respect to this line. Those which were settled by voyagers around Cape Horn had calendars one day behind those settled by voyagers about the Cape of Good Hope, without respect to their situation as regards the 180th meridian. In some cases this difference still exists. When our government bought Alaska the reckoning there was one day ahead of ours.

When it is 9 o'clock A.M., Wednesday, at St. Louis (90° 15′ W.), over what part of the earth is it Wednesday, and what day is it over the rest of the earth?

*Ans.*—From 134° 45′ E. of Greenwich to 180° W. it is Wednesday. Over the rest of the earth it is Thursday (according to Art. 104).

[2] If the light comes down perpendicular to the dense surface it cannot become more perpendicular, and so it is not bent at all.

object always seems to be in the direction in which the light comes to the eye, the part under water seems to be higher than it really is. Refraction is fully explained in Natural Philosophy, and various experiments and illustrations of it will be found there.

106. *Refraction of the Heavenly Bodies by the Air.*—The lower part of the air is denser than the upper part, and the light from the heavenly bodies is consequently refracted by coming through the air, and they appear to be higher up in the sky than they really are. Fig. 25 illustrates this. O is the position of the observer, and Z his zenith. The curved lines represent the atmosphere. The lower ones are closer together, indicating that the atmosphere there is denser, while the higher part of the atmosphere is much rarer, as the lines indicate. The true position of the star is at S, but its light in passing through the air is bent down, as shown in the figure, and the star *seems* to be at S′, above

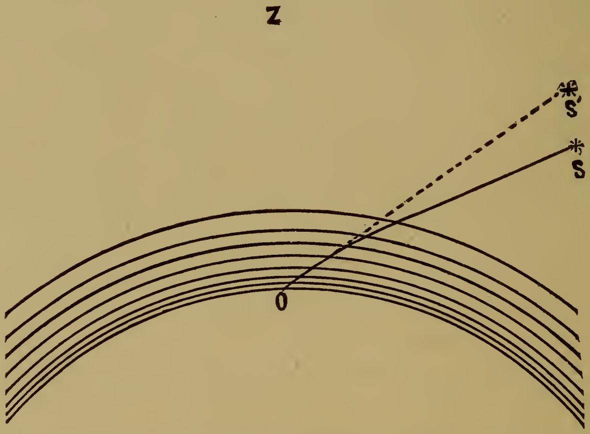

Fig. 25.—The Apparent Elevation of a Star by Atmospheric Refraction. (Greatly exaggerated.)

its true place. As the atmosphere *gradually* grows denser, the path of the light through it is a continued *curve* clear to the observer's eye, as shown in the figure. The amount of the refraction is not truly represented, but greatly exaggerated, to show it more clearly. Refraction is greatest when the heavenly body is at the horizon, for its light is then most inclined, and therefore most bent out of its course. It is then over half a degree (35′), but decreases fast at first, then slowly, until in the zenith there is no refraction (note 2, p. 113).

In making observations on the height of heavenly bodies, astronomers must always correct for refraction. That is, they must subtract (Why?) from the apparent height the amount of refraction for that height. This is found from tables made for the purpose.

107. *Curious Effects of Refraction.*—Since refraction elevates heavenly bodies more than ½° when they are at the horizon, and the sun and moon are each about ½° in diameter, these two bodies when rising and setting seem to be just above the horizon when they are really just below it. This makes the sun (or moon) rise three or four minutes earlier, and set three or four minutes later, than it would if there were no refraction, thus adding six or eight minutes to the length of the day.

When just above the horizon, the sun and moon—especially the latter—are sometimes seen to be flattened, the vertical diameter being shorter than the horizontal one. This is also due to refraction. Because the lower edge of the sun or moon is nearer the horizon, it is elevated by refraction more than the upper edge, thus causing the flattening.

108. *Why the Sun and Moon appear Largest when*

*Rising and Setting.*—The apparent enlargement of the sun and moon when rising and setting is sometimes attributed to refraction; but this is a mistake. This enlargement is an optical delusion. When the sun and moon are near the horizon they seem larger, because the long stretch of country between gives us a better appreciation of their great distance from us. Every one knows from his own experience that we habitually judge of the size of objects from their known or suspected distance. Besides, near the horizon we can compare the sun and moon with objects whose size we know, as fences, trees, houses, and the like. If they are looked at through a tube,—a roll of paper, for instance,—the illusion will disappear. And if carefully measured, the moon's diameter is found to be really *less* at the horizon than when overhead, for at the horizon it is farther from us.[1]

109. *Twilight.*—After the sun has set upon us at the surface of the earth it still shines for a while upon the clouds and air above us. The reflection (*not refraction*) of this light causes *twilight.* The same cause gives us twilight in the morning. As the sun sinks lower and lower, less of our sky is lighted up, and the evening twilight gradually fades away. Observation shows that it does not entirely disappear until the sun is about 18° below the horizon. Near the equator twilight is short, for there the sun always goes down nearly per-

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[1] When rising, the moon is farther by the length of the earth's radius (How many miles?) from us than when it is overhead. Let the student draw a figure of the earth with the moon upon the horizon, and also overhead, and explain this clearly. The sun is so far away that the difference between its morning and its noon diameter could not be detected by measurement.

pendicular to the horizon. But in the temperate and frigid zones the sun always moves obliquely to the horizon at sunset and sunrise, and must move *more* than 18° in its *path* to go 18° *below the horizon.* The nearer we go to the poles, the more oblique is the sun's motion, and the longer twilight lasts.[1] In Northern Europe twilight in midsummer lasts all night, and at the north pole it lasts more than two months.

110. *The Aurora Borealis.*—The aurora borealis,[2] or simply the aurora, is in some years a frequent phenomenon in our northern skies. It commonly consists of rays of light, sometimes of a reddish tinge, extending up above the northern horizon. It is more common the farther north one goes. But it is more frequently seen around the Arctic Circle and the magnetic pole than near the north pole itself. Many attempts have been made to measure the height of the aurora, and the results vary from a few thousand feet to five or six hundred miles.

How the aurora is produced is not yet known. It is probably caused in some way by electricity, for auroral displays are very frequently accompanied by electric storms upon the earth; strong currents of electricity

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[1] This may be very clearly shown with any globe which has a horizon (a horizontal ring about the middle). For a place in the northern hemisphere, slide the globe around until the north pole is as many degrees above the horizontal ring as the place is north of the equator. Now mark with chalk the probable place of the sun at that time of year (on a celestial globe the place is marked), and revolve the globe. (Which way?) If the place is far north, the pole will be near the horizon, and the chalk-mark will be seen to turn through a long arc before it is as much as 18° below the horizon.

[2] Aurō′ra boreă′lis, from Latin *aurora*, daybreak, and *borealis*, northern.

pass along telegraph-wires, and compass-needles are much disturbed. And, besides, if electricity be allowed to pass through a long glass tube from which the air has been almost exhausted with an air-pump, an appearance very much like the aurora is produced.

At certain periods displays of the aurora are unusually frequent and brilliant. As has been said in Art. 42, these periods seem to occur about every eleven years, and at the same times as the periods of numerous sun-spots, with which they are probably in some unknown way connected. For several years before 1881 the auroras were very infrequent, but during 1881 and so far during 1882 they have been increasing in numbers and in brilliancy. During the remainder of 1882, and for the two or three following years, they should be frequent. Records and descriptions of auroral displays would be well worth making.

## THE TIDES.

111. *What the Tides are.*—Every one who has spent even a short time on the sea-coast, on a bay, or near the mouth of a river, has noticed that every day for about six hours the water slowly rises (*flood tide*) until it is several feet deeper, and then as slowly falls (*ebb tide*) for the next six hours. The same thing is repeated in the night. These risings of the waters of the ocean are called *tides*. They are caused by two waves which are constantly passing around the earth from east to west, *opposite* to the direction of the earth's rotation. They are not exactly twelve hours, but nearly twelve and one-half hours apart, so that each of the two tides comes about one hour later every day.

112. *Tides caused mainly by the Moon.*—If the matter

be looked into a little more closely, it will be noticed that high tide always comes when the moon is about the same place in the sky.[1] The moon rises about one hour later every night, and we have seen that high tide comes about one hour later every day. This remarkable connection between the moon and the tides was noticed in very ancient times, and men knew that the moon in some way caused the tides, long before they could explain how it caused them. Sir Isaac Newton was the first to show just how they were caused by the moon.

113. *How the Moon causes the Tides.*—To show exactly how the moon causes the tides requires a difficult mathematical demonstration. But the common explanation is illustrated by Fig. 26. Because the water on the side of the earth nearest to the moon is more strongly attracted by the moon than the earth itself is attracted by it, the water is heaped up on that side, forming the *direct tide*, at D in the figure. And because

FIG. 26.—THE TIDES. High tide at O and D. Low tide at the two points half-way between, immediately in front of and behind the middle of the figure.

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[1] This is true of either of the two daily tides, although only one of them would occur while the moon was above our horizon. At New York high tide always occurs when the moon is about southeast; at New Castle, Del., when the moon is south; and at Baltimore when the moon is rising and setting. Why these intervals differ at different places is explained in Art. 115.

the moon attracts the earth itself more strongly than it attracts the water on the opposite side of the earth, it pulls the earth away from the water there, leaving it heaped up on the opposite side, and forming the *opposite tide* there, at O in the figure. This explanation shows pretty clearly how the direct tide is formed; but most persons cannot see how the earth can be pulled away so as to leave the opposite tide behind it and yet approach no nearer to the moon. The following explanation may help to make the cause of the opposite tide clear.

114. *How the Opposite Tide is produced.*—We are accustomed to say that the moon revolves about the earth. But it is proved in Natural Philosophy that it is impossible for one body to stand still while another revolves about it in this way. *They must both revolve about their common centre of gravity.*[1] The centre of gravity of the earth and moon is within the earth, about three-fourths of the way from the centre to the surface, at C in the figure, so that the earth as well as the moon is really revolving about this point C. As the earth revolves around this point, the water at O, being attracted less strongly by the moon, *swings out into a little larger circle.* This heaps up the water there, and always makes a tide on the opposite side from the moon. If a hollow india-rubber ball be pulled on its two opposite sides by two strings, it will take this spheroidal shape. The opposite forces in the case of the last are the moon's attraction and centrifugal force. The land is solid and cannot be pulled out of shape, but the water

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[1] The centre of gravity of two bodies is the point about which they would balance each other.

yields. The revolution of the earth and sun around their common centre of gravity takes about a month ($27\frac{1}{3}$ days). The reason we have a tide about every twelve hours is that the earth in rotating on its axis turns *under* these two projections and carries *us* around to *them*. It is this turning of the earth under these two projections that causes the tidal friction which it is thought may be slowly retarding the earth's rotation (Art. 68). This also explains the fact that the main motion of the tidal waves is from east to west, for we are carried towards the east *to them*.

115. *The Sun's Influence upon the Tides.*—Although the sun is so much farther than the moon from the earth, yet its prodigious size makes its attraction far greater upon the earth than the moon's attraction. But the power to raise a tide depends not so much upon the *strength* of the attracting force as upon the *difference* of its attractions upon the opposite sides of the earth. The sun is so far away that it draws the opposite side of the earth almost as strongly as the near side, so that it does not draw up a high direct tide, nor does it draw the earth much away from the opposite waters to raise an opposite tide. Yet the sun's influence is perceptible. The sun can raise tides about two-fifths of the height of the moon's tides, but these are generally combined with those raised by the moon. If, in Fig. 26, the sun were to the right of M (new moon), the sun's tides would be piled upon the moon's tides, which would make them unusually high. The same result would follow if the sun were opposite to the moon (full moon). These are the *spring tides*, and occur every two weeks. But if the sun and moon are 90° apart, as when the sun is directly in front of or behind the earth, in Fig. 26,

they pull the water in opposing directions. Then the sun lowers the moon's tides: these are called *neap tides*. The difference between spring and neap tides at New York is about two feet.

116. *The Land modifies the Action of the Tides.*—If the whole earth were covered with water of the same depth, the tides would pass regularly around the earth;[1] but continents and shallow water greatly modify the action of the tides. Since the Antarctic Ocean is the only one extending around the earth, the tidal waves are believed to originate there. Branches of these run up the great oceans opening into the Antarctic, and these run into our harbors and bays, causing the tides there. As the tide at the mouth of a river rises, it presently becomes higher than the water farther up the river, and, as it must flow down-hill, the water rushes up the river and causes the tides there. Along the lower part of rivers emptying into the ocean, while the tide is rising a current runs *up* the river. At high tide the current turns and begins to run down again towards the sea. But for some distance from the mouth the current runs down for more than half of the twelve hours, for it is some time after high tide begins before the water rises to the ordinary height of the river there.

117. *Effect of Bays upon the Height of the Tide.*—If a bay has a broad mouth opening in the direction of the

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[1] In the deep waters of the ocean the tide-wave, like other water-waves, moves forward by the *rising and falling of the particles of water*, and not by their moving forward. The motion of each particle forward and backward is very slight; just as when a breeze sweeps across a wheat-field, a *wave* passes swiftly over the field, but each head of wheat only bends over and rises again. Near a shore, where the water grows shallow, the tide may have considerable forward motion.

tidal wave, and gradually becomes narrow towards its upper end, it acts like a funnel, and the water may be forced up to a great height there. This accounts for the different heights of the tide at various places along the coast. In mid-ocean the average height of the tides is about three and a half feet. At New York it is four and a half feet; at Boston, more than twice as great. At the upper end of the Bay of Fundy, and in the English Channel, the tides sometimes rise to a height of seventy feet.

118. *Tides on Inland Seas and Lakes.*—Seas which have little or no communication with the ocean have very little tide. On the Mediterranean, much the largest of these seas, there is a tide about eighteen inches high, which must be raised upon the sea itself, for the narrow Strait of Gibraltar allows the ocean tides to affect but a small part of the sea. On the great American lakes a tide one or two inches high has been detected.

# CHAPTER V.

## THE MOON. ☽

**Distance from the Earth, 240,000 Miles. Diameter, 2,160 Miles. Length of Year, the same as that of the Earth. Length of Day, 29½ Days. Specific Gravity, 3½.**

119. *The Moon a Satellite of the Earth.*—The moon revolves about the earth[1] from west to east, just as the earth revolves about the sun, but makes a revolution every 27⅓ days. Every one must have noticed this motion of the moon among the stars towards the east from night to night.[2] The *new moon* is first seen in the early evening, low in the *west.* At the same hour the next evening it is higher up in the sky: *it has moved eastward among the stars since the night before.* The next evening it is higher still, and in two weeks it is in the opposite side of the heavens, and is seen in the early evening just rising in the east. This motion of the moon causes it to rise nearly an hour later every night,—a familiar fact, and one often useful in determining off-hand a few days in advance how early in the evening there will be moonlight.

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[1] Really both earth and moon revolve about their common centre of gravity (Art. 113), but, as their centre of gravity is inside of the earth, the statement here is correct.

[2] Be careful again to distinguish this motion from the nightly motion from east to west caused by the earth's rotation.

120. *The Moon's Orbit around the Earth.*—The moon's orbit around the earth, like the orbits of all the planets around the sun, is an ellipse. Its eccentricity (Art. 25) is about $\frac{1}{15}$: four times that of the earth's orbit. This makes the moon's distance from the earth vary nearly 40,000 miles; but the eye could not distinguish its orbit from a circle, although it could easily see that the earth is not in the centre of the orbit. The point in the moon's orbit which is nearest to the earth is called the *perigee*;[1] the farthest point is the *apogee*.[2]

121. *The Moon's Path around the Sun.*—While the moon is revolving about the earth, the earth itself is moving forward more than $1\frac{1}{2}$ millions of miles a day in its own orbit around the sun. This makes the moon's real path a waving line, crossing the earth's orbit backwards and forwards. Fig. 27 shows this.

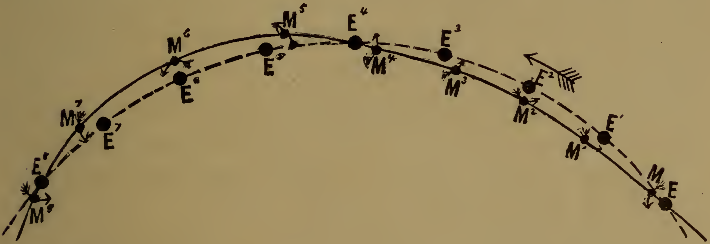

Fig. 27.—The Dotted Line, Part of the Earth's Path around the Sun. The Full Line, Part of the Moon's Path around the Sun.

When the earth is at E, the moon is just in front of it, at M. But the earth by its attraction holds the moon back, and gradually gains upon it, until, one week later, at $E^2$ and $M^2$, they are side by side. The earth's

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[1] Per′i-gee, from Greek *peri*, near, and *gē*, the earth.

[2] Ap′o-gee, from Greek *apo*, from, and *gē*, the earth. (G is soft in both words.) What points of the earth's orbit correspond to these?

swifter motion carries it on past the moon, and in another week it is at $E^4$, just in front of the moon. In these two weeks the moon seems to us to have made half a revolution around the earth; really it has moved along the curve $MM^4$, inside of the earth's path, and somewhat slower than the earth, so that from being immediately in front of the earth it has fallen back and is now right behind it. Here it crosses the earth's path, and, pulled on by the earth's attraction, gains upon it, and in another week is beside it again, at $M^6$; and at the end of the month it is immediately in front of the earth again, and crosses its path. It has now, as it seems to us, completed a revolution around the earth, and so it has. It is just as if a person while on the deck of a fast-sailing ship should walk slowly around the mast. He really does walk around the mast, but on account of the swifter motion of the ship his path over the surface of the earth is a wavy line crossing the path of the ship's mast.

The figure necessarily exaggerates the amount of this wavy motion: so small is it in comparison with the size of the earth's orbit, that the moon's path could scarcely be distinguished from a perfect ellipse. And if the earth were suddenly destroyed, the moon would keep on in a perfect ellipse about the sun, which could not easily be distinguished from its present path.

122. *The Moon's Phases.*—The most noticeable feature of the moon is its varying phases, from the thinnest crescent to the round full moon, and then back to the crescent again. To understand these phases, it must be remembered that the moon shines only by reflecting sunlight, and therefore the half of the moon which is turned towards the sun is always bright, while the other

half is always dark. When the moon passes between the earth and the sun,[1] its dark side is turned towards us. This is *new moon*, but we cannot see it then. A day or two later, it has moved to one side of the line between the sun and the earth, so that we can see a narrow strip of the bright side of the moon looking like a thin crescent.[2] We call this the new moon; but the exact time of new moon as given in the almanac was when the sun and moon were in conjunction (Art. 24). In a week the moon is around *beside* the earth, so that of the side turned towards us half is light and half is dark. The moon is half full: it is at the *first quarter*. Then it becomes *gibbous*, or more than half full; in a week from half full it is on the opposite side of the earth from the sun, and we see the whole surface lighted up by the sun: it is *full moon*.[3] In another week the moon is beside us again: it is again half full, and is at the *third quarter*. As it goes around towards the sun, more and more of its dark side turns towards us, and the crescent grows narrower and narrower, until it disappears at new moon again.

Fig. 28 illustrates these changes. The sun is sup-

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[1] The moon does not generally pass directly between the earth and the sun, but a little above or a little below it. When it does pass directly between, we have an eclipse of the sun. Nor at full moon are the three bodies generally in a straight line. When they are, the moon is eclipsed.

[2] The horns of the new and of the old moon always point *away from* the sun. Do you see why?

There is a wide-spread superstition that if the horns of the new moon point *upward* there will be dry weather, because the moon holds the water, but that if the horns point *downward* there will soon be rain. What do you think about it? (See Art. 135.)

[3] What time of day, and where in the sky, do we see the new moon? the full moon? the old moon? Why?

posed to be above the figure. The figures upon the circumference of the circle represent the moon in its

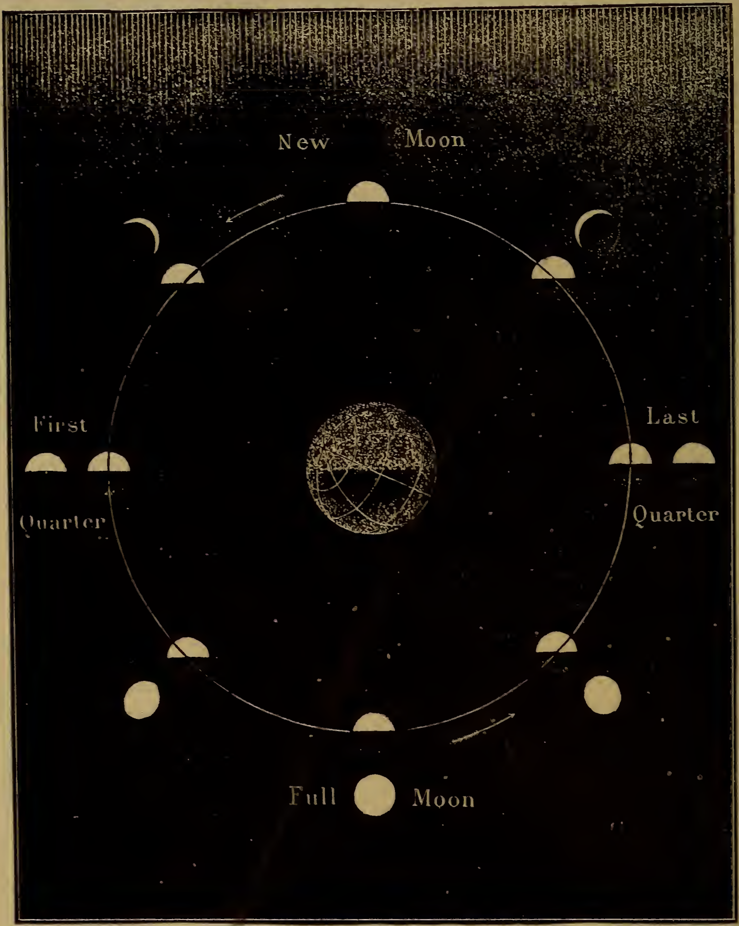

FIG. 28.—THE MOON'S PHASES.

different positions: the half turned towards the sun will be noticed to be always bright. The outside figures show the different phases.

123. *Time in which the Moon Revolves around the Earth.*—The moon makes a revolution around the earth in 27⅓ days. That is, if the moon passes a certain star at twelve o'clock to-night, it will pass the same star again 27⅓ days afterwards. But if the moon passes the *sun* at a certain time (new moon), when it comes around to the same place the sun has moved forward in *its* apparent yearly motion around the earth, and it takes the moon more than two days longer to catch the sun. So that the time from new moon to new moon is 29½ days. This is called a *lunation*,[1] or *lunar*[1] month. It is the foundation of our months.

124. *The Same Side of the Moon always turned towards the Earth.*—A little attention shows that we always see the same side of the moon. The well-known dark markings upon it are always seen when enough of the side next us is lighted up to show them. Closer examination with the telescope proves the same thing. The moon must therefore turn upon its axis just as fast as it revolves around the earth,[2] or in 27⅓ days. This is the moon's *sidereal day*. Its *solar* or real day is the time from new moon until new moon again, 29½ days. Daylight and night on the moon are each, then, nearly fifteen days in length.

A curious and quite probable cause of this remarkable motion of the moon is this. The present appearance of the moon's surface gives strong evidence of the fact that the moon was once at least partly liquid or molten. The earth's attraction must then have

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[1] From Latin *luna*, the moon.

[2] Let the student walk around a table, always keeping his face towards it, and he will find that his body has turned completely around, so that he has faced every side of the room in succession.

raised enormous tides in this molten surface, and the friction of these tidal waves may have retarded its rotation until it turned upon its axis just as it revolved about the earth. We have already learned that the tides upon the earth may be retarding its rotation slightly.

125. *The Moon's Librations.*—Although the moon always keeps the same side turned towards the earth, still there are some small oscillations that allow us to see a small part of the other side along the edge. These oscillations are called *librations.*[1] There are three of these. The moon turns on its axis uniformly, but since its path around the earth is an ellipse, its motion in that path is not uniform (Art. 29). On this account the moon sometimes turns on its axis a little faster or a little slower than it revolves about us, and allows us to see somewhat farther than usual along its equator. If the moon's path were a circle, there would be no such libration as this.

A second libration is due to the fact that the moon's axis is not quite perpendicular to the plane of its orbit, and its poles therefore lean towards the earth alternately, just as the earth's poles lean towards the sun to produce summer and winter. This allows us to see at every revolution of the moon a little way beyond its poles.

And, finally, two observers on opposite sides of the earth can each see farther around the moon in his direction than the other can, so that both together see more than half of the moon's surface. This is the third libration.

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[1] From Latin *libratio*, a balancing.

These three librations together enable us to see at various times nearly one-fifth of the opposite side of the moon, so that in all about six-tenths of the moon's surface can be seen by us.

126. *The Harvest Moon.*—A celestial globe shows very clearly that near the autumnal equinox (September 22) the ecliptic (Art. 30) is most inclined to the horizon—that is, it makes the smallest possible angle with it—about sunset. And it is also about sunset that the *full* moon rises. The figure shows the full moon just on the horizon at sunset on September 22. At the time of sunset on September 23 the moon has moved its regular daily journey of 13° *along the ecliptic*[1] to the position shown in the figure. It is now below the horizon, but, because the ecliptic makes so

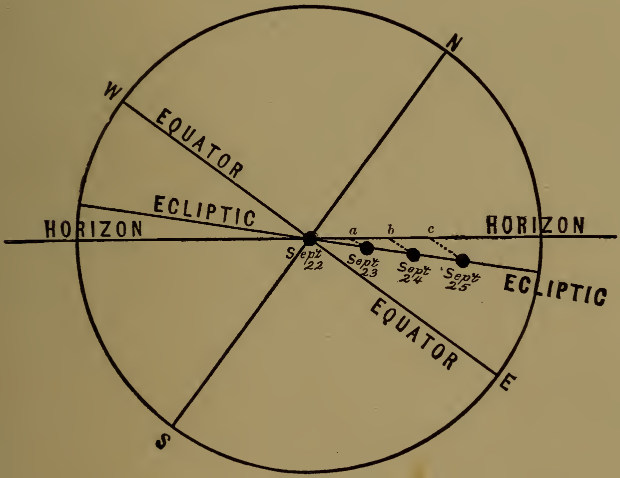

FIG. 29.—THE HARVEST MOON.

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[1] The moon's path does not quite coincide with the ecliptic, but does so very nearly, never being more than about 5° from it.

small an angle with the horizon, the moon is but a short distance below it, and will rise at *a* only a few minutes later than on the night before. By the next evening the moon is another 13° farther along on the ecliptic, but still it is not far below the horizon, and will rise at *b* a few minutes later again. The next night it will rise at *c* a few minutes later still. And so the full moon which comes *on, or nearest to*, the autumnal equinox rises only a few minutes later evening after evening for several days.[1] This is called the *harvest moon*, because in England harvest comes at this time, and the moon being about full, and rising night after night nearly at the same time, helps with its light in the gathering of the harvest. The harvest moon is much more noticeable in England and other high latitudes than here. In Edinburgh, if the moon rose at six o'clock on September 22, it would rise only fifteen minutes later the next night, and only fifteen minutes later again on the next. In the northern United States the harvest moon rises about half an hour later each night.

127. *Observation of the Moon.*—To the naked eye the moon's surface shows only the dark patches which vivid imaginations sometimes call "the man in the moon." These patches are simply parts of the moon's surface which are darker than the rest. But through a telescope its appearance is very different. The moon

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[1] The figure will probably make the explanation of the harvest moon clear to the student, but a globe having the ecliptic marked upon it is better than any figure. If the successive daily positions of the moon be marked upon the ecliptic with chalk, beginning at the equinox, when the globe is revolved these marks will appear at the horizon only a short time apart.

is much nearer to us than any other heavenly body, and for small telescopes it is therefore one of the most interesting and beautiful objects in the heavens. The best time for evening observation of the moon is from the time it is new until it is half full. The inner edge

FIG. 30.—THE MOON NEAR THE LAST QUARTER. (From Newcomb's Popular Astronomy.)

of the crescent, separating the light and dark parts of the moon, called the *terminator*, will be very uneven and

Fig. 31.—A Group of Lunar Mountains.

jagged. This is caused by the rough mountainous surface of the moon. Near the terminator, round pits, resembling pock-marks, will probably be seen: these are the great *crater mountains.* It is their dark shadows beside them that make all these mountains and craters distinct. At full moon these shadows disappear, for the sun is then shining directly down upon them. The bright *rays* or streaks that run out in all directions from some of the mountains constitute the most interesting feature of the full moon.

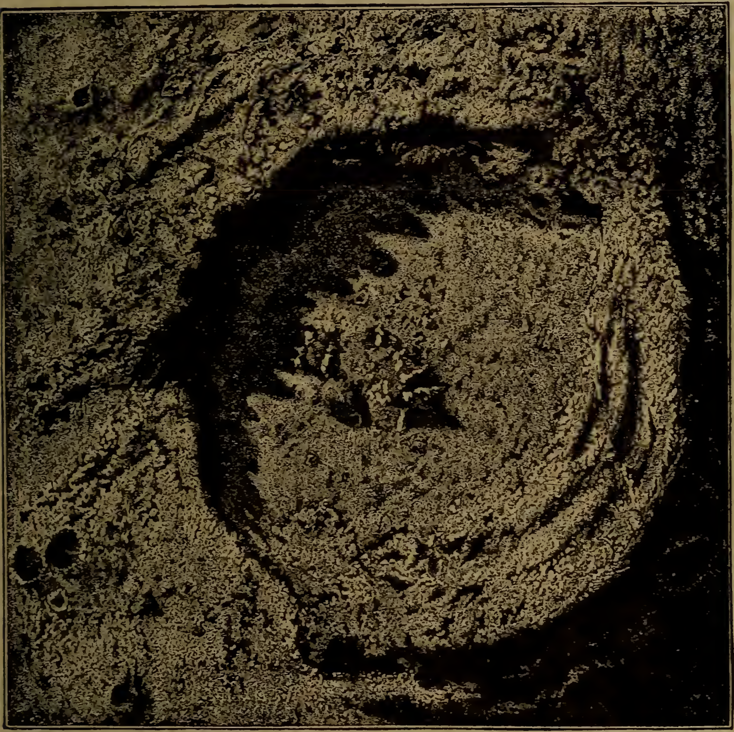

FIG. 32.—THE LUNAR MOUNTAIN, COPERNICUS.

128. *The Geography of the Moon.*—The dark patches on the moon's surface were formerly supposed to be

seas, and were accordingly named as the different seas on the earth are named; and, although it is now known that there is no water on the moon (Art. 130), they are still called seas. They seem to be great plains, like our prairies. The moon's surface is very mountainous. By measuring the length of their shadows the height of many of these mountains has been calculated. Some of them are over 25,000 feet high, nearly or quite as high as any upon the earth, although the moon is so much smaller than the earth. The larger mountains have been named after eminent scientific men.

129. *The Crater Mountains* are the most curious feature of the moon. They are saucer-like depressions surrounded by ring-mountains, and resemble the craters of our volcanoes, but many of them are on a much larger scale. Sharp peaks often rise from the middle of the craters, like the cones in our volcanic craters. Fig. 31 shows a part of the moon's surface covered with such craters of all sizes, while Fig. 32 shows a single one of the largest of these crater mountains. The diameter of this crater is about fifty miles. The bright rays running out from the mountains seem to be great cracks which have filled up with a whiter sort of rock.

The moon's surface has been carefully observed by astronomers, and very accurate maps of it have been drawn and published.[1] We undoubtedly have a much

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[1] The best map of the moon yet published is by two German astronomers, Beer and Maedler. It is two and a half feet in diameter. Dr. Schmidt, of Athens, Greece, has made one nearly eight feet in diameter; but no publisher has yet been willing to take the risk of publishing it.

better knowledge of the outline features of the side of the moon which we can see than of the great part of the earth's surface. Magnificent photographs[1] of the moon have also been taken, which picture with wonderful beauty and accuracy the moon's surface as seen through a telescope. Fig. 30 is from a photograph by Prof. Henry Draper.

130. *No Air or Water on the Moon.*—There is no reliable evidence of either air or water upon the moon. The moon in its monthly journey around the earth frequently passes between us and a star. If the moon had an atmosphere, the star's light would be *refracted* by it, just as it goes behind the edge of the moon. This refraction would displace the star slightly, just as refraction by our atmosphere does (Art. 105). But the most careful observations of these *occultations*,[2] as they are called, fail to show any such displacement. This does not prove that the moon is absolutely without atmosphere, but does prove that if there is any it must be very insignificant. Besides, if the moon had an atmosphere of any extent, we should expect it to make the moon's surface somewhat indistinct, and also to cause a twilight or sort of shading along the edge of the bright part of the moon. But nothing of the kind can be noticed. The inequalities of the moon's surface stand out with the utmost sharpness and distinct-

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[1] The best photographs of the moon yet taken are by Mr. Rutherford, of New York.

Mr. Henry Harrison, of New York, is publishing six very accurate and beautiful colored representations of the moon at different phases. The diameter of the moon is eighteen inches, and all the features are distinctly given. The colors are such as are seen in the telescope.

[2] Occulta′tion, from Latin *occultatio*, a hiding.

ness, and the terminator, the boundary-line between day and night, is perfectly defined, giving no evidence of a twilight. Observations with the spectroscope (p. 289) also prove that there is no considerable atmosphere on the moon.

If there were water upon the moon, it would evaporate and form an atmosphere of vapor as easily detected as one of air. The visionary idea has been advanced that the moon's centre of gravity is so much nearer the other side of the moon that all the air and water have run around to the opposite side, which we never see. But there is no evidence of anything of the kind. In all probability, the unseen side of the moon is very much like the side we do see.

131. *Is the Moon Inhabited?*—The absence of air and water at once answers this question in the negative. Besides, changes of heat and cold upon the moon must be so extreme as to destroy any sort of living beings that we know anything of. Two weeks of constant sunshine, unchecked by any atmosphere or the slightest cloud, must raise the temperature of the surface of the moon as high as that of boiling water. And during the two weeks of night it radiates this heat just as freely, until its temperature probably sinks two or three hundred degrees below zero. Lord Rosse[1] estimated that the change of temperature on the moon is more than 500° Fahrenheit.

132. *The Moon's Past and Present.*—The moon gives strong evidence of having been at one time molten. The great craters were probably formed then by the

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[1] An Irish nobleman, owner of the largest telescope in the world. See page 271.

bursting forth of great bubbles of gas from the interior. There is also clear evidence of volcanic action there in the past. But there is no trustworthy evidence that any such volcanic action has ever been seen by men. The moon's volcanoes have probably been long extinct. There has, indeed, been considerable evidence of change in the appearance of some small portions of the moon's surface in late years, but the matter is still in doubt. In order to account for the absence of air and water upon the moon, it has been suggested that, as the moon cooled off, the contraction in its interior caused great caverns there, which have swallowed up its atmosphere and oceans. The idea is ingenious and not improbable, but of course nothing is really known about it. Whether the moon ever contained life we cannot say, but it is now a dead, sterile mass of rock.

133. *The Occultation of Stars by the Moon.*—An occultation of a star by the moon is an interesting and at first a surprising sight. Small stars are frequently occulted, the larger ones and the planets more rarely. The moon's brightness overpowers the light of all but the small stars as they come to its edge, so that a telescope is needed to watch their occultation. If the star disappears at the dark edge of the moon, which is always the case if the occultation comes before full moon, the phenomenon is very striking. The star disappears suddenly and apparently without there being anything to cause its disappearance. Its reappearance on the other side is just as sudden. This proves that the stars have no apparent size whatever, but are mere points of light (Art. 204), and also furnishes a further proof of the absence of atmosphere or vapor on the moon, which would make it fainter just before its disappearance. An occul-

tation of one of the prominent planets is rather rare, and always attracts attention. As in the telescope these show disks of considerable size, they disappear gradually. Fig. 33 shows an occultation of Jupiter. All the occultations of stars bright enough to be seen by the naked eye are predicted every year in the Nautical Almanac,[1] for the use of observers. Students having the use of telescopes should be on the lookout for them.

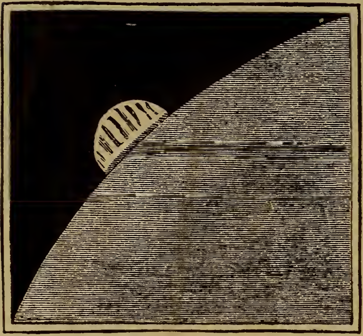
Fig. 33.—An Occultation of Jupiter.

134. *Light and Heat from the Moon.*—Several astronomers have tried to determine the amount of light shed by the moon. The results are generally expressed by comparing the moon's light with that of the sun. The latest and most reliable result is, that the sun gives 618,000 times as much light as the full moon. Chambers aptly says that "if the whole sky were covered with full moons they would scarcely make daylight."

Until recently, not the slightest heat from the moon could be detected. But by concentrating its heat with the largest telescopes, and using the most delicate apparatus, it has finally been detected and measured. It is found that the moon's heat would raise the mercury in a thermometer only about $\frac{1}{5000}$ of a degree Fahrenheit.[2]

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[1] See foot-note on page 169.

[2] So slight a rise in temperature could not be noticed in any thermometer, even if the moon's heat were concentrated upon it by the largest telescope in the world. The *Thermo-electric Pile*, by which

So that, while the moon's light is a great advantage to us, its heat does nothing to warm us.

135. *The Moon and the Weather.*—It is very commonly believed that the moon exercises great influence upon the weather. This is a mere superstition. No good reason for this supposed influence has ever been given, and accurate records of the weather kept for many years show that not the least reliance can be placed upon the moon's "weather signs." It is true that various scientific men have attempted to prove that there is on the average a slight difference in the rainfall at different phases of the moon. But, unfortunately, they seem to come to directly opposite about as often as to the same conclusions; and the greatest difference thus claimed by any of them is so slight that ordinary observation would never notice it at all. So that we may fairly conclude that any such differences in the amount of rainfall at different ages of the moon are simply accidental, and will, as likely as not, be reversed during the next period of equal length.[1]

The best-supported of these theories is that the heat of the full moon does something to clear away clouds. If the moon has any such effect,—which is doubtful,—it must be inconsiderable. The notion that the signs of the moon in which they were planted influence the

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the slightest heat starts a current of electricity, was used in the experiments.

[1] Mr. Vennor's repeated conspicuous failures recently in his weather prophecies should convince people of the absolute impossibility in the present state of science of foretelling the weather for any particular day more than a day or two in advance.

It is scarcely necessary to remark that the weather prognostications so often to be found in our common almanacs have not the slightest value.

growing of the crops is still extremely prevalent, especially among farmers. This is still more absurd than the belief in the moon's influence upon the weather. There is nothing in reason or in facts to warrant any such beliefs. They are as foolish, if not so hurtful, as was our forefathers' belief in witches.

136. *Appearance of the Earth from the Moon.*—From the moon the earth would seem to be a splendid large moon, having nearly four times the diameter and thirteen times the surface of our moon. The earth would go through its phases just as the moon does for us, but these phases would be exactly opposite to those of the moon. When the moon is *new* the earth would be *full*, and while the moon increases from new to full the earth would decrease from full to new.

Every one has noticed that when the moon is only a few days old the dark part is faintly lighted up, and the whole moon can be distinctly seen. This is often called "the old moon in the new moon's arms." It is simply the *earth-shine* lighting up the moon's surface, or, as it might fairly be called, moonlight on the moon. It can be seen as well before as after new moon.[1]

Since the same side of the moon is always turned towards us, the earth to an observer on the moon would never rise or set. At any one place on the moon it would always be seen in the same place in the sky,[2]

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[1] Why should it be seen about the time of new moon?

[2] Although the earth would stay at about the same place in the sky, it would not stay at the same place among the stars. They would rise and set as they do for us, but would take two weeks instead of twelve hours to pass from east over to west.

Because there is no atmosphere to reflect the sun's rays everywhere, and thus overpower their light, the stars could be seen upon the moon day and night, and the sky itself would always be intensely black.

subject only to slight oscillations from the librations. And there it would go through all its phases, growing from new to full and waning back to new again. To an observer about the middle of our side of the moon the earth would be always overhead. To one near the edge it would always be on the horizon, while on the opposite side it would never be seen.

Notwithstanding its size, it is not likely that the features of the earth's surface could be distinctly seen from the moon. Our atmosphere, by reflecting the sun's light, and by obstructing the light coming through it from the earth, would always produce an indistinctness, and clouds would of course completely hide everything beneath them. It is probable that the earth is a better reflector of light than the moon, and would therefore be more brilliant as well as larger than the moon.

# CHAPTER VI.

## ECLIPSES.

137. *Causes of Eclipses.*—The moon is eclipsed by passing into the earth's shadow. As the moon shines by reflecting sunlight, and the earth then cuts off this sunlight, the moon is of course darkened. When this occurs, the moon must be on the opposite side of the earth from the sun: so that an eclipse of the moon can occur only at full moon. The sun is eclipsed when the moon passes directly between the sun and the earth. The sun and the moon must then be on the same side of the earth. An eclipse of the sun, therefore, can occur only at new moon.

138. *Why Eclipses do not occur at every New and Full Moon.*—If the moon's orbit were in the plane of the earth's orbit, as it seems to be in Fig. 34, we should have an eclipse of the sun at every new moon, for it would always pass then between the earth and the sun, and at every full moon we should have an eclipse of the moon. But the moon's orbit is inclined to the earth's orbit at a small angle (about 5°). It is just as if one were to take hold of the moon's orbit at O (Fig. 34) and lift that side of it up a little way, letting it swing about an axis from A to B. The side T would be as far below the page as O is above it. The page on which the rest of the figure still lies represents the plane of the ecliptic or earth's orbit. The points A

and B would be the moon's *nodes* (Art. 32). Because of this inclination of its orbit, the moon in passing around the earth generally passes a little way above or below the sun and the earth's shadow, and so there is no eclipse.

139. *The Eclipse Seasons.*—When the earth is on or near the line along which the two orbits intersect, the axis AB about which we turned the moon's orbit in the last article, then one or more eclipses will occur. The earth in passing around its orbit must cross this line twice a year.[1] The eclipses, therefore, are all grouped together in two seasons, nearly six months apart. In 1882 the earth crosses the intersecting line (called the line of the moon's nodes) on May 20 and November 12. Owing to a change in the position of the moon's orbit, in 1883 the dates of crossing will be May 1 and October 25, and so on, coming about nineteen days earlier each year. Eclipses can occur only within seventeen or eighteen days of these dates, as the almanac will verify.

140. *Shadows cast by the Moon and the Earth.*—Because the sun is larger than the earth or the moon, the shadows cast by these bodies are *cones:* they taper off

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[1] A little thought will make this clear. The earth in Fig. 34 moves around the sun in a direction opposite to the motion of the hands of a watch, carrying the revolving moon along with it. The line between the earth and the sun will at first run *above* the *T* side of the moon's orbit. As we look at the figure, the new moon now passes *above* the line between the earth and the sun, and the full moon *under* the shadow, causing no eclipses. In about six months the earth is at the line of nodes again, and the eclipses occur. For the next six months the line between the sun and the earth is *below* the *O* side of the moon's orbit, and the new moon passes *under* and the *full moon* above, causing no eclipses as before.

to a point. The earth's shadow is of course larger and longer than the moon's. Fig. 34 shows parts of these shadows. To an observer in either of these shadows the sun is entirely hidden.

If one were between the earth's shadow and the line MC or ND, it is evident that the earth would hide a part of the sun. This space around the shadow is called the *penumbra*. The nearer one is to the edge of the shadow the greater is the part of the sun hidden, and the less light there is. The penumbra does not grow narrower and finally come to an end, like the shadow, but grows wider constantly. The moon's penumbra is also shown in the figure.

141. *Eclipses of the Moon.*—When the moon passes entirely into the earth's shadow, the eclipse is *total*. When only one side of the moon passes through the shadow, the eclipse is *partial*. Although the almanac gives the time when the moon enters the penumbra, yet the light shed upon it then is so little diminished that it cannot be noticed. There is no perceptible dimming of the moon until it almost reaches the shadow. When the moon enters the shadow, a notch seems to be cut out of the moon. This notch is always round, proving, as mentioned in Art. 63, that the shadow must be round, and therefore that the earth, which casts it, must be a sphere. In a partial eclipse this round notch grows larger and larger until the middle of the eclipse, then it grows less until it is over. In a total eclipse the shadow gradually covers the whole moon. When totally eclipsed, the moon can generally still be seen, shining with a faint reddish light. This is caused by the sun's rays being bent around the earth to the moon by the refraction of the earth's atmosphere (Art. 105).

The light which thus reaches the moon is red, because the moisture in the earth's atmosphere absorbs the other colors of the sunlight, but allows the red to pass through. The sun itself sometimes looks red when rising or setting, from the same cause. When only a small part of the moon is eclipsed, that part is generally entirely invisible to the eye, because the brightness of the rest overpowers its feeble light.

The magnitude of an eclipse is expressed by mentioning the fractional part of the moon's diameter which is covered by the shadow. If the magnitude is 1, the eclipse is just total; if more than 1, the moon is entirely within the shadow. The greatest possible duration of a total eclipse of the moon is about one and three-fourths hours.

142. *Eclipses of the Sun.*—When the moon passes between the sun and the earth, the sun is eclipsed.[1] At all places in the moon's shadow (see Fig. 34) the sun is wholly hidden, and the eclipse is *total.* In the penumbra the sun is partly hidden, and the eclipse is *partial.* The sun and the moon are apparently about the same size; but, as the distances of both from the earth vary somewhat (Arts. 70, 120), their apparent sizes vary a little. When the moon is nearest to us, and the sun farthest off, the moon will seem *larger* than the sun, and will entirely cover it. The moon's shadow then *reaches* the earth, as shown in the figure, and the eclipse is total. But if at the time of the eclipse the

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[1] It may not be amiss to remark that the darkness which followed the crucifixion of Christ could not have been caused by a solar eclipse, for the feast of the Passover, during which the crucifixion took place, was always held at *full moon.*

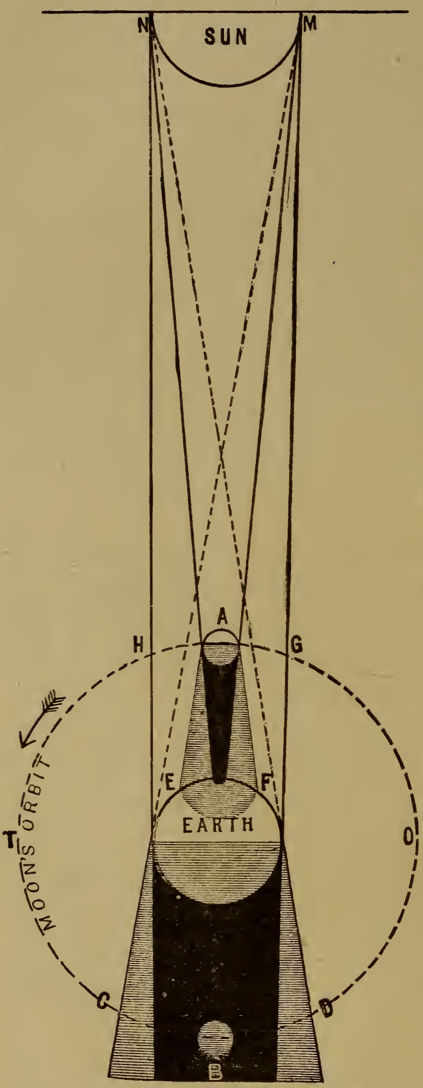

FIG. 34.—ECLIPSES OF THE SUN AND MOON.

sun is nearest to us, and the moon farthest off, the moon would seem *smaller* than the sun, and would not hide it all. The moon's shadow would *not reach* quite to the earth. In this case a ring of light would be seen around the edge of the sun. The eclipse is not total, but *annular*.[1]

143. *Total Eclipses of the Sun.*—The section of the moon's shadow which falls upon the earth is very narrow, never as much as 200 miles wide. And though two or more solar eclipses occur every year, yet a total eclipse of the sun is a very rare occurrence at any one place. The next one visible in the eastern United States will be in the year 1900. Par-

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[1] An′nular, from Latin *annulus*, a ring.

tial eclipses of the sun last two or three hours, but total eclipses only five or six minutes. Yet so wonderful is the sight, and so great are the opportunities then afforded of studying the sun, that astronomers travel thousands of miles to witness them. A total eclipse of the sun is one of the sublimest of phenomena. The crescent of sunlight becomes narrower and narrower, until presently the great shadow is seen rushing over the earth towards us with immense rapidity, and in an instant is upon us. The surface of the

Fig. 35.—A Total Eclipse of the Sun.

moon is as black as ink. At various places on its edge the red prominences stand out in fantastic shapes, great tongues of flame projecting many thousands of miles beyond the sun's chromosphere, from which they come. Surrounding this is the silvery corona, brilliant at the sun's edge, but fading out to imperceptibility. The darkness varies according to the duration of the eclipse and the clearness of the sky, but it is usually too great to allow ordinary print to be read. The brighter stars are visible. Animals seem to think that night has come. No wonder that uncivilized peoples have always feared eclipses of the sun. We cannot behold them without awe. Suddenly the light bursts forth, the great shadow flies away as fast as it came, and the most wonderful spectacle of the generation is over.

144. *Number of Eclipses.*—At every eclipse season there is certain to be one eclipse of the sun, and there may be two. Besides, the moving of the eclipse season backward nineteen days a year may throw a part of a third eclipse season into the year. The least number of solar eclipses that can occur in a year is two, and the greatest number is five.

The moon can be eclipsed only once at each eclipse season, and may not be eclipsed at all. The number of lunar eclipses in a year varies from none to three. The greatest possible number of eclipses in a year is seven, of which four or five are of the sun, and two or three of the moon. The least possible number is two, both of the sun. We may see from Fig. 34 why there are more eclipses of the sun than of the moon. The sun is eclipsed whenever the moon is partly or wholly between G and H, but, because the shadow tapers, the distance HG is greater than the width of the shadow at B; the moon will therefore oftener pass between the earth and the sun than it will pass through the earth's shadow.

145. *Why we see more Eclipses of the Moon than of the Sun.*—Although eclipses of the sun are about one and one-half times as numerous as those of the moon, yet at any one place on the earth lunar eclipses are more frequently seen. This is because the moon's shadow in a solar eclipse does not cover the whole earth, and the eclipse is seen only at those places which happen to be in the path of the shadow or penumbra. But in a lunar eclipse the moon's light is *put out*, and the eclipse is seen over all that half of the earth which is then turned towards the moon.

146. *Calculation and Prediction of Eclipses—The Saros.*—When and where eclipses will be seen can be calculated beforehand with great accuracy; but considerable knowledge of mathematics is required for this. They are always announced in our almanacs, and are frequently worked out many years in advance.

Long before eclipses could be calculated, men found by observation that they repeated themselves so exactly about every eighteen years[1] that they could by this means be predicted. This is because at the end of this time the sun, moon, and earth are in almost precisely the same positions as at the beginning, so that they again describe the same paths, and, with only an occasional exception, cause the same eclipses, as in the past eighteen years. This round of eclipses was called by the ancients the *Saros*. The discovery of the Saros is

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[1] More exactly, eighteen years and ten or eleven days, according as four or five leap-years are included.

credited to the Chaldeans,[1] who predicted eclipses by it hundreds of years before Christ.

147. *Eclipses as seen from the Moon.*—When we have an eclipse of the sun, an observer on the moon would see only a small, round, ill-defined shadow crossing the earth. It would be a partial eclipse of the earth (Fig. 34). The earth could never be totally eclipsed.

When we have a total eclipse of the moon, the sight from the moon would be a very strange one. The sun would be wholly behind the earth, and hence totally eclipsed, but his light would be so refracted by the earth's atmosphere that a dull red ring of light would surround the black earth.

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[1] Eclipses, especially total eclipses of the sun, were greatly dreaded by the ancients, and are still dreaded by uncivilized peoples. The Hindoos believe that in a solar eclipse some monster is trying to swallow the sun. At these times they all turn out with gongs and every possible noise-producing instrument, and keep up the loudest and most hideous noises until the frightened monster disgorges his fiery mouthful.

The foreknowledge of an eclipse of the moon was once of great service to Columbus, when, in 1504, he was wrecked off the coast of Jamaica. When neither threats nor persuasion would induce the natives to furnish him with food, he told them that their Great Spirit was displeased with them for their treatment of him, and that the moon would that night be darkened. When the eclipse came, the Indians were convinced that Columbus had told the truth, and hastened to bring supplies for himself and his crew, beseeching him to pray that the Great Spirit might receive them again into his favor.

# CHAPTER VII.

## THE SUPERIOR PLANETS.

### MARS. ♂

**Distance from the Sun, 142,000,000 Miles. Diameter, 5000 Miles. Length of Year, 2 Years.[1] Length of Day, 24½ Hours. Specific Gravity, 4. Two Satellites.**

148. *Relations to the Solar System.*—Next outside of the earth's orbit comes Mars,[2] the last of the group of four smaller planets to which the earth belongs. Except Venus, Mars is the nearest of all the planets to us; and next to Mercury, it is the smallest of the principal planets. Its surface is but little more than one-fourth, and its mass about one-seventh, of those of the earth. One would there receive less than one-half the light and heat that he receives upon the earth.

149. *Motions and Phases.*—Unlike Mercury and Venus, Mars in its revolution around the sun passes entirely around the earth. Its motion among the stars is generally direct, or eastward, but when near opposition, as explained in Art. 24, it seems to us to move westward. Being an outside planet, Mars is never seen as a crescent, but when 90° from the sun the telescope

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[1] These tabular statements are given in *round numbers* for convenience in remembering them. For the exact data, see Art. 27.

[2] Mars was the god of war. The symbol of the planet (♂) represents his shield and spear.

shows it to be decidedly *gibbous.* It is then of about the same shape as the moon three days before or after being full.[1] At opposition Mars is nearest to the earth, and of course brightest. The oppositions occur every twenty-five or twenty-six months. The average distance of Mars from the earth at opposition is less than fifty millions of miles, but if the opposition should occur when Mars is *nearest* to the sun and the earth is *farthest* from the sun, their distance apart would be only thirty-four millions of miles.

150. *Description of Mars.*—To the naked eye the most noticeable feature about Mars is his fiery-red color: he is the reddest of all the heavenly bodies. Although he does not come so near to us as Venus, yet Mars is in a better position for observation than any of the rest of the planets except our own, because at opposition, when he is nearest to us, the whole of his bright surface is turned towards us, while when Venus is nearest to us her dark side is towards us. The moon alone, of all the heavenly bodies, is better situated in this respect. Indeed, we are not certain that the real surface of any of the rest of the planets has *ever* been seen. In a large telescope patches of different colors are seen upon the surface of Mars which bear a strong resemblance to land and water. The parts supposed to be seas have a greenish hue, like our seas, while the parts which have been taken to be land are red, which has been ascribed to the color of the soil and rocks, perhaps like our red sandstone. The red parts overpower the green, and give their color to the planet. Maps and globes of Mars have been made,

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[1] Can there be a *transit* of Mars?

upon which these supposed continents and seas are drawn and named, the names given them being those of various famous astronomers. Unlike the earth, Mars seems to have more land than water, and the seas there are long and narrow. But the most striking features of Mars's surface are two brilliant white spots near his poles. They are probably ice and snow, such as are found about the poles of the earth. And they seem to decrease when in summer they are turned towards the sun, and to increase again when turned from the sun in winter, just as the ice and snow about the earth's poles do. Besides these resemblances to the earth, Mars has seasons like ours. His equator makes a somewhat larger angle with his orbit than the angle between our equator and the ecliptic. And his orbit is more eccentric than the earth's, so that the difference between his summer and winter distances from the sun is greater. These two causes make the changes of seasons, then, greater than upon the earth. The markings upon the surface of Mars have enabled us to determine the time of his rotation with great exactness. It is a little more than twenty-four and one-half hours.

FIG. 36.—A TELESCOPIC VIEW OF MARS.

151. *The Satellites of Mars.*—Before 1877, Mars was not known to have any satellites. At the opposition which occurred that year the planet came very near the earth, and gave an unusually good opportunity of observing him. At that time Prof. Hall[1] began to search carefully for satellites of Mars with the great twenty-six-inch telescope in the Naval Observatory at Washington. In August of that year he found two satellites. These satellites are very small and very close to the planet. They are too small to be measured, but, estimating their size from the amount of light they reflect, Prof. Pickering[2] concludes that the diameter of the inner is about *seven*, and of the outer one about *six*, *miles*. The outer one is about 12,000 miles from the surface of Mars, while the inner one is not quite 4000. But the most remarkable fact about the satellites is that the inner one revolves about Mars in about seven and one-half hours, *less than one-third of the time that it takes Mars to turn on his axis.* This causes the inner satellite to *rise in the west* and *set in the east.*[3] To an observer on Mars it would seem to revolve around his planet from west to east *twice every day*,[4] all the while going through its changes from new to full and back to new again every

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[1] Prof. Asaph Hall, attached to the United States navy, and in charge of the great twenty-six-inch telescope at Washington.

[2] Prof. E. C. Pickering, Director of the Harvard College Observatory, Cambridge, Massachusetts.

[3] Since the inner satellite revolves around Mars from west to east *faster* than the planet itself turns in that direction, it must rise in the west and set in the east.

[4] Since the planet turns *once* in its daily motion while the satellite revolves about it *three* times, and both in the same direction, the satellite would *seem to an observer on Mars* to revolve about his planet only twice a day.

seven or eight hours. As the outer moon rises in the east and sets in the west, like ours, the two moons *meet* each other in the sky. The discovery of the moons of Mars is justly regarded as one of the greatest in recent astronomy.

152. *Observation of Mars.*—Although so interesting an object to the possessor of a large telescope, for the owners of small telescopes Mars has little interest. Small instruments show none of the markings on the planet distinctly, if at all; and he has very little change of phase such as makes Mercury and Venus interesting. As has been said, Mars is much brighter at opposition than at other times. The following are the times of the next two oppositions: January 31, 1884, and March 6, 1886. About these times Mars's brilliancy and redness will make him an interesting object to the naked eye; nor will a small telescope add much, if any, interest to him. Like all heavenly bodies when in opposition, Mars will then rise about the time the sun sets, and shine all night. This fact, together with his fiery redness, will make it easy to distinguish him. Every fifteen or seventeen years Mars comes especially near to the earth at opposition. His brilliancy then almost rivals that of Venus and Jupiter. The last of these near approaches was in 1877, when the satellites were discovered. The next will occur in 1892. The satellites of Mars can be seen only in first-class telescopes,[1]

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[1] The foolish statement that Mars's moons can be seen by looking at the planet in a common looking-glass is sometimes heard, and even seen in the newspapers. The points of light which are seen in the looking-glass beside the image of Mars are faint reflections of the planet's light from the inner and outer surfaces of the *glass*, while the main reflection is from the quicksilver behind the glass. Any of the

and then for but a few months about the time of the planet's opposition. No telescope in the world will show them when Mars is in the farther part of his orbit.

## THE MINOR PLANETS.

**Distance from the Sun, 200,000,000 to 325,000,000 Miles. Diameters, from about 300 Miles down. Lengths of Years, 3 to 7 Years. Lengths of Days and Specific Gravities unknown. Number discovered up to April, 1882, 223.**

153. *Relations to the Solar System.*—Between the inner group of four small planets and the outer group of four large ones is a wide gap, in which hundreds of very small planets are revolving about the sun. These are called *Planetoids*, or, better, *Minor Planets.*[1] Their number is unknown, and may be very great; but the mass of all of them put together is much less than that of the smallest of the principal planets. The orbits of these planets are much more elliptical than those of the larger ones; some of them are twice as far from the sun at aphelion as at perihelion. And while the orbits of the principal planets all make *small* angles with the ecliptic, the orbits of some of the minor planets make *large* angles with it. Their distances from the sun vary greatly. Some of them almost intersect the orbit of Mars, others swing out nearly as far as Jupiter's orbit, while the whole space

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bright stars, and even the moon, will show such "moons" in a looking-glass. But if a piece of polished metal be used as a mirror, they will disappear from Mars as well as from the rest.

[1] Also often called *asteroids* (star-like), but the term is gradually giving way to the more appropriate one of *minor planets*.

between is filled with them. But their orbits are so entangled that, if they were actual rings, scarcely one of them could be picked up without disturbing all the rest.

154. *The Discovery of the Minor Planets.*—The gap between Mars and the outer group of planets was long since noticed by astronomers. Besides, a law, known as Bode's law,[1] had been devised, which, if this gap were only filled by a planet in its proper place, expressed quite accurately the relative distances of the known planets from the sun. These facts led astronomers, about the beginning of this century, to make careful search for the missing planet. Twenty-four astronomers divided the zodiac[2] into as many parts, and began the search. But on the first day of the present century,[3] before they got fairly started, an Ital-

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[1] If the series 0, 3, 6, 12, 24, 48, 96, etc., be formed by doubling each term *after the first* to get the next one, and then 4 be added to each term, we shall have 4, 7, 10, 16, 28, 52, 100, etc. If we multiply each of the first four of these numbers by 9,000,000, we shall have pretty nearly the distances of the inner group of planets from the sun. Fifty-two multiplied by the same number gives about the distance of Jupiter, the first of the outside group, while 28 times 9,000,000 was supposed to be the distance of the undiscovered planet. This is called Bode's law, after a celebrated German astronomer who died in 1826, but it was devised long before his time by Titius. The law held good for all the principal planets until the discovery of Neptune, the outermost of the outside group, in 1846, for which it was found to fail. These coincidences are now believed to be merely accidental.

[2] It will be remembered that the zodiac is a belt of the sky extending about 8° on each side of the equator, in which all the principal planets are always found. It was therefore very natural that they should examine the zodiac for the new planet. But the minor planets, as we now know, are not all within the zodiac.

[3] What day was this? See page 14, note 3.

ian astronomer, an outsider, discovered a small planet in the vacant space. In seven years three more were found, but after that no more until 1845. Since that time a large number have been found, and sometimes ten or twelve are discovered in a year. The number already known is 223.

The discovery of these planets is a difficult task. None that are now discovered can be seen with the naked eye, and in the best telescopes they look exactly like very small stars, from which they can be distinguished only by their motions among the stars. Among the astronomers who have occupied themselves largely with this work, two Americans, Profs. Peters[1] and Watson,[2] and Palisa, an Austrian, have been most successful. The new planets whose discovery we see occasionally announced in the newspapers are always some of these.

The first minor planets found were named after various goddesses, and this custom is still adhered to. But their great number has made it very difficult to find enough such names for them, so that many of those lately discovered have not yet been named. They are usually designated simply by numbers, which show the order of their discovery, the numbers being enclosed in circles, thus: ㉑, ㊹, (219).

155. *Description of the Minor Planets.*—As has been said, these planets are very small. Two or three of them may rarely and under the most favorable circumstances be seen by the naked eye, but only as very faint stars. Many of them can be seen only through good

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[1] C. H. F. Peters, 1813—, Professor of Astronomy at Hamilton College, Clinton, New York.

[2] See page 64, note 3.

telescopes. None of them have any apparent size even in the largest telescopes, so that their size can be estimated only from the amount of light they give. The largest of them may be three hundred miles in diameter, while the smallest yet discovered is probably not more than fifteen miles in diameter. On these planets the attraction of gravity is slight, and one would therefore weigh much less than upon the earth. Sir John Herschel remarks that "a man placed upon one of the minor planets would spring with ease sixty feet, and sustain in his descent no greater shock than he does on the earth from leaping a yard." Of their rotation, surface, atmosphere, etc., we know nothing. Their appearance presents no features of interest in any telescope.

156. *Are the Minor Planets Fragments of one Large Planet?*—When the first two or three of these planets had been found, it was suggested that they might be fragments of a larger planet which had from some cause burst to pieces. The theory at first seemed probable, but it has been long since rejected by astronomers. So far as we can tell, they have been revolving about the sun ever since the solar system was created.[1]

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[1] And yet the facts of their revolving about the sun all in a ring together, and of having their orbits so entwined, seem to indicate some connection between them originally. Perhaps we might regard them as a group of great meteoroids revolving about the sun, just as many groups of small meteoroids (shooting-stars) are now known to be revolving about the sun (Art. 197), and just as Saturn's rings are probably dense groups of small meteoroids revolving about him (Art. 169).

## JUPITER. ♃

**Distance from the Sun, 480,000,000 Miles. Diameter, 90,000 Miles. Length of Year, 12 Years. Length of Day, 10 Hours. Specific Gravity, 1⅓. Four Satellites.**

157. *Jupiter's Relations to the Solar System.*—The first of the outside group of four planets is Jupiter.[1] He is the largest of all the planets, his volume[2] being one and a half and his mass[2] two and a half times as great as that of all the other planets put together. Compared with Jupiter, our earth is insignificant. It would take about 1400 earths to make a planet as large as Jupiter, although 300 earths would make one as heavy as he, for Jupiter's specific gravity is less than one-fourth of the earth's. Yet his volume and mass are only $\frac{1}{1000}$ of those of the sun. At his great distance, one would receive from the sun only about $\frac{1}{25}$ as much heat and light as upon the earth. If he depends solely upon the sun for heat, the temperature of his surface must be nearly 500° below zero. Notwithstanding his great size, Jupiter's day is not half as long as ours. His year is as long as twelve of ours, but, as his equator makes an angle of only 3° with his orbit,[3] he has no changes of seasons of any consequence.

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[1] Ju′pĭ-ter, the chief of the gods. His symbol (♃) is perhaps a rude representation of an eagle, the bird of Jupiter.

[2] The student must be careful to have a very clear notion of what these mean. *Volume* is *size* or *bulk;* it varies according to the *cube* of the diameter. *Mass* is *quantity of matter;* it varies according to the *weight.* Then if all of the planets could be weighed at the same place (at the sun, for instance), Jupiter would weigh two and a half times as much as all of the rest together.

[3] How many degrees wide is Jupiter's torrid zone? his frigid and temperate zones?

158. *Jupiter's Motions and Phases.*—Jupiter is so far off that he shows no phases to the ordinary observer. His disk in the telescope is always *full.* But the great velocity of his rotation upon his axis makes him noticeably flattened at the poles. Like Mars and all the other superior planets, Jupiter has a retrograde motion among the stars when he is at opposition. But, as this occurs only once in twelve years, his motion is usually eastward.

FIG. 37.—JUPITER, AS SEEN IN THE TELESCOPE OF HAVERFORD COLLEGE OBSERVATORY (INVERTED), JANUARY 7, 1882; SHOWING THE SHADOW OF A SATELLITE ON ITS DISK, ANOTHER SATELLITE JUST EMERGING FROM IN FRONT, AND THE OVAL "RED SPOT."

159. *Jupiter's Belts.*—When seen through a telescope, the most conspicuous feature of Jupiter is his *belts.* These are dark bands or streaks stretching across the planet. Usually there are two conspicuous ones, just above and below the planet's equator. But others are often seen, sometimes covering the greater part of his surface. They are well shown in Fig. 37. Sir William Herschel[1] thought that the belts were openings in the planet's atmosphere, through which we can see the darker surface of the planet itself. Jupiter is certainly surrounded by an atmosphere, but so dense and deep is it that it is probable that we never see the planet's surface. The belts seem to be fissures in the upper clouds and atmosphere, through which we see the lower strata of atmosphere and clouds, which are darker because they reflect less sunlight. In small telescopes the belts are simply dark, but in better instruments they often display colors. This color is usually a dull red, but occasionally varied and more brilliant ones have been seen. The cause of these colors and their changes is not known.

160. *Spots on Jupiter.*—Besides the ever-present belts, *spots* are also sometimes seen upon Jupiter's surface. They are commonly dark or of a dull-red color, but bright white ones have been seen. The dark ones may be openings in the upper atmosphere, while the white ones look somewhat like the round masses of white cloud which are so common here in summer. Some of these spots have remained visible for a considerable time, and it is by observations of these that the period

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[1] Born 1738, died 1822. A German by birth, but spent all of his manhood in England. Generally conceded to be the greatest practical astronomer that has yet lived.

of the planet's rotation has been determined. The various observations show that these spots have some motion of their own, so that it is not possible to determine the period of Jupiter's rotation as exactly as that of Mars. A very large spot, known as "the red spot," which appeared in 1878, still remains [1882] of about the same shape and size. It is in the southern hemisphere of the planet, rather oval in shape, about 24,000 miles long, and of a dull-red color. It appears to be quite permanent, though showing some changes of outline, and probably of color and intensity. Astronomers are watching it with much interest.[1]

161. *Jupiter's Temperature.*—There is strong evidence that Jupiter is still very hot. The sun's rays are too feeble there to raise the thick clouds which constantly envelop him, and the great changes continually going on in his atmosphere must be caused by intense heat within. The earth shows plainly that it was once in a molten state, and if it was created at the same time as Jupiter, the great mass of the latter would keep him hot long after the earth had cooled off. If the body of the planet has yet solidified, it is still probably white-hot. So that Jupiter is more like the sun than like the earth. And indeed there is evidence that he actually gives out some *light* of his own, even through his dense cloudy atmosphere. The amount of this, however, cannot be great: the most of his light is reflected sunlight.

162. *Jupiter's Satellites.*—Among the first objects which Galileo's little telescope revealed to him were

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[1] As determined by observations on this spot, Jupiter rotates in about 9 h. 55 m. 35 sec.

four moons revolving around Jupiter. They are almost bright enough to be seen by the naked eye, and indeed they have on rare occasions been thus seen by persons

FIG. 38.—JUPITER AND HIS SATELLITES.

having exceptionally good eyesight. Were it not for the overpowering brightness of Jupiter, they would be usually visible. The satellites are known by their numbers, the one nearest the planet being called the *first*,[1] the next one the *second*,[1] and so on. The nearest one is a little farther from Jupiter than the moon is from the earth, the fourth is more than a million miles off. The second is the smallest, and is about the size of our moon; the third, which is the largest, is about 3700 miles in diameter, being considerably larger than Mercury. They all revolve about Jupiter in the same direction that the planets revolve about the sun, from west to east. The first makes his revolution in $1\frac{3}{4}$ days, the fourth in less than 17 days. Their orbits are all nearly circular, and lie almost in the plane of Jupiter's orbit. On this account they

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[1] They are generally designated by the Roman numerals, I., II., III., IV.

are never far out of a straight line passing through Jupiter (Fig. 38).

163. *Eclipses and other Phenomena of Jupiter's Satellites.*—Jupiter's moons, like our own, are eclipsed, but, owing to the size of the planet's shadow and the coincidence of their orbits with the plane of Jupiter's orbit, they are eclipsed much oftener than our moon. The three inner satellites are eclipsed at every revolution, and the outer one generally is. In Fig. 39 the satellite is eclipsed while passing from 1 to 2. It is then entirely invisible, which proves that if Jupiter emits any light of his own it must be very little. From 3 to 4 the satellite is again invisible, because it is behind the planet. This is an *occultation* of the satellite. 1 and 3 are the points of *disappearance*, 2 and 4 of *reappearance*. The orbit of the first satellite in the figure shows that the occultation may begin before the eclipse ends. On the opposite side of its orbit, from 5 to 6, the satellite is between the sun and Jupiter, and partly eclipses the planet. The shadow of the satellite, a small round black spot, is seen crossing Jupiter's disk. From 7 to 8 the satellite transits across the planet, and in a good

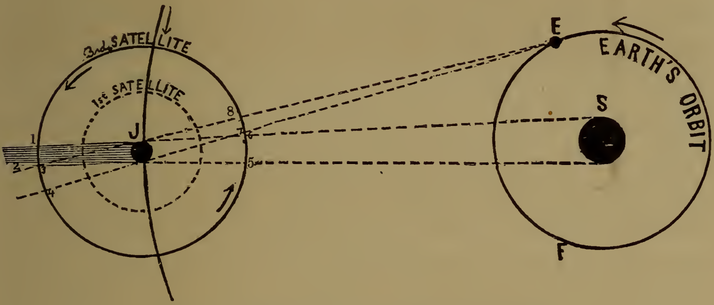

FIG. 39.—PHENOMENA OF JUPITER'S SATELLITES.

telescope may be seen, being sometimes a little brighter and at other times a little darker than the surface of the planet behind it. Sometimes the satellite and its shadow will be seen upon Jupiter at the same time, as the orbit of the first satellite in the figure shows. The passing of the satellite or shadow *on* the edge of the planet is called *ingress;* the passing off, *egress.*

It was by observations of Jupiter's satellites that the velocity of light was first found. See Art. 239.

164. *Observations of Jupiter.*—Next to Venus, Jupiter is the brightest of the planets, and of course far brighter than any of the fixed stars. But while Venus, being an inferior planet, is never seen far from the sun, and never at a late hour of the night, Jupiter, being a superior planet, may be at any distance from the sun, and may shine all night. These facts, together with the information given about the times when it is an evening and when a morning star, will usually enable one to recognize Jupiter. And when once found, one may keep track of him from year to year, for, on account of the great length of his orbit, he moves but slowly among the stars. As he takes twelve years to journey around the sun, he moves through one constellation in the zodiac each year. Although Jupiter is always bright, and can always be observed with interest, except when too near the sun, yet it is of course brightest and best seen when in opposition. In 1881 this occurred on November 13, in 1882, it will occur on December 18, and so on, coming a little more than a month later each year. As at these times the planet rises about sunset and shines all night, Jupiter for several years now will be an evening star in winter and a morning star in summer. Through even a very

small telescope Jupiter is interesting, and his moons may be seen through a small spy-glass or a common opera-glass. They look like small stars, and will be easily distinguished by their being about in a straight line with the planet. Generally one or two will be on one side, and the others on the other; rarely all four will be seen on one side, and sometimes one or two may be invisible from being eclipsed or in occultation. Under favorable circumstances (see p. 278), a two-inch telescope will show the principal belts of Jupiter, and in larger instruments the other belts and spots may be seen. Great activity is now manifest upon Jupiter, and all who can do so should watch it, observing the period of rotation from the spots, noting the colors and any changes or peculiarities, and making maps of its surface. While the present or any future spot is upon Jupiter, those having suitable instruments ought to note the times of the passage of the spot over the planet's central meridian for as long a time as possible, to determine the period of the planet's rotation. In all astronomical observations the time must be carefully noted.

165. *Observations of Jupiter's Satellites.*—For telescopes of moderate size the most interesting observations of Jupiter are those upon the phenomena of his satellites. All of the phenomena described in Art. 163 are predicted in the Nautical Almanac,[1] and may be

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[1] The Nautical Almanac is published by the United States government at Washington, D.C., for each year, and comes out about three years in advance. It is indispensable to the navigator and the astronomer. It may be obtained by sending one dollar to the Bureau of Navigation, Washington, D.C.

The following data are taken from page 474 of the Almanac for observed at the times given there.[1] The Nautical Almanac also gives figures showing the positions of the satellites for every day in the year, by which the different satellites can be distinguished. For the *apparent* order of the distances of the satellites from the planet may not be the *real* order of their distances. If Satellite IV. were almost in front of or behind Jupiter, it might appear to be the nearest of all. Satellite III. may generally be distinguished by its size.

When a transit or occultation is to be observed, everything should be ready at least five minutes before the predicted time; and the error of the watch which is to be used for taking the time must be known. In an eclipse, the times of the first diminution of brightness

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1882. They give the times of the phenomena about the period of Jupiter's opposition in 1882.

DECEMBER, 1882.

| Date. | | | | No. of Satellite. | Phenomenon. | Phase. |
|---|---|---|---|---|---|---|
| *d.* | *h.* | *m.* | *s.* | | | |
| 16 | 4 | 25 | 33.4 | III. | Eclipse. | Disappearance. |
| | 6 | 27 | 29.4 | III. | Eclipse. | Reappearance. |
| | 7 | 23 | | III. | Occultation. | Disappearance. |
| | 8 | 42 | | II. | Shadow. | Ingress. |
| | 9 | 46 | | III. | Occultation. | Reappearance. |
| | 10 | 17 | | II. | Transit. | Ingress. |
| | 11 | 5 | 28.0 | I. | Eclipse. | Disappearance. |
| | 11 | 24 | | II. | Shadow. | Egress. |
| | 12 | 59 | | II. | Transit. | Egress. |
| | 14 | 4 | | I. | Occultation. | Reappearance. |
| 17 | 8 | 15 | | I. | Shadow. | Ingress. |
| | 9 | 2 | | I. | Transit. | Ingress. |
| | 10 | 29 | | I. | Shadow. | Egress. |
| | 11 | 17 | | I. | Transit. | Egress. |

("Shadow," in the third column, means the transit of the satellite's shadow across Jupiter's disk.)

[1] The dates in the Almanac are in *Washington astronomical time.* These must be reduced to solar time (see Art. 89), and then the corresponding *local* time found, as in Art. 102. The dates given may be one or two minutes in error.

and of final disappearance should be noted. At reappearance the order will be reversed, the times of first reappearance and of complete restoration of brightness being noted. Two persons can take time better than one: while one observes, the other can consult the watch. In occultations the time of first contact, that is, when the satellite first touches the edge of the planet, and that of last contact, when the last part of the satellite disappears behind the planet, should be noted if the telescope is large enough to show them. The transits of the satellites and the shadows are more interesting, but require rather better telescopes. To see them well, a four-inch glass is needed. The transit of the shadow is seen more easily than that of the satellite, although the times of ingress and egress are harder to determine than those of the satellite. Sometimes a satellite and its shadow may be seen upon the planet at the same time. The first and last contacts in a satellite's transit, like those of the occultation, should be noted. If the state of the atmosphere is such that the exact times cannot be determined, they may be carefully estimated. Records of all observations, with notes upon the state of the atmosphere and the reliability of the observations, should be kept.[1]

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[1] Fig. 40 shows that when the earth is at E the eclipses come *before* the occultations, and the transits of the *shadows before* the transits of the *satellites*. When the earth is in this part of its orbit, Jupiter rises *more* than twelve hours after the sun, and therefore in general *rises in the night*. But when the earth is at F in the figure, the occultations and transits of satellites come first. And when the earth is in this part of its orbit, Jupiter rises *less* than twelve hours after the sun, or in general in the daytime. The following approximately correct rule may be derived from these facts: If Jupiter rises in the night, the eclipses will precede the occultations, and the shadows will

In ordinary telescopes the satellites will be simply points of light like the stars. In large instruments their disks can be seen, and some curious and unexplained changes in their appearance have been observed.

Observations of the eclipses of Jupiter's satellites are sometimes used to determine the difference of longitude between two places (Art. 102); but the *gradual* disappearance of the satellites as they pass into the shadow makes the determination of the exact time of the eclipse so uncertain that this method is not very often used.

## SATURN. ♄

**Distance from the Sun, 890,000,000 Miles. Diameter, 73,000 Miles. Length of Year, 30 Years. Length of Day, 10 Hours. Specific Gravity, ¾. Eight Satellites.**

166. *Relations to the Solar System.* — Next beyond Jupiter, but almost twice as far from the sun, is Saturn.[1] Next to Jupiter he is the largest of the planets. His volume is 700 times that of the earth. But his mass is only about 100 times as great, which shows that Saturn must be made of very light material. His specific gravity is the least of all the planets, and he is only three-fourths as heavy as a globe of water of his size. He would float in water. What has been found to be true of the densities of Jupiter and Saturn is also

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cross the planet ahead of the satellites; but if Jupiter rises in the daytime, in which case it will be found up some distance in the sky in the evening, the occultations and transits of the satellites will come first.

[1] Sat′urn, the god of time, father of Jupiter. His symbol (♄) represents an old-fashioned scythe or sickle.

true of the other two outside planets. None of them differ much from water in density; all are much lighter than the four inner planets. But in all of these we see

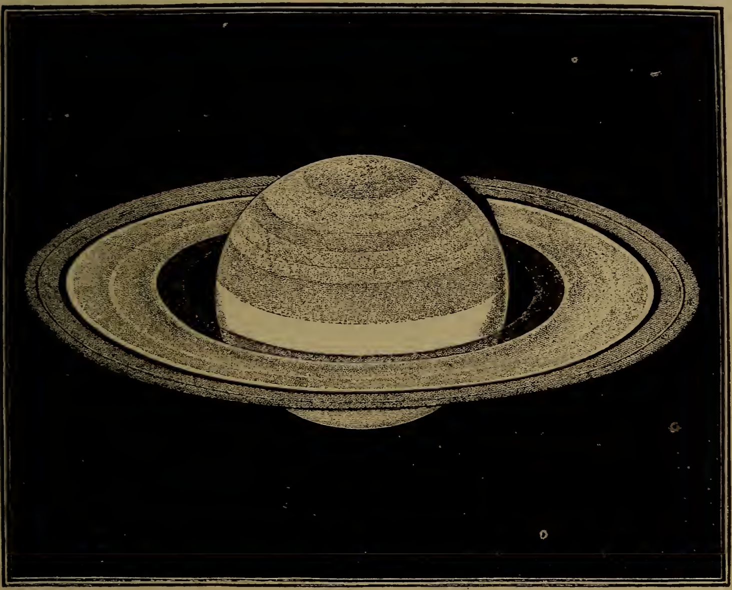

FIG. 40.—SATURN.

and measure the outside of their *atmospheres*, so that what we give as the specific gravity of the planet is really the average specific gravity of the planet and its atmosphere taken together. If the atmosphere is deep, the real body of the planet is smaller and denser. The size and density of the real planet we cannot determine, because it cannot be seen through the atmosphere. Since Saturn is nearly twice as far from the sun as Jupiter, one would there receive only about one-fourth as much light and heat from the sun as upon Jupiter.

167. *Description of Saturn.*—Saturn's enormous dis-

tance from us makes it impossible for us to see much of his surface. But, so far as we can tell, the body of the planet is very much like Jupiter. He has faint belts, and probably he has not yet cooled off into a solid body like the earth, and is surrounded by a dense atmosphere and clouds. Spots have rarely been seen upon his surface, and when seen have been used to determine the time of his rotation upon his axis. He is even more flattened at the poles than Jupiter.

168. *Saturn's Rings.*—The most remarkable feature about Saturn, and one possessed by no other body in the solar system, is a set of enormous rings surrounding him. Fig. 40 well represents these remarkable rings, and also the planet itself. Through a small telescope one bright ring is seen, but a larger instrument shows that this ring is divided into two, one within the other. The inner ring is the wider of the two. In 1850, Prof. Bond[1] discovered a very faint third ring inside of the others, a continuation of the inner bright ring; it is commonly called the *dusky ring.* The diameter of the rings from outside to outside is about 170,000 miles, and the two bright rings together are some 30,000 miles wide.[2] The dusky ring extends about half-way from the inner bright ring to the body of the planet (shown in Fig. 40). The rings are very thin, probably not more than 100 miles through. A ring of good writing-paper one foot in diameter will

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[1] G. P. Bond (1826–1865), associate of, and successor to, his father, W. C. Bond (1789–1859), at Harvard Observatory.

[2] How far is the inner edge of the bright rings from the body of the planet?

The division between the two bright rings is less than 2000 miles wide.

represent their proportions pretty correctly. Other divisions of the rings have been suspected by astronomers, but if any have been seen they must have been but temporary ones.

169. *The Constitution of the Rings.* — Mathematical reasoning[1] has shown that in all probability the rings are composed of small, distinct particles of matter, too small to be seen separately, and so close together that we cannot see through them; just as a column of smoke or a cloud looks like one solid mass, when it is really made up of a great many little particles of matter crowded together. In the dusky ring the particles may not be crowded together so thickly as in the bright rings. The rings shine by reflecting the sun's light. The particles composing the rings must revolve about the planet, or they would fall to his surface. The rings are then really a cloud of small satellites chasing each other around in a ring about Saturn. The time of rotation is thought to be a little greater than that of the planet.

170. *Appearances of Saturn's Rings.*—The rings are not perpendicular to the earth's orbit, but inclined to it at an angle of 27°. We never, therefore, get a full front view of the rings; when widest open, they seem to us like rather narrow ellipses. Twice during Saturn's revolution about the sun, or about every fifteen years, the *edge* of the ring is towards the earth. So

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[1] Prof. Benjamin Peirce (1809–1880), of Harvard University, proved that the rings could not be continuously solid, and thought they were probably liquid. But Prof. J. Clerk Maxwell (1831–1879), of Cambridge University, England, proved that they could not be liquid, and hence inferred their probable constitution to be as given above.

thin is the ring that at this time it is entirely invisible in ordinary telescopes, and Saturn seems to be simply a round planet like the rest. In powerful telescopes the ring at this time looks like a fine wire running through the centre of the planet. This occurred in February, 1878, and will occur again in December, 1891. After passing this point, the ring gradually opens wider and wider, until, when half-way to the next disappearance, we see it at an inclination of about 27°, the most favorable position for its observation. As the figure shows, this will be its position in 1885 and in 1899.

Fig. 41.—The Different Appearances of Saturn's Rings.

171. *Saturn's Satellites.*—Saturn has eight satellites, —twice as many as any other planet. The nearest is about half as far from Saturn as the moon is from the

earth, the farthest is more than 2,000,000 of miles away. The sixth satellite is the largest, being over 3000 miles in diameter; the smallest ones are too small for measurement. The sixth can be seen in any telescope. The eighth is as bright as the sixth when west of the planet, but can be seen only in large telescopes when east of it. It is supposed that one side of it is much darker in color than the other, and as it turns on its axis the bright and dark sides are turned towards us alternately. From the fact that it always disappears upon the same side of Saturn, it is inferred that, like our moon, it rotates once on its axis during each revolution about the planet. The smallest satellites are visible only in the largest telescopes.

Fig. 42.—Saturn and his Satellites.

The satellites revolve about Saturn nearly in the plane of the rings,—at an angle, therefore, of nearly 27° to Saturn's orbit as well as to our own; for Saturn's orbit is nearly in the same plane as the earth's. Hence they are seldom eclipsed. In passing around the planet they generally cross above or below the shadow. When they do occur, on account of their great distance and the small size of most of the satellites, the eclipses and transits are of little interest.

172. *Views from Saturn.*—If an observer on Saturn could see through its atmosphere, the view of the heavens must be striking. Although the sun there has but $\frac{1}{10}$ of the diameter that he has to us, and sheds then scarcely $\frac{1}{100}$ of the light and heat that we get, yet the eight moons and the wonderful rings would be an interesting spectacle. The rings form broad, bright, rainbow-shaped arches crossing the heavens, each side being bright and dark alternately for fifteen years at a time. The rings must cause frequent and long-continued eclipses of the sun.

173. *Observation of Saturn.*—To the naked eye Saturn is not an object of much interest. It is not nearly so bright as Venus or Jupiter, and is surpassed in brightness by one or two of the fixed stars. On account of its distance, its brightness does not vary much, although it is somewhat increased when the rings are opened wide. Hence it is not so easily found as the brighter planets; but the data given on the first page and in the body of an almanac, together with the fact that it is a *strange star* in the constellation[1] where it happens to be, will, with a little attention, enable one to find it. And

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[1] It will be remembered that the planets are not to be looked for all over the sky. They are always in the constellations along the zodiac.

when once found it may be followed from year to year, for its motion is so slow that it is two and one-half years in passing through a single constellation. The following are the dates of opposition for a few years:

November 14, 1882.
November 28, 1883.
December 11, 1884.

The subsequent dates may be found almost exactly by adding thirteen days for every year. Remembering that about these dates Saturn rises in the evening and shines all night will aid in finding the planet.

In a telescope Saturn is unmistakable, and is the most beautiful object in the heavens (Fig. 40). The rings, with one and sometimes two of the satellites, can be seen with a telescope of two or three inches of aperture. The other satellites and the marks on the planet require larger instruments. The rings will be widest open in 1885 and again in 1899; the best views of the planet will be had a few years before and after these dates. The years 1882–1885 will be exceptionally favorable. The fall and winter will be the best seasons for observations during these years. In 1891–92 the edge of the ring will be towards the earth. This will be of great interest to astronomers who have large telescopes, but for owners of small telescopes Saturn about this time will possess little interest.

## URANUS. ♅

**Distance from the Sun, 1,800,000,000 Miles. Diameter, 34,000 Miles. Length of Year, 84 Years. Length of Day Unknown. Specific Gravity, 1¼. Four Satellites.**

174. *Position and Description of Uranus.*—Uranus[1] is the third in order from the sun, and the smallest in size, of the outer group of planets. In the largest telescopes no markings have ever been certainly seen upon it: it shows only a bright, round disk. From its great size and its position, it is likely that it resembles Jupiter, and, like him, may not have cooled off yet. But of this we have no direct evidence. In a large telescope Uranus has a greenish tinge.

175. *Discovery of Uranus.*—This planet was discovered by Sir William Herschel in 1781. Herschel was a German music-teacher, who had settled in England and was at this time a church organist in the city of Bath. Having a great fondness for astronomy, he made a number of telescopes with his own hands, and became a diligent amateur observer. At the time of his discovery of Uranus he was almost entirely unknown as an astronomer. But this discovery at once made him famous. George III. made him his private astronomer, and gave him a pension of one thousand dollars a year. The rest of his life was devoted entirely to astronomy, in which he made many great discoveries.

When first discovered, Uranus was supposed to be a

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[1] U′ranus, the oldest of the gods. So named because this was supposed to be the most distant of the planets.

tailless comet; but it was soon found to be a planet. Its discovery awakened the greatest enthusiasm in the scientific world. Not even a new satellite had been discovered for nearly one hundred years, and all of the known planets had been known from the very earliest times. It was found that Uranus had frequently been seen before, but had always been taken for a fixed star.

176. *Satellites of Uranus.*—Sir William Herschel announced the discovery of six satellites to this planet, but it is now generally agreed that he really saw only two, and that he was mistaken about the other four. Two others were afterwards discovered, and it is certain that these four are all that have ever been seen, although some of the older works on astronomy still credit Uranus with six. The last two discovered are extremely faint; very few telescopes will show them at all.

The most remarkable fact about these satellites is, that, unlike every body in the solar system that we have yet considered, they do not revolve in their orbits from west to east. They revolve around Uranus almost from north to south,[1] and what little motion they have in the other direction is towards the *west*, and therefore retrograde.

177. *Observations of Uranus.*—When nearest to the earth, Uranus is just visible to the naked eye, and looks exactly like a very faint star. Unless, therefore, one knows just where it is, Uranus cannot be distinguished by the naked eye from the stars. Its position is best

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[1] That is, in the direction which is to *us* north and south. It may be that Uranus rotates in the same direction, and that his moons therefore revolve about him nearly parallel to his equator.

found from the Nautical Almanac, where its right ascension and declination (Art. 31) are given for each day in the year. These will show its position on a good celestial globe or map, from which it may be found.[1] But it is scarcely worth finding, for to the naked eye, or in an ordinary telescope, it possesses no great interest.

## NEPTUNE. ♆

**Distance from the Sun, 2,800,000,000 Miles. Diameter, 37,000 Miles. Length of Year, 165 Years. Length of Day Unknown. Specific Gravity, 1⅓. One Satellite.**

178. *Position and Description.*—Neptune[2] is the outermost planet of the solar system. It is rather larger than Uranus, and it is not unlikely that it resembles him and the others of the group of great planets. Of its condition nothing can be determined with any certainty. The largest telescopes show nothing but a small bright disk. No markings can be seen upon it, and therefore the period of its rotation cannot be determined.

179. *Discovery of Neptune.*—After Uranus had been discovered and watched for a number of years, it was found that its motion was not quite what it should be if acted upon solely by the attraction of the sun and the known planets. It is true that this deviation was very slight: it amounted altogether only to 2′,

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[1] When a telescope is properly mounted, it may be pointed at once to any right ascension and declination, and a planet or star, even if invisible to the naked eye, can thus be found.

[2] Nep′tune, god of the sea, son of Saturn, and brother of Jupiter. The planet's sign is the trident of the god.

or one-sixteenth of the apparent diameter of the moon. If one star were where astronomers had calculated that Neptune ought to be, and another were where it really was, the two would seem to the naked eye to be one. But this was a distance entirely too great to be overlooked in astronomy. So it began to be suspected that there was still another planet outside of the orbit of Uranus, which by its attraction was causing this deviation. Two young mathematicians, Le Verrier,[1] of France, and Adams,[2] a student at Cambridge University, England, each without any knowledge of the other, attacked the problem. This was to determine whether this deviation of Neptune was caused by the attraction of an unknown planet, and, if so, where that planet must be. The problem was one of the greatest difficulty. Adams solved the problem first, and determined very nearly the true position of the unknown planet. But he failed to publish his results, and, although he sent them to the Astronomer Royal of England, they were not thought to be of sufficient importance to justify a search for the planet with a telescope. The next year, 1846, Le Verrier reached a result, which he published. This was found to agree closely with that of Adams, and search for the planet was at once begun at Cambridge at Adams's suggestion. But, while this search was going on, Le Verrier, who, like Adams, had no telescope at his command, wrote to Dr. Galle,[3] of Berlin, asking him to point his telescope to a certain spot

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[1] See foot-note on page 64.

[2] John Couch Adams, born 1819, still living (1882).

[3] Dr. J. G. Galle (Gäl′eh), 1812– , then assistant at the Berlin Observatory, now director of the Observatory at Breslau, Prussia.

in the heavens, and to look for the new planet. Dr. Galle did so, *and found the planet within less than one degree of the place designated.*

This most remarkable discovery in all the history of astronomy excited even greater enthusiasm than the discovery of Uranus. It made Le Verrier probably the foremost and most famous astronomer of the world, a place which he held for the rest of his life. In this wonderful discovery, Adams, prevented by no fault of his own from being the chief instrument in it, has received almost equal credit with Le Verrier; and their names are usually coupled together in the story of the discovery of the planet.

180. *Neptune's Satellite.*—Only one satellite has been discovered revolving about Neptune. It is about as faint as the two smaller satellites of Uranus, and can be seen only in a large telescope. Its motion is still more retrograde than the motions of Uranus's satellites. It revolves about its planet from east to west.

181. *Observation of Neptune.*—Neptune is never visible to the naked eye. It can be found only by having a telescope properly mounted, and pointing it to the place of the planet in the heavens as given in the Nautical Almanac. In an ordinary telescope it possesses no interest, and very little in a large one.

182. *The View of the Heavens from Neptune.*—From Neptune the sun's apparent diameter would be only about one-thirtieth of his apparent diameter to us, or about the same as that of Venus when she is nearest to us. Yet his light would be more than one hundred times as great as that of our full moon, insignificant as that would be compared with the light which we receive from the sun (Art. 134). Owing to the smallness

and brilliancy of the sun, it is not likely that he would show any disk at all to an observer on Neptune, but would be only an exceedingly brilliant star. Uranus and Saturn, and possibly Jupiter at times, are the only planets which could be seen by the naked eye from Neptune. All the planets within Jupiter's orbit would be too close to the sun to be seen. Although seemingly so far out towards the stars, they would not be appreciably brighter at Neptune than upon the earth. For, as we shall presently learn, the *nearest* star is so far away that the distance to Neptune, enormous as it is, becomes as nothing beside it.

### Are the Planets Inhabited?

183. This is a question of great popular interest, and one that is often asked. But it is one to which astronomers pay very little attention, because of the impossibility of finding any satisfactory answer to it. The only heavenly body near enough to us to allow us to form an intelligent opinion about its being inhabited is the moon. And there the absence of air and water, and of any changes such as would be caused by our seasons, makes us certain that no life such as we know anything about exists. So far as we can tell, Mars most resembles the earth, and it has often been supposed that it may be inhabited. But upon Mars one would receive less than half as much heat from the sun as he gets upon the earth. This, unless modified by other circumstances, would reduce the temperature of Mars's surface far below zero,—a condition which of itself would, as it seems to us, make it impossible for life to exist there. As has been said, there is a

strong probability that Jupiter and Saturn, and perhaps Uranus and Neptune, are still intensely hot, and, if so, incapable of sustaining life. If they have cold, solid crusts like that of the earth, the argument against the habitability of Mars would apply to them with increased force. But Prof. Tyndall[1] has pointed out that if the atmospheres of these distant planets were composed in part of certain vapors known to us, they would admit the sun's heat freely, but would prevent it from passing out again: just as window-glass allows the sun's heat to pass through it into a room, but allows very little of the heat of the room to pass out. Such an atmosphere would store up the sun's heat, and might make the distant planets inhabitable.

Of the inferior planets, the one that seems to us most likely to be inhabited is Venus. As we never see Venus's surface through her dense atmosphere, we do not know how much resemblance she bears to the earth. But, as she receives twice as much heat from the sun as the earth gets, it seems to us scarcely possible for life to exist there. Still, it may be that Venus has an atmosphere so dense as to protect her surface from the intense heat of the sun's rays.

The question may be summed up by saying that if the earth as now constituted were suddenly put into the position of any one of the other planets, it seems certain that all life upon it would be speedily destroyed. As to whether varieties of life adapted to the different planets exist there, or whether these planets have con-

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[1] John Tyndall, born 1820, Professor of Natural Philosophy in the Royal Institution of Great Britain. He is one of the greatest of living scientists.

ditions and surroundings unknown to the earth which adapt them to such life as exists here, we do not know, and in all probability shall never find out. "Here we may give free rein to our imagination, with the moral certainty that science will supply nothing tending either to prove or to disprove any of its fancies."

# CHAPTER VIII.

## COMETS AND METEORS.

We have so far considered, in the solar system, sun, planets, and moons. There yet remain to be mentioned two other classes of bodies, *comets* and *meteors*. We will first treat of these separately, and then show an interesting connection between the two.

### Comets.

184. *General Appearance.*—A comet is a body which, when visible to the naked eye, usually presents the appearance of a star with a tail extending out to one side. This tail nearly always points away from the sun. The smaller comets, such as can be seen only with a telescope, frequently have no tail at all, being simply

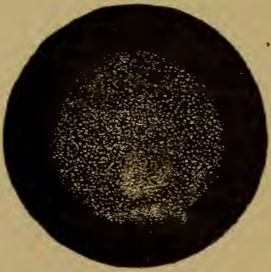

Fig. 43.—Telescopic Comet without a Nucleus.

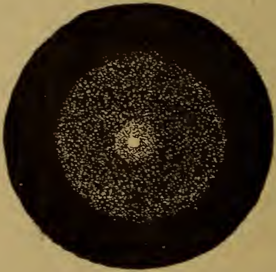

Fig. 44.—Telescopic Comet with a Nucleus.

round masses of hazy light, either uniformly bright, or with a brighter spot near the centre. Figs. 43 and 44 show two telescopic comets, one with and the other without a central condensation.

185. *Parts of Comets.*—Comets are usually composed of three parts, the *nucleus*, the *coma*, and the *tail.* The *nucleus* is the star-like head in which a large portion of the light is concentrated. It is often bright enough to be seen in the daytime. In 1843 and 1858, in recent times, and in many cases mentioned in history, comets have been distinctly noticed in the midst of the glare of sunlight. Though so bright, it is known that they have very little substance. While giving sometimes more light than the planet Jupiter, they are probably not one-millionth part as heavy. We know this from the slight effect they have on the planets when they approach them. A heavy body would attract a planet out of its path and change its orbit about the sun. Nothing of the kind has ever been noticed. It is supposed that on one occasion the earth passed through the tail of a comet. In 1770 a comet was discovered, which, in its approach to the sun, passed very close to Jupiter, and remained in its neighborhood for several months. But it did not seem to have any effect whatever on Jupiter or his satellites, while the planet's attraction changed the comet's orbit completely.

The *coma*[1] is the envelope immediately surrounding the nucleus. It usually shades off from it, so that no distinct line of separation can be seen. Frequently it is composed of a series of circular bands of light, as in the drawing on the following page, made from a

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[1] Latin for *hair.*

telescopic view, of *Coggia's* comet. The nucleus and coma together make up the *head.*

The *tail* stretches out from the coma, growing fainter till entirely lost. It usually broadens as it recedes from the head. It also is extremely thin and rare. Even very faint stars can be seen through it. In the case of

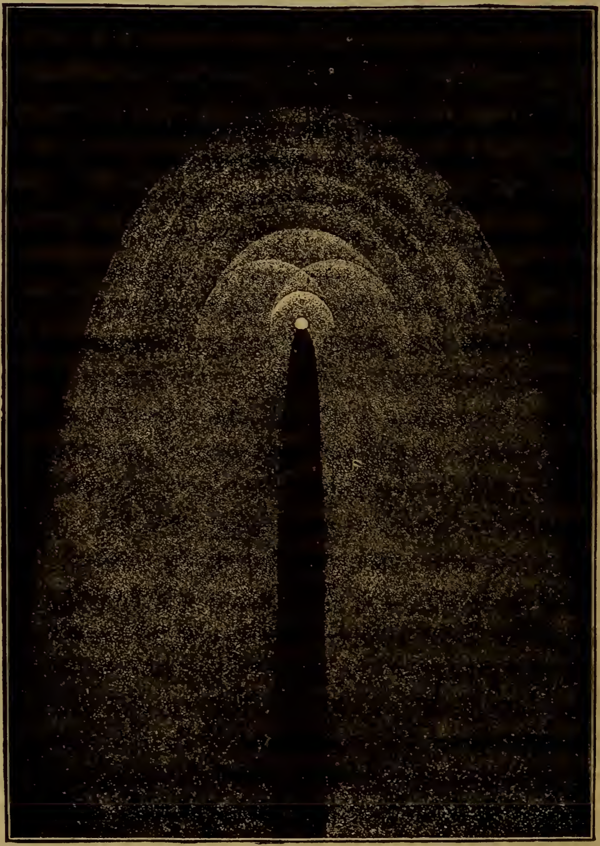

FIG. 45.—COGGIA'S COMET, 1874.

FIG. 46.—DONATI'S COMET, 1858.

the faint comets the tail is often not distinguishable at all, while in many of the brighter ones mentioned in history it stretched from the horizon to the zenith. Thus, we have an account of a comet in the year 134 B.C. that "lasted seventy days; the heavens appeared all on fire; the comet occupied a fourth part of the sky, and its brilliancy was superior to that of the sun; it took four hours to rise and four hours to set." Fig. 46 shows the appearance of the tail of Donati's comet of 1858. What the faint comets lack in brilliancy and extent of tail they make up in number. Six or more telescopic comets are frequently discovered in one year, while but few great naked-eye comets are seen in a lifetime. Since the Christian era about five hundred comets have been recorded as visible to the unaided eye, while the number of telescopic comets seems to justify the saying of Kepler, that celestial space is as full of comets as the sea is of fish.

186. *Orbits of Comets.*—Comets sometimes move in ellipses and sometimes in parabolas and hyperbolas.[1] When the orbit is either of the latter curves, they approach the sun from outside space, we know not whence, swing around it, and go away never to return. When it is an ellipse, they move around the sun like the planets, returning again and again to the same point. The latter kind are called *periodic comets*, because they have a regular period of revolution. Their reappearance can be expected, and the exact point in the heavens where they may be seen at a given time accurately calculated. The ellipses which the comets

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[1] Ellipses and parabolas have been explained on page 33. A hyperbola is a curve resembling in general appearance a parabola. It is not closed up like an ellipse.

describe are, however, much flatter than those of the planets. Fig. 47 shows the orbit of Halley's[1] comet. Its point farthest from the sun is outside of Neptune's orbit, and its nearest about the distance of the earth. Such a comet, when far from the sun, will move very slowly, but as it approaches, its velocity, like that of a falling body, will increase. It will swing around the sun with immense rapidity, and fly off, moving continually more and more slowly.

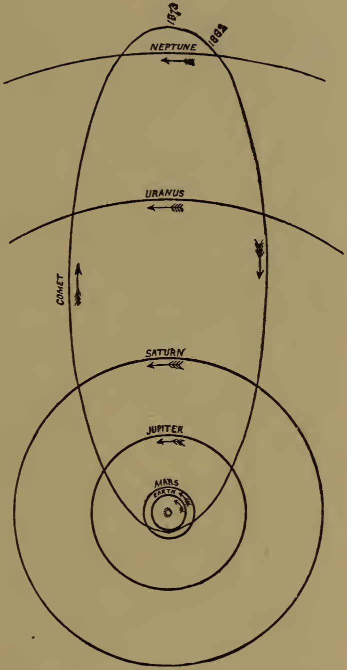

FIG. 47.—ORBIT OF HALLEY'S COMET.

Many of the comets have doubtless been secured to the solar system as permanent members by the attraction of the planets. If a comet, coming in from outside space in a parabola, were to pass in front of a planet, the planet's attraction might diminish its velocity, and change its orbit to an ellipse. The comet of 1770 thus came in from without, but Jupiter changed its orbit to a small ellipse, with a period of five and one-half years. It then performed two revolutions around the sun, when it again

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[1] Halley, a friend of Newton, lived in England 1656 to 1742. Comets are sometimes named after their discoverers, and sometimes after the astronomers who calculate their orbits.

approached the great planet, and had its orbit affected so that it has never since been seen. A number of comets revolve about the sun having their aphelia[1] at about Jupiter's distance, and it is supposed that these have all in past times been delayed by Jupiter, and so changed into permanent members of our system.

187. *Growth of Comets.*—When a comet is first detected by a telescope as it approaches the sun, it usually appears as a round mass of hazy light of uniform brightness. Presently an increase of brightness shows itself in one point, which gradually grows into a nucleus. As it still draws nearer to the sun, an arch is seen partly to envelop the nucleus on the side next the sun; this grows longer and brighter, and finally the tail itself begins to grow away from the sun, reaching out farther and farther as the comet nears the sun, till at perihelion[2] it is longest and brightest. Sometimes a number of envelopes surround the nucleus, the whole presenting the appearance of a fountain shooting out towards the sun and then falling away from it. This appearance is shown in the drawing of Coggia's comet, and also in those of the comet of 1861. The rapidity with which the tails of comets grow is wonderful; an increase of 35,000,000 miles in a single day is recorded in one case. As the comet recedes from the sun it goes through its changes in reverse order, apparently drawing in its tail, and, finally, its envelopes, and returning to its condition of uninteresting uniformity. It has its brief day of light and activity, to be followed by a long night of darkness and rest.

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[1] Points farthest from the sun.

[2] Point nearest the sun.

188. *What are Comets?*—This is a question to which it is difficult to give a complete answer. The spectroscope seems to indicate that they are partly solid and partly gaseous. The nucleus is probably solid, and shines by reflecting the light from the sun. The coma and tail are gaseous, the former giving out light of its

**Fig. 48.—Comet of 1861.**

own. This light is due largely to glowing carbon vapor, and resembles somewhat the flame of ordinary house-gas. It is a property of gases to expand indefinitely, unless held in by a central attraction; also it is known that in one case at least a comet vanished from sight, and a shower of solid meteors took its place. We may, then, think of a comet as a solid nucleus or a collection of solid particles surrounded by a dense gaseous atmosphere in a state of great activity. This activity shows itself in the violent and rapid changes which are often noticed in the heads of comets. Sometimes a mass is thrown off from the nucleus and forms a separate body, which afterwards disappears. Sometimes there are jets seen extending from the nucleus towards the sun and on either side, which usually curve backward into the tail. The sun seems to have a repulsive instead of an attractive force upon it, and the substance shot out into the tail represents so much waste matter to the comet. The tail is probably in the form of a hollow tube, as its edges often seem brighter than its centre. It is kept up by a constant flow of particles from the head. The enormous velocity of the head around the sun makes it improbable that the tail is rigidly attached to it, for if so it would be cast away by the great centrifugal force of the outer end. It is generally curved backward, thus showing that the particles as they move out retain only the slower motion of the inner parts, and are therefore left behind. The bright comet of 1881 showed a great many of these changes, and was carefully watched. The cuts on the opposite page show the varying appearances of the head at short intervals of time.

189. *Danger from Comets.*—The ancients looked upon

Fig. 49.—June 24.

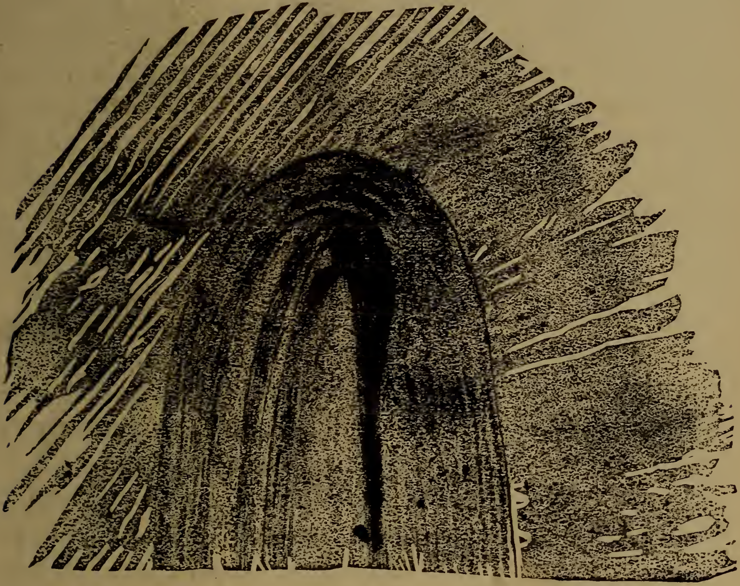


Fig. 50.—June 25.

Fig. 51.—June 28.

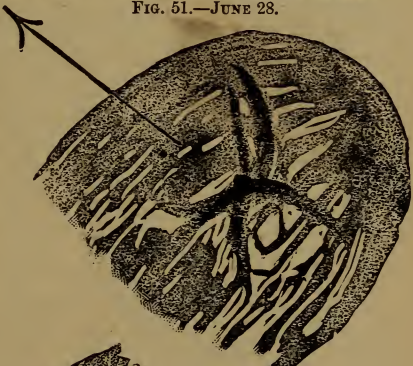
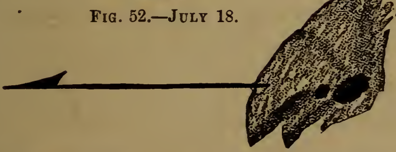


Fig. 52.—July 18.



Bright Comet of 1881.—Drawn by Prof. E. S. Holden, of Washburne Observatory, Madison, Wisconsin.

comets as the forerunners of war, pestilence, the death of kings, and all things evil. Their writings hence give numerous and detailed descriptions of many of them, and astronomy is thereby the gainer. The real danger from a comet is that the large nucleus of one might strike the earth. This would produce such a blinding light and intense heat that all life on that side of the earth would be immediately destroyed. Most nuclei are, however, too small to produce such serious effects, and the chances of striking are so slight that we may as well dismiss all thought of its happening.

190. *Remarkable Comets.—Halley's* comet was remarkable as being the first whose period of revolution was calculated or even suspected. After Newton had discovered the cause of the motion of the planets around the sun, he predicted that comets would be found to obey the same laws, and hence that their regular return might be expected. This set Halley to work to searching among the old records to find comets separated by uniform distances of time and whose orbits agreed. The comet of 1682 had just been an object of interest, and his search showed that in 1531 and 1607 similar ones had appeared : he therefore felt justified in stating that they were successive returns of the same object, and that it would reappear about the early part of 1759. The event corresponded to the prediction. On the night of Christmas-day, 1758, it was first seen, and it reached its perihelion passage on March 12, 1759. It returned again in 1835, and its next return will probably be in 1910.

191. *Encke's*[1] comet has probably been studied more

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[1] Enk′eh, a German, 1791–1865.

than any other. It was discovered at various times by different observers, among others by Caroline Herschel,[1] though it was never suspected that it was the same object. Encke, finding that its orbit was not a parabola, went into an elaborate investigation, and found that it revolved in an ellipse with the very short period of three and one-half years. Then, counting back, he found many records of its previous discovery. It has been watched several times since. Its last return was in the fall of 1881.

This comet is of special interest to astronomers from the fact that its time of revolution is not uniform. It arrives at its perihelion about two and one-half hours before the calculated time, so that its periodic time has diminished two days since it was first discovered. This indicates that it must be continually approaching the sun, as a small orbit and short periodic time always go together. The only plausible explanation of this fact is that the comet, being very light, is resisted in its motion by the ether which is supposed to fill all space. This resistance would tend to decrease the velocity and centrifugal force, and hence the comet would gradually fall towards the sun. It is a small telescopic comet, usually, though not always, seen without a tail. Fig. 53 represents its appearance at one of its returns.

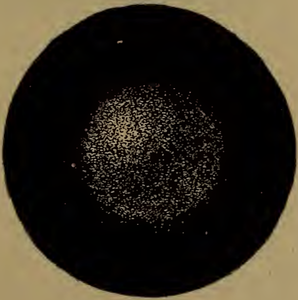

FIG. 53.—ENCKE'S COMET.

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[1] Caroline Herschel, the sister of Sir William Herschel, and his faithful assistant in much of his astronomical work.

192. *Biela's*[1] comet is remarkable for other reasons. Like Encke's, it was a small telescopic comet, and it had a period of about six and one-half years. *Olbers*[2] had called attention to the fact that in 1832 it would pass within 20,000 miles of the earth's orbit, though, as the earth would not reach the same point till a month later, no danger was apprehended by astronomers. Many other people, however, looked forward to the time with considerable anxiety. The comet came punctually as predicted, but no harm resulted therefrom. In 1846 it again returned very close to the earth, and was carefully studied. Much to the surprise of astronomers, while their telescopes were pointed at it, it began to divide into two comets, which gradually receded from each other as long as they were visible. When it came back in 1852 the division had increased, and measured one and one-quarter millions of miles. At the return

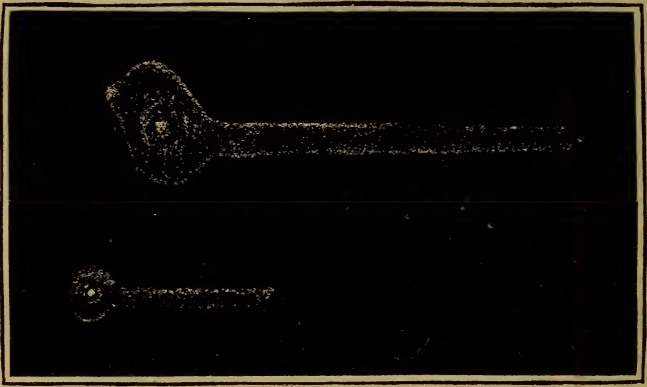

Fig. 54.—Biela's Comet, 1846.

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[1] Bie′la, a German, 1782–1856.

[2] Ol′bers, a German, 1758–1840.

of 1859 it would not be in a good position for observation, but in 1866 it was expected with great interest, in order to notice what further changes might have taken place; but Biela's comet has never since been seen. No satisfactory explanation of its division and subsequent disappearance has ever been offered. Some other interesting facts in connection with this comet will be given in the section on meteors. The drawing represents its appearance just after the separation.

193. *Comet b*,[1] 1881.—This, the brightest comet since the spectroscope has been perfected, was observed more carefully than any other. The tail was nearly 40° long, and the head was as bright as, and larger than, a first-magnitude star. Most of the phenomena described in paragraphs 187 and 188 were noticed in this comet. At one time (see Fig. 52) a separation in the nucleus led astronomers to think that it would follow the example of Biela's comet; but by the following night the smaller part had disappeared. Very frequent changes were observed by the telescope, in the shape of the jets and envelopes around the nucleus. Many drawings were made of it, it was carefully studied by means of the spectroscope, and (for the first time with comets) a photograph was taken of it.

194. *How to Look for Comets.*—From what has been said we may infer that new and interesting comets may be expected at any time and in any part of the heavens. The number of those whose return can be predicted is very small as compared with the number of new ones which may be discovered. Prizes of medals or sums

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[1] So many comets are now discovered that all of one year are named by the letters of the alphabet. This was the second one of 1881.

of money have been offered at various times for the discovery of comets, and this and the honor connected with it have led many to search for them with great perseverance. The work does not need large telescopes, nor does it require any skill which an ordinary person with a good eye cannot acquire. The instrument used should have a low power, such a one as would magnify about twenty-five times, and it should have a large field of view. The comet is detected partly by its appearance and partly by its change of place among the stars. Judging by appearance alone, a nebula or cluster might be mistaken for a comet. But a little watch will show whether there is any change of position with reference to the neighboring stars. If a discovery is made, it should be immediately telegraphed to some observatory. American observers have divided the sky into zones, for systematic comet-seeking. They are supplied with catalogues of clusters and nebulæ, and, besides their announcements of discoveries, report their work monthly.

## Meteors.

195. *General Remarks.*—Every one is familiar with "shooting-stars." This name describes their general appearance, but in reality they are very different from stars. The stars are all at an immense distance from us, while meteors are in our atmosphere. Stars are very large bodies, while meteors are quite small. No instance of visible motion in a star has ever been noticed, nor is it likely ever to be. When we use the name "shooting-star," we must remember the great difference which exists between them and the real stars.

Upon almost any clear, moonless night we can see meteors. It has been calculated that the average number visible is about five an hour. Sometimes it vastly exceeds this. As many as 30,000 an hour is given as the number seen on several occasions. When a watch for them is carefully maintained, it is noticed that on certain nights of the year they are especially numerous. About the 10th of August and the 14th of November a person cannot fail to notice a large number during any clear and moonless night.

196. *What are Meteors?*—Meteors are small, cold, solid bodies which are revolving about the sun entirely independently of the earth. Sometimes, however, as the earth is moving on its orbit with tremendous velocity, it approaches some of these little bodies. The earth's atmosphere probably extends a hundred or more miles in all directions from its surface, and the meteors strike it with great energy. Now, we know that heat is produced when a nail is struck with a hammer; just so when a meteor, probably with a great velocity of its own, comes in contact with the atmosphere moving to meet it at a rate of 66,000 miles per hour, it is made so hot that it burns. It keeps on moving until entirely consumed, and thus we see the blazing streak across the sky. The train which is sometimes seen to follow it and to float away like a light cloud is the red-hot ashes, which gradually and imperceptibly fall to the earth. Sometimes the concussion is so violent as to break the meteor into fragments, and we hear a loud report and see the flying masses in their separate tracks. If the body be very large and bright, and seem to pass a long way through the atmosphere, and to approach very near the earth, it is called a *fire-ball;* and if still

larger, so as not to be consumed by the time it reaches the earth, it is usually called an *aerolite*.[1] Many aerolites have been seen to fall which have afterwards been picked up and examined. They show the indications of intense heat in their glazed surfaces, which have evidently been molten. This has been done in their passage through the atmosphere. But, besides this, when they are carefully examined with a microscope their whole interior structure is found to be crystalline: this proves that at some time they must have been either wholly molten or gaseous. They are usually largely composed of iron, but often have a number of other substances in connection with it, though they contain no elements which are not found on the earth. It is interesting to know that the matter that comes in to us from outside space contains the same substances which exist here. We have seen that the sun is made up largely of terrestrial elements, and we shall find the same to be true of the stars. It is probable that on the earth we have specimens of nearly every element that exists in the universe.

It is calculated that meteors begin to burn at about the height of seventy-four miles from the earth, and the smaller and more inflammable are usually consumed after a course of forty-two miles through the air. They are mostly small, not exceeding a pound in weight.

197. But how are these little masses arranged in space? It is known that they are not uniformly distributed, but that they are collected into rings about the sun. These rings are not circular, but are elliptic,

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[1] A′erolite, a stone from the air.

like the orbit of a comet, having the sun in a focus. There are many millions of meteors in every ring, and they follow one another in this ring round and round the sun. They are in reality very minute planets which have been crowded together and are performing their revolution around the sun in company, every one, no doubt, much influenced by the attractions of the others. The meteors are not always arranged in the rings uniformly, but are collected in groups, with comparatively barren spaces between them.

198. *November and August Meteors.*—While the meteors themselves revolve about the sun, the ring, considered as a whole, retains the same position all the time. Hence if the earth passes through the ring in one of its revolutions, it will pass through it on each succeeding revolution at the same time of year. Every year, accordingly, when the earth reaches the point of its orbit which intersects the ring, unusual displays may be looked for. If the meteors were distributed uniformly along the ring, the same number would be seen every year; but if there were one main bunch in the ring and the remainder of the meteors were more thinly scattered along, the display would be most striking when the earth encountered this main body. Since the meteors have a regular time of revolution about the sun, we might expect these striking displays to recur at regular intervals, when the main bunch comes around.

Such is the case. Every year on the 14th of November, and on several nights on both sides of this date, unusual showers of meteors are observed; while at intervals of about thirty-three years the display is remarkably brilliant. One of these occurred on November 12, 1799, when Humboldt[1] saw it in South America, and described it as follows: "Thousands of bodies and falling stars succeeded each other during four hours. From the beginning of the phenomenon there was not a space in the firmament equal in extent to three diameters of the moon which was not filled every instant with falling stars." On November 13, 1833, the most brilliant display of meteors on record occurred. It was visible all over North America. The whole heavens seemed on fire, and the greatest consternation prevailed among ignorant people. Again on November 13, 1866, the shower returned, this time visible in England. It was observed with care, and about 8000 were counted in one night at the Greenwich Observatory. As the meteor-bunch occupied some time in passing the point of contact with the orbit of the earth, the display appeared for several years succeeding this.

The explanation of these regularly returning showers has already been indicated. Every year, on the 14th of November, the earth in the course of its journey around the sun passes through this meteoric ring, and we have the yearly display. But the meteors which constitute the ring are not uniformly distributed along its course. There is one main collection of them and probably several smaller ones. Moreover, these meteors are themselves revolving about the sun, completing a revolution in thirty-three and one-fourth years. Hence at intervals of this time the earth encounters this main swarm and ploughs a path through it. The bodies are attracted to the earth, which is also

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[1] Hŭm′bōlt. A great German scientist, 1769 to 1859.

advancing to meet them, and the collision and friction with the atmosphere give us the splendid displays of

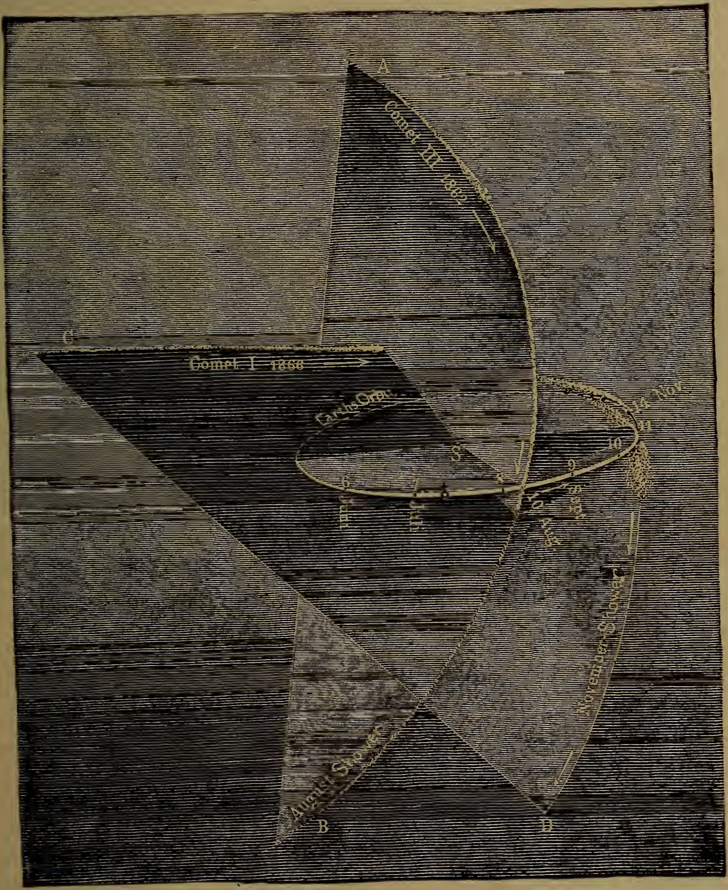

FIG. 55.—ORBITS OF AUGUST AND NOVEMBER METEORS. (From Schellen's Spectrum Analysis.)

shooting-stars. Fig. 55 shows how the earth's orbit comes in contact with the November meteor rings. When this point is reached by the earth, we have the yearly display. If a bunch of meteors happens to be passing at that time, the display is magnified.

Meteors are also abundant on and about the 10th of August. Unlike the November meteors, these are about equally conspicuous every year. They are probably distributed along their ring uniformly, so that their period of revolution has not been certainly determined.

199. *Radiant Point.*—When the paths which the November meteors describe in the heavens are marked on a celestial map, it is found that if produced backward they would all intersect nearly in one point. This is shown in Fig. 56. They all seem to radiate from this portion of the heavens, and hence the name *radiant point* is given to it. The radiant point for these meteors is in the constellation Orion. They are therefore called *Orionids.* The radiant point of the August meteors is in Perseus, and they are hence called *Perseids.* The November meteors are *Leonids.* It must not be inferred that the meteors actually move in divergent lines. Their paths are really parallel; but just as railroad-tracks seem to approach each other as they recede from an observer, so these parallel lines appear to radiate from a common point. Just in the radiant point the meteors are seen without any train, because they are directly approaching us. In the case of the great November showers, it is stated that in Leo the sky seemed phosphorescent from the large number of meteors shooting directly towards the observer.

200. *How to Watch for Meteors.*—Observations on meteors are especially adapted to young astronomers, as they require no expensive implements and no skill which cannot be easily acquired by a patient watcher.

It is important that the position of the radiant point be accurately determined, as this distinguishes the meteors of one group from those of another, and is also necessary to calculate their orbit. The following is the method to be employed. Procure a reliable map of the heavens,[1] and, spreading over it a sheet of thin, partly transparent paper, mark on it a number of the principal stars, being especially careful to place those near the radiant point with great accuracy. Mark also the points of the compass around the horizon. Now become very familiar with the map thus formed, so that it will be easy to find any part of the heavens and any star quickly. Whenever a meteor is noticed, note with great accuracy its path in the sky, and transfer it to the map, indicating the length of the track and the direction of the motion as in Fig. 56. Notice also the brightness of the meteor as compared with Jupiter, a first-magnitude star, etc., and write the same by the side of the mark. Record also the exact time as nearly as may be, the color of the meteor, whether it left a streak behind it or not, whether its course was slow or rapid, and any other interesting facts connected with it. Look out especially for meteors with short tracks near the radiant point, and record them with especial care; and if a meteor blazes out without any track at all, its position should be exactly found. When the watch is over, trace back to their intersection the various paths belonging to a common system, and determine the right ascension[2] and declination[2] of this point. Preserve the map for future reference. Should

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[1] A planisphere set to the middle of the watch is convenient for ordinary work.

[2] See page 42.

there be a great shower, it is well for one person to count the number seen in each five minutes of the watch, while another records the principal ones. The following table shows the times in the year when the earth passes through some of the principal meteor rings, and the radiant point for each:

| Date. | Radiant Point. | | Name. |
|---|---|---|---|
| | R. A. | Dec. | |
| January 2-3. | 232° | +49° | Quadrantids. |
| April 19-20. | 272° | +35° | Lyrids. |
| July 27-31. | 337° | — 6° | Aquarids. |
| August 9-11. | 44° | +56° | Perseids. |
| October 18-20. | 89° | +15° | Orionids. |
| November 12-14. | 149° | +23° | Leonids. |
| November 27. | 25° | +43° | Andromedes or Bielas. |
| December 9-12. | 105° | +31° | Geminids. |

Instead of a map a slated globe may be used. This is more reliable than a map, but more expensive. It may be prepared by marking on it with white paint the circles of right ascension and declination, and the positions of the principal stars down to the fourth magnitude. The meteor tracks may be marked on this with a soft slate-pencil or sharp chalk and afterwards transferred to a piece of paper. In all cases it is well to rule a table something like the following, and record all prominent meteors:

| Time. | Beginning of Track. | | End of Track. | | Brightness. | Rate of Motion. | Color. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | R. A. | Dec. | R. A. | Dec. | | | | |
| November 14, 1881, 4.20 A. M. | 153° | +37° | 228° | $+68\frac{1}{2}$° | 1st mag. star. | Rapid. | Yellow. | Leonid; not very well observed; streak. |

Fig. 56 shows a map of Orionids made at Haverford College Observatory on the morning of October 19, 1881, and is the result of an hour's watch. The neighboring hours were quite as fruitful of meteors as this, but the addition of any more would only confuse. The general divergence of the tracks from a point marked by a small circle is quite noticeable. Some of them do not seem to radiate strictly from it, but this is due probably to errors of recording, a large portion of which are unavoidable. Some of them belong to other showers than the Orionids, and their presence with the

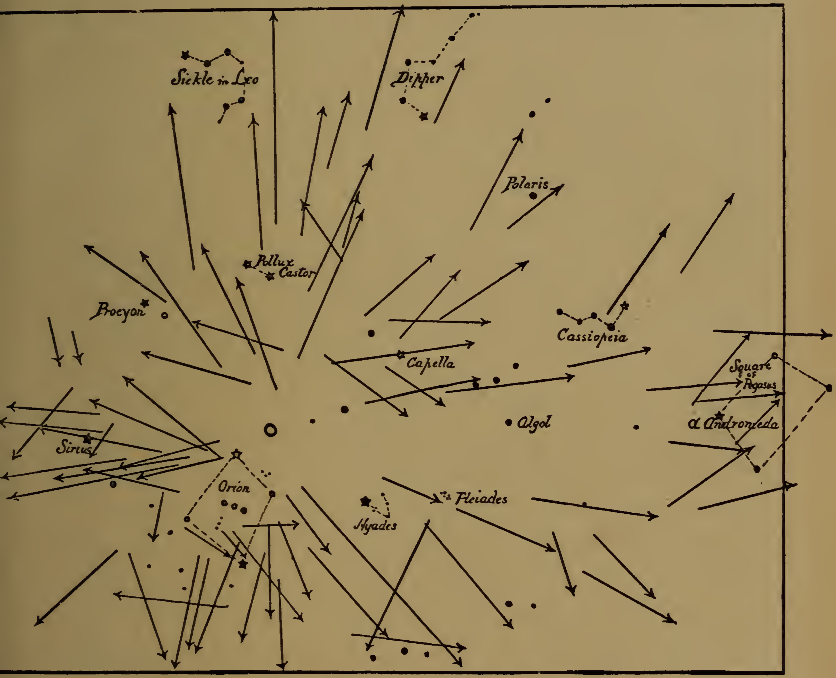

Fig. 56.—Orionids of October 19, 1881.

others is only accidental. All are given to show the appearance of such a map at the close of a watch.

201. *Zodiacal Light.*—This name is given to a faint light which may be seen after sunset on clear evenings of the winter and spring. It is triangular in appearance, its base being on the western horizon, and its greatest length extending back along the path of the sun; it may, on favorable evenings, be observed to extend nearly to the meridian, where it fades away so that no distinct outline may be noticed. Some people with very good eyes claim to be able to see it all the way to the eastern horizon. It really exists in the summer and autumn as well, but in our latitude the ecliptic[1] lies so near to the horizon at these times that the light cannot be easily distinguished. It is then, however, visible in the morning just before sunrise on the other side of the sun. It is not certainly known what it is, but the most probable theory is that it is composed of an immense number of meteoroids, reflecting the sunlight, and which are so small that their united lustre is barely distinguishable. They surround the sun on all sides, revolving about him like little planets, and frequently fall to his surface, thus assisting in keeping up his heat and light, as explained on page 62. The light should be looked for from a half-hour to an hour before sunrise or after sunset.

## Relation between Comets and Meteors.

202. Prof. Newton, of Yale College, and Prof. Adams, of England, entered into an elaborate investigation to

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[1] See page 39.

find the orbit of the November meteors. They based their work on the old records of former displays and the observations of the shower of 1866. The result of their labors was to lay down very accurately the size and position of the orbit. When this was done it was found that it agreed almost exactly with that of a small comet commonly known as Comet I., 1866, or Tempel's comet, which also had a period of about thirty-three and one-fourth years, and which returned to perihelion in the early part of the same year in which the brilliant meteoric display occurred. It was thus found that the main group of November meteors followed around in the orbit of the comet; that the earth met the comet about ten months before the meteoric swarm; and that the comet led the way round and round the sun, with the swarm immediately and continually following it. Fig. 55 shows the identity of the two orbits.

But this is not an isolated instance. It was soon found that the August meteors and Comet III., 1862, had identical orbits, and, later, a similar relation was found to exist between the Lyrids of April 20 and Comet I., 1861. Another interesting case is that of Biela's comet. We have said (page 200) that in 1866 it was expected, but that it never appeared. The next return would have been in 1872. On the night of November 27 the earth and the comet, it was calculated, would be at the same point at nearly the same time. But there came, instead of the comet, a shower of meteors. They rained down on England at the rate of over ten thousand an hour; they brightened up the earth and sky, and many an observer recorded the fact that they all radiated from the same point in the constellation Andromeda, and *that* point was just where the comet was expected to come from. The comet had gone no one knows where, but a swarm of meteors had assumed its place. Every year, on the 27th of November, the shower may be seen, and its brightness increases as the time for the regular return of Biela's comet approaches.

These coincidences cannot be attributed to chance. There must be some connection between comets and meteors, but what it is astronomers have not certainly determined. We should keep on observing facts, trusting that soon the mystery will be thoroughly cleared up. It is probable that the solid portion of the comet has been broken up by some internal convulsion, and that the meteors are the fragments.

# PART II.

## THE SIDEREAL UNIVERSE.

## CHAPTER I.

### THE CONSTELLATIONS.

203. *Introductory.*—So far we have kept within the limits of the solar system. We have been struck with the immense intervals of space which separate its different members. The distance to the moon is greater than anything we can conceive of, yet it is but a trifle when compared with the distance to the sun; but even the earth's orbit seems small when we think of the enormous length of the path which Neptune passes over in each revolution about the sun. We now are about to consider bodies whose distance is so great that the huge orbit of Neptune seems but a point in comparison. When we gain some familiarity with them, the solar system, great as it is, will seem to us like a little company of orbs, near at home, clustered together in infinite space; a very insignificant portion of the whole universe. These distant bodies are the *stars* and the *nebulæ.* Taken as a whole, they constitute the *sidereal system.* This system embraces all the heavenly bodies. The solar system is a part of it, to us a very conspicu-

ous part, but, compared with the whole, quite diminutive. We must not include under the name *stars* the various members of our solar system.

Though Jupiter and Venus and the other planets resemble stars to the eye, they really differ widely. The planets revolve around the sun like the earth; the stars do not. The planets are comparatively close to us; the nearest star is more than seven thousand times as far from the sun as is Neptune. The planets shine by the light which they reflect to us from the sun; the stars give out their own light.

204. *What are Stars?*—The stars are suns. They give out light and heat like the sun. As soon as we come to treat of the distance to the stars we shall see that it would be impossible to consider that they receive the light which they send us from the sun as the planets do. They must be hot and glowing bodies themselves, some of them as large and as bright as the sun, and some of them probably much larger and brighter. If we were to look at the sun from their distance, it would appear to be a little point of light as they do. The sun is a star. We must consider space to be occupied with a countless number of suns scattered very thinly through it; and, though we have never seen any worlds surrounding any sun but our own, it is very probable that they exist, and that each star is the centre of a system to some extent resembling the solar system. There is another proof of the fact that the stars are like the sun. The spectroscope tells the same story of both: they both consist of a glowing mass, the light from which shines through a gaseous, less bright atmosphere, and the materials of which this atmosphere consist are largely the same in all.

The ancients had in general very incorrect ideas as to what the stars were. They were variously supposed to be studs nailed to the celestial sphere; fires which were nourished by the igneous matter which streamed out from the centre of the earth; luminous stones whirled up from the earth; breathing-holes in the universe. Pythagoras had a more exalted idea of them, considering them to be worlds having land, water, and air.

205. *Constellations.*—In very remote antiquity the heavens were divided up into groups of stars which were called *constellations.* Names were given to some of these, probably on account of their fancied resemblance to certain animals and other objects, though it is difficult to see any such resemblance now. The seven stars commonly called the *Dipper* are a part of the constellation "*Great Bear,*" yet the arrangement of the stars in this constellation does not seem to suggest anything of the kind. Other names, as *Hercules*, were probably given for the sake of honoring their deities or great men. Astronomers have found it convenient to retain these names to mark certain portions of the heavens. Thus, *Leo* does not now mean a great lion or anything resembling one, but a definite section of the celestial sphere containing certain stars.

206. *Names of the Stars.*—The heavens being thus divided up into small areas, with a name for each, it remained to adopt some plan for distinguishing one star from others in the same constellation. The method now in use was suggested by *Bayer*[1] in 1603. The brightest star of the constellation is named by prefixing

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[1] Bayer, a German astronomer and Protestant preacher, 1572 to 1660.

the first letter of the Greek alphabet to the genitive case of the name of the constellation. Thus, the brightest star in the *Great Bear* is α *Ursæ Majoris.* The brightest in *Leo* is α *Leonis.* The other Greek letters then follow in order; then the Roman letters; and if this does not exhaust the stars of any constellation, the remaining ones are numbered. This order is not strictly correct; the namers sometimes misjudged the brightness of the stars, and it is probable that the splendor of some of them has changed since the names were given. Thus, β Orionis is in general brighter than α Orionis, but sometimes the latter greatly exceeds it in light. Besides this, the stars in the different constellations have been independently numbered, so that a single star is sometimes designated by its letter as well as by its number. This double system often causes confusion. Many hundreds of the stars had received special names from the ancients, particularly from the Arabians; but the inconvenience of remembering these has kept them from being extensively used, except in the case of a few of the most conspicuous of them. Thus, α Boötis is Arcturus, α Lyræ is Vega, etc.

207. *Magnitudes.*—For convenience of classification the stars have been divided according to their brightness into magnitudes, the first-magnitude stars being the brightest. Stars of the first five magnitudes can be seen with the naked eye, and on favorable nights many stars of the sixth magnitude may also be seen. The number in each of the first six magnitudes is approximately given in the following table:

| | | | |
|---|---|---|---|
| 1st | 20 | 4th | 450 |
| 2d | 65 | 5th | 1100 |
| 3d | 200 | 6th | 4000 |

It thus appears that there are about 6000 stars which under the most favorable conditions can be seen by the naked eye. Some of these are never above the horizon in the Middle States, and only a part of the remainder are above at any given time. Many eyes cannot see the fainter ones of the sixth magnitude, so that 2000 will cover all commonly seen, by most people, at any one time. Telescopes reveal them by the millions. Fig. 57 shows the appearance of a portion of the heavens as seen by a telescope. There are not more than two stars here visible to the naked eye.

Sir William Herschel gives the following table as representing the light given out by a star of the different magnitudes, an average sixth-magnitude star being taken as unity:

| | | | |
|---|---|---|---|
| 6th | 1 | 3d | 12 |
| 5th | 2 | 2d | 25 |
| 4th | 6 | 1st | 100 |

As a general rule, an average star of any magnitude is about two and one-half times as bright as an average star of the magnitude next fainter.

It must not be supposed that all stars of the same magnitude are equally brilliant. There are all grades of brightness, from Sirius, the light from which is estimated to be 234 times as great as that from a sixth-magnitude star, to those so faint as scarcely to be visible. There is no distinct line to be drawn between the different magnitudes. A star lying between the fourth and fifth magnitudes, for example, might be considered to be a faint star of the fourth by some astronomers and a bright star of the fifth by others. These intermediate stars are often designated by decimals. Thus, magnitude 4.8 would mean nearer the fifth than the fourth.

208. The following list contains the names of twenty of the most brilliant stars of the heavens arranged nearly in the order of brightness; those in *italics* are never seen in the latitude of New York:

α Canis Majoris, or Sir′ius.
α *Argus*, or *Cano′pus.*
α *Centauri.*
α Boötis, or Arctu′rus.
β Orionis, or Ri′gel.
α Aurigæ, or Capel′la.
α Lyræ, or Ve′ga.
α Canis Majoris, or Pro′cyon.
α Orionis, or Betel′geuse.
α *Eridani*, or *Acher′nar.*
α Tauri, or Aldeb′aran.
β *Centauri.*
α *Crucis.*
α Scorpii, or Antar′es.
α Aquilæ, or Altair′.
α Virginis, or Spi′ca.
α Piscis Australis, or Fo′malhaut.
β *Crucis.*
β Geminorum, or Pol′lux.
α Leonis, or Reg′ulus.

These should all be found on a celestial globe or map, and then in the heavens. They will serve as valuable starting-points from which to locate the fainter stars. To give examples of stars of the lower magnitudes, we will go over the stars of the *Dipper:*

The brightest of the pointers is of the second magnitude; the other pointer is of the third; the star next to this is also of the third; the star which joins the handle of the dipper to the bowl is of the fourth; the next star in the handle is of the third; the next, of the second; and very close to it is one of the fifth; the last one in the handle is of the third. On a moonless night, with a clear atmosphere, there are three little stars of the sixth magnitude which may be seen near the star at the end of the handle of the dipper, and in the direction of the pole-star.

209. *The Milky Way, or Galaxy.*—This is a ring of

hazy light, which seems to encircle the earth, and is visible on moonless nights. By the telescope it is shown to consist of millions of stars clustered together. They are either so small or so distant that we cannot

Fig. 57.—Part of the Constellation Gemini, as seen with a Telescope.

see them separately by the unassisted eye. The Milky Way partakes of the diurnal motion of the heavens, and is therefore seen in varying positions at different times. But it never changes its place among the stars. The telescope shows that nearly all the faint stars are clustered in or around it. We see but few near its poles,[1] but as we approach they increase in number very rapidly. A careful observer can see this—less conspicuously, though—with regard to the brighter stars. A large majority of all the stars are clustered in or near the plane of the Milky Way.

In the Galaxy itself the stars are not distributed uniformly, but grouped in large or small clusters, with blank spaces between them. The edge is jagged and irregular, and wherever there is an outlying streamer there the lucid stars seem also to be congregated, so as to suggest some connection. At one point it divides into two parts, which afterwards join each other.

210. *Distances of the Stars.*—If a person were walking past a grove of trees, they would seem to him to be continually changing their places among one another; the trees nearest him would appear to move backward, with respect to those beyond; two trees which were in a line with him at one instant would seem to separate as he advanced; others would appear to approach one another. Now, the earth is sweeping through space around the sun, passing every six months from one side of its orbit to the opposite. These points are separated from each other about 186,000,000 miles. It would seem, then, that the stars ought to change their apparent places among one another just as the trees do; in other words, that the stars ought to show some parallax. Evidences of this were sought with great care for a long time without any success. The stars were so distant that any change of position was inappreciable. With in-

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[1] Points 90° from it.

struments capable of greater precision a very small parallax has in modern times been detected for certain stars, though in no case has it been found to equal one second of arc. Let us consider the meaning of this. Suppose that an observer were on the *nearest* star, with a telescope steadily pointing to the earth as it moved from one side to the other of its immense orbit. The direction of the telescope at the beginning of the watch would deviate from that at the end by an angle of less than two seconds. The radius of the earth's orbit would subtend an angle of only one second; if it were a luminous rod, it would appear no longer than a foot-rule would at the distance of twenty-one miles. A calculation shows that the distance to this star is about 20,000,000,000,000 miles; but there is no advantage in expressing a distance as great as that to the stars in miles. The number is utterly inconceivable. If we take the distance to the sun as our unit, or measuring-rod, there would be 225,000 such units in the line joining us to the *nearest* star. Such distances are usually measured by the time it takes light to pass over them. Light moves with a velocity of about 186,000 miles per second. It would take it about one and a third seconds to pass between the earth and the moon; in a little over eight minutes it comes to us from the sun; but to reach us from the *nearest* fixed star three and one-half years are required, while its time in coming from many of the stars is measured by centuries.

The nearest known star, *α Centauri*, in the Southern hemisphere, is a very bright one. The next one, 61 *Cygni*, is only of the sixth magnitude. It is not found, as a rule, that the brightest stars are the nearest.

Sirius, the most brilliant star of the whole heavens, is three times as far away as 61 Cygni. This requires us to suppose that the stars are of different sizes. Sirius must be very much larger than 61 Cygni to give out so much more light at a greater distance. Knowing the relative distances from us of Sirius and the sun, and the light given by each, we can calculate that, supposing their surfaces to be equally bright, Sirius must have about fifty-six times as much surface as the sun, and hence over seven times as long a diameter.

Though the stars are such large bodies, they show no diameters in the most powerful telescopes. They are merely points of light, brighter, but no larger, than when seen by the eye. This is shown by an occultation of a star by the moon. (Page 139.)

211. *Motions of the Stars.*—The ancients called the stars *fixed*, because they did not seem to change their places among one another as the planets did. By comparing their relative positions now with what they were when the first star catalogues were made, it is found that many of them have very considerable motion. This motion of the stars among one another is called *proper motion.* In the course of an immensely long period the constellations will be distorted. As an illustration of how this is possible, we may take the case of the Great Bear. Of the seven principal stars forming the Dipper, it has been found that five are moving in parallel lines and with equal velocities. Their relative positions will therefore be preserved; but the two pointers are moving in opposite directions. After centuries have elapsed they will cease to point to the pole-star, and the Dipper will change its shape.

This motion can be detected only by very delicate measurements. It is probably extremely rapid, but the great distance makes it appear to be very minute. We must also remember that the stars are not bodies at the same distance from us, set in the surface of the same sphere, and moving in that surface, but are at varying distances, and moving in all directions, towards us and away from us, as well as sidewise. The latter we might hope to detect, but, until recently, motion to us or away from us appeared hopelessly undiscoverable. But the spectroscope has enabled us to solve the difficulty, and we can now tell with reasonable accuracy which way nearly all the bright stars are moving.

Like the other stars, the sun has a proper motion, carrying with it the whole solar system. This has been proved by the apparent motion of the stars. Let us recur to our illustration of the grove. Suppose the observer to be directly approaching it: the trees would then appear to be separating from one another. If he were moving away from it, the trees would seem to close up. Now, if in any part of the heavens the stars are apparently opening out, and in the opposite portion closing up, it is evidence that we, in common with the rest of the solar system and the sun, are approaching the centre of the former part. This point has been calculated by various astronomers, and they agree in placing it in the constellation *Hercules.*

212. *Colors of the Stars.*—It is easily observed that the stars vary in color. Any one carefully noticing the colors of Sirius and Betelgeuse, for example, would not fail to see a striking difference. They are usually either blue, white, yellow, or red. Of the stars which have a blue or green tinge, Sirius, Vega, and Rigel may be mentioned; of the white stars, Regulus and

Polaris; of the yellow, Capella and the sun; of the red, Antares and Betelgeuse.[1] There are also a number of faint telescopic stars which are of a deep blood-red color; these are usually remarkable for changes in their brightness. The student should carefully examine these and other stars and make out lists of the colors of all the conspicuous ones.

The telescope shows sometimes a beautiful collection of stars of different colors grouped together. Such a cluster in the Southern hemisphere, Sir John Herschel said, produced on his mind the effect of a superb piece of fancy jewelry. Frequently a red and a blue star are associated together in close contrast.

213. *Twinkling of the Stars.*—One of the most noticeable features about the stars is their twinkling. This is due to the different temperatures and densities of the strata of the atmosphere through which their light passes. We know this from the fact that stars near the horizon, the light from which traverses a greater stretch of atmosphere, twinkle more than those in the zenith. But there is some other cause connected with it, for some stars at the same altitude twinkle more than others. If Castor and Pollux be watched when they are near the horizon, it will be noticed that Pollux twinkles the most. The cause of this difference is not known.

On the nights when the stars twinkle the most the

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[1] J. Norman Lockyer, a noted living English astronomer, has propounded the theory that the colors of the stars indicate the intensity of their heat. Just as a piece of metal goes through its changes from red-hot to white-hot as the temperature is raised, so the red stars are the least heated of all visible stars. Then follow in order the yellow, the white, and the blue. This is not fully established.

greatest number of faint stars are visible, though for telescopic work such nights are apt to be poor, on account of the unsteadiness of the atmosphere.

### Description of the Constellations.

214. We will now, by the aid of star maps, give a description of the position in the heavens of the constellations and brighter stars. The student should, after carefully reading this over, go out of doors on a clear and moonless night and endeavor to become familiar with the stars in the sky. Stars of the first magnitude are represented in the maps which follow by a five-pointed star. The size of the dots roughly indicates the brightness of the others. All stars down to the fifth magnitude are represented, and some of the fifth magnitude.

215. The first map, Fig. 58, represents the heavens around the north pole. All that part nearer the pole than 40° does not set in latitude 40°, and every twenty-four hours seems to make a complete revolution about Polaris, so will have different positions at different hours of the night and times of the year. The circles are circles of declination (see Art. 31), ten degrees apart. The radiating lines are meridians, fifteen degrees, or one hour, apart. If the student face the north, and hold up the map in front of him, it will give the position of the constellations at

6 o'clock P.M. on February 5.
8 " " January 5.
10 " " December 5, and so on.

For other times he must turn the map so as to bring the pointers and Polaris in their true positions with respect to each other.

*Ursa Major* is the first constellation to find. The handle of the Dipper is in the tail of the Bear, its bowl

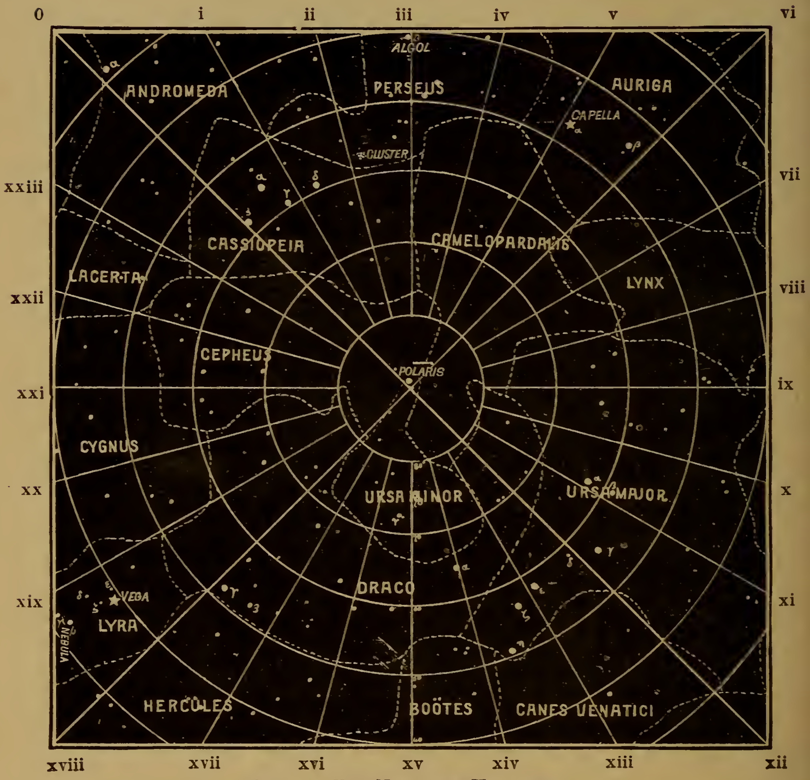

Fig. 58.—The Northern Heavens.

forms a part of the body, and his head and feet extend some distance from it, embracing, however, no very conspicuous stars.

*Ursa Minor* embraces Polaris. In it may be found the "Little Dipper," with the pole-star in the end of the handle.

*Cassopeia* is directly opposite Polaris from the Great Dipper. The conspicuous part is an irregular W, in which its five brighter stars are arranged. The arrangement also bears some resemblance to a chair, and the ancients represented Cassiopeia as a queen seated on a throne. If a line be drawn from the faintest star of the seven in the Dipper to $\beta$ in Cassiopeia, Polaris will be nearly in the middle of this line.

The two stars $\gamma$ and $\delta$ Cassiopeia point to a cluster which to the naked eye seems a mere haze of light, but which a small telescope resolves into a beautiful collection of stars. This is in the constellation *Perseus*. Continuing this line as much farther, we come to several stars of medium brightness, which constitute the principal part of the constellation. $\beta$ Persei, or Algol, is a little farther from the pole than this group. Its peculiarity will be explained in the next chapter.[1]

The constellation *Auriga* adjoins Perseus on the side away from Cassiopeia. It has two stars of considerable brightness, the brightest being the first-magnitude star Capella.

Not quite opposite the pole from Capella is the equally bright Vega in *Lyra*. Lyra can hardly be con-

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[1] According to ancient mythology, Cassiopeia was the queen of Cepheus, King of Ethiopia. Becoming vain of her beauty, she boasted that she was fairer than Juno, the sister of Jupiter, or than the sea-nymphs. To punish her presumption, it was ordained that she should chain her daughter, Andromeda, whom she tenderly loved, to a desert rock, exposed to the fury of a sea-monster. But Andromeda was rescued and the monster destroyed by the great warrior Perseus.

sidered a circumpolar constellation, and will be mentioned again.

The other constellations do not contain stars of much brightness, and can be traced in rough outline by the aid of the map.

216. *Southern Maps.*—In the maps which follow we have the constellations which pass to the south of the zenith at different times of the year. The maps overlap each other, so that the constellations found on the right-hand edge of one are also found on the left-hand edge of another. They extend also to about 50° north declination, and so embrace some of the stars shown on the preceding map.

The straight horizontal line through the centre is the celestial equator. The parallels of declination are 10° apart, and are numbered at the edge. The meridians are one hour apart, and are numbered from the vernal equinox. Hence the right ascension and declination of a star can be ascertained quite accurately by an examination of the maps. Also, if we know the right ascension and declination of some body, as a comet, it may be located on the map, among the stars, and then found in the heavens. Thus, suppose an object be given whose right ascension is 4 h. 20 m. and declination 15° north. This will be readily found to be among the Hyades. If the declination is greater than 40° north, it should be sought on Fig. 58.

217. *Southern Constellations Visible in Winter.*—Fig. 59 represents the southern constellations as they appear in winter. If the observer face the south, and the map be held so that the central meridian shall coincide with our meridian, it will show the appearance of that part of the sky at 8.30 o'clock about January 1.

Cassiopeia is now west of the zenith, and the Great Dipper is rising in the east.

The Milky Way extends across the heavens from the northwest to the southeast, passing through the zenith.

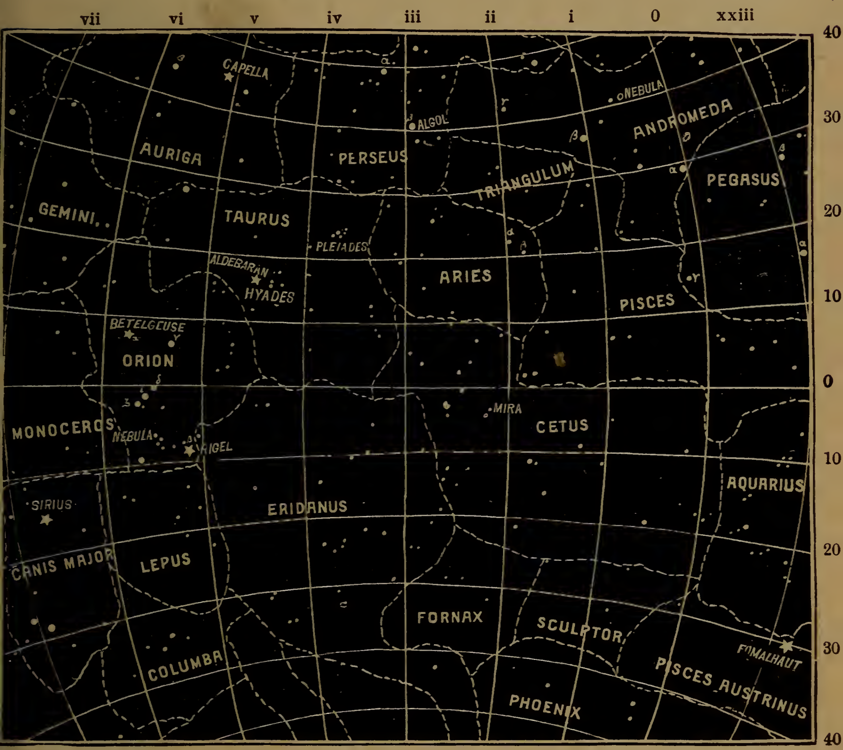

FIG. 59.—THE SOUTHERN HEAVENS IN WINTER.

Just on its edge, in the east, is the most brilliant constellation of the northern heavens, Orion, which on old star maps is represented by the figure of a hunter. Four bright stars form an irregular four-sided figure. One of these, a red star of the first magnitude, in the shoulder, is Betelgeuse ($\alpha$ Orionis). The other first-magnitude star is Rigel (β Orionis), in the foot. Three stars of the third magnitude lie in a row in the belt. Below the belt is another row of three fainter stars, the central one of which is surrounded by the famous nebula of Orion. On a moonless night this may be seen as a faint haze by the naked eye.

*Taurus* lies between Orion and the zenith. The group Hyades is easily known by its V-shape. The first-magnitude star at one extremity of the V is Aldebaran. Farther away from Orion are the Pleiades, a little cluster which cannot be mistaken.

*Canis Major* lies opposite Orion from Taurus. The very bright Sirius is its brilliant ornament. Two second-magnitude stars are about 11° southeast of Sirius.

Procyon,[1] in Canis Minor, makes a nearly equilateral triangle with Sirius and Betelgeuse.[2]

About half-way between Orion and Polaris is Capella, the brightest star of the constellation *Auriga*. A little farther from the zenith is β Aurigæ.

*Gemini*[1] lies between Capella and the east. Castor and Pollux, two bright stars about 4° apart, are easily distinguished. Between Castor and Polaris is a barren part of the heavens.

The variable star Algol will be almost exactly in the zenith, with the rest of Perseus a little to the north.

*Eridanus* is a large constellation south of Taurus, which does not contain any very conspicuous stars.

*Cetus*, west of Eridanus, is also a large constellation.

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[1] See Fig. 60.

[2] Taurus is usually represented as a bull charging at Orion, while the Hunter's two dogs, Canis Major and Canis Minor, follow him around the sky.

It contains two stars of the second magnitude, and the variable Mira.

On the western side of the zenith the most conspicuous group is the "Square of Pegasus." This consists of four stars in the form of a large quadrilateral, so arranged that two pairs point nearly to Polaris. The brightest of these, that one nearest the zenith, is not in Pegasus, but is α Andromedæ. The others are α, β, and γ Pegasi. Between α Andromedæ and Algol is β Andromedæ.

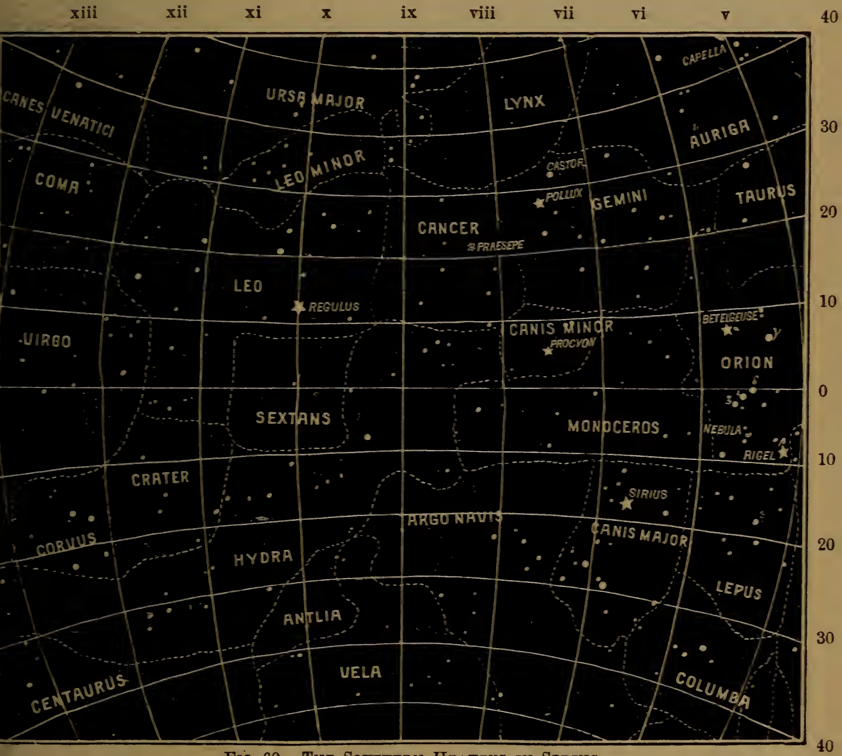

Fig. 60.—The Southern Heavens in Spring.

The above description will also answer for 10.30 o'clock, December 1; 12.30, November 1; and so on.

218. *Southern Constellations Visible in Spring.*—Fig. 60 shows the spring constellations visible in the evening. At 8.30 o'clock on April 1 the centre of the map will be on the meridian. The pointers will now be nearly overhead, and Cassiopeia low down in the northwest. Orion and Taurus will be sinking to the western horizon. Sirius will be low in the southwest, and Procyon nearer the zenith. Castor and Pollux will lie between Orion and the zenith, and Capella between Aldebaran and Polaris. The western heavens have therefore already been described. Just east of the meridian, to the south of the zenith, is the constellation *Leo.* The most conspicuous group of stars is the Sickle, in the head of the Lion. At the end of the handle is Regulus, a first-magnitude star, but not a very bright one. East of the Sickle about 16° is $\beta$ Leonis.

*Corvus* is low down in the southeast. It contains four stars of medium brightness, forming an irregular four-sided figure.

*Hydra* stretches from Procyon across south of the zenith all the way to the southeastern horizon. One second-magnitude star, $\alpha$ Hydræ, is nearly on the meridian.

*Coma Berenices* (Berenice's Hair) is a faint cluster readily seen by the naked eye, following Leo up the sky. Between it and the horizon is the brilliant Arc-tu′rus in *Boötes.* This will be found on Fig. 61.

*Virgo*, containing the brilliant Spica, is near the horizon, southward from Boötes.

This also describes the heavens at 10.30 o'clock on March 1, at 12.30 on February 1, and so on.

219. *Southern Constellations Visible in Summer.*—Fig. 61 shows the constellations around the meridian about 8.30 o'clock near July 1. The Dipper is now west of the meridian, with handle upward. The Milky Way

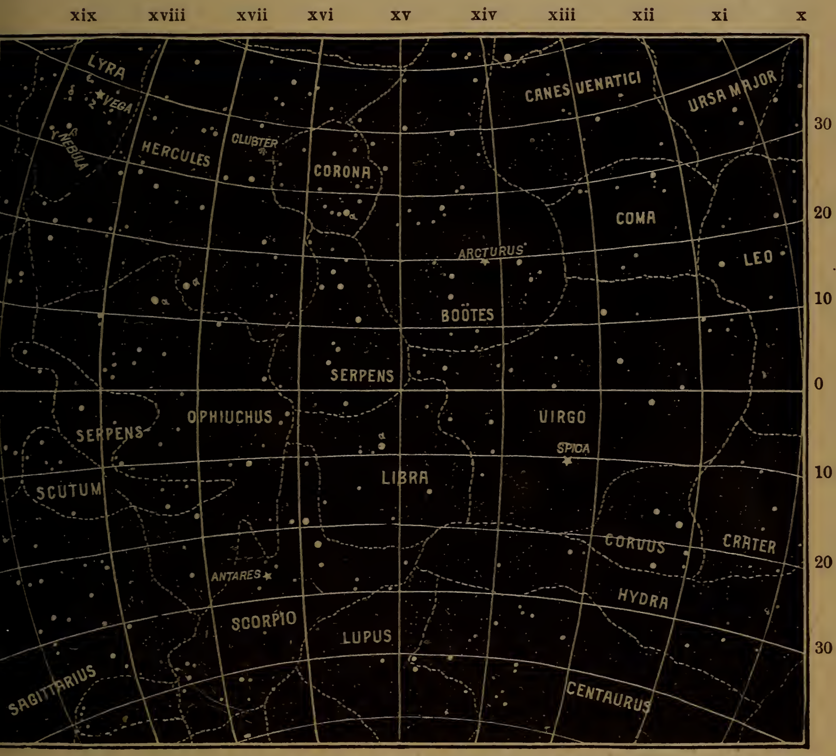

Fig. 61.—The Southern Heavens in Summer.

extends from the north to nearly the south point of the horizon on the east side of the zenith.

Of the constellations previously described, Leo will be near the western horizon, and Coma Berenices just above it. Virgo will be low in the southwest. Boötes will be on the meridian, with Arcturus southwest of the zenith.

*Corona*, a semicircle of stars, of which $\alpha$ is of the second magnitude, is on the meridian, nearly in the zenith.

*Hercules* is a large constellation not containing any very bright stars, which adjoins Corona on the east.

*Lyra*, east of Hercules, is a small but interesting constellation. The brightest star is Vega ($\alpha$ Lyræ), a star of the first magnitude. Two fainter stars form with it an equilateral triangle. The one of these nearest the pole is $\epsilon$ Lyræ, a quadruple star further described on page 241. The other star, $\xi$, is double. South of these are $\beta$ and $\gamma$, between which lies the ring nebula described on page 253. $\beta$ is a variable star (see page 245).

*Ophiuchus* lies south of Hercules, and contains nothing of special interest.

South of this, again, is *Scorpio*. The bright star in it is Antar′es. It may be known by its ruddy color and by the two stars of the third magnitude between which it is set.

*Cygnus* (Fig. 62), between Lyra and the east, contains the "Cross." It lies exactly in the Milky Way, with the long arm extending in its direction. At the head of the cross is *Deneb* ($\alpha$ Cygni).

*Aquila*, joining Cygnus on the south, contains Altair, of the first magnitude. It lies between two third-magnitude stars, the row pointing nearly north and south.

*Delphinus* contains "Job's Coffin," a little diamond of stars near the eastern horizon.

The above description is also applicable to 10.30 o'clock on June 1; 12.30 on May 1; and so on.

220. *Southern Constellations Visible in Autumn.*—Fig. 62 shows the heavens around the southern meridian about

8.30 o'clock on October 1. The Dipper is now near the northern horizon. The Milky Way stretches through the zenith from the northeast to the southwest.

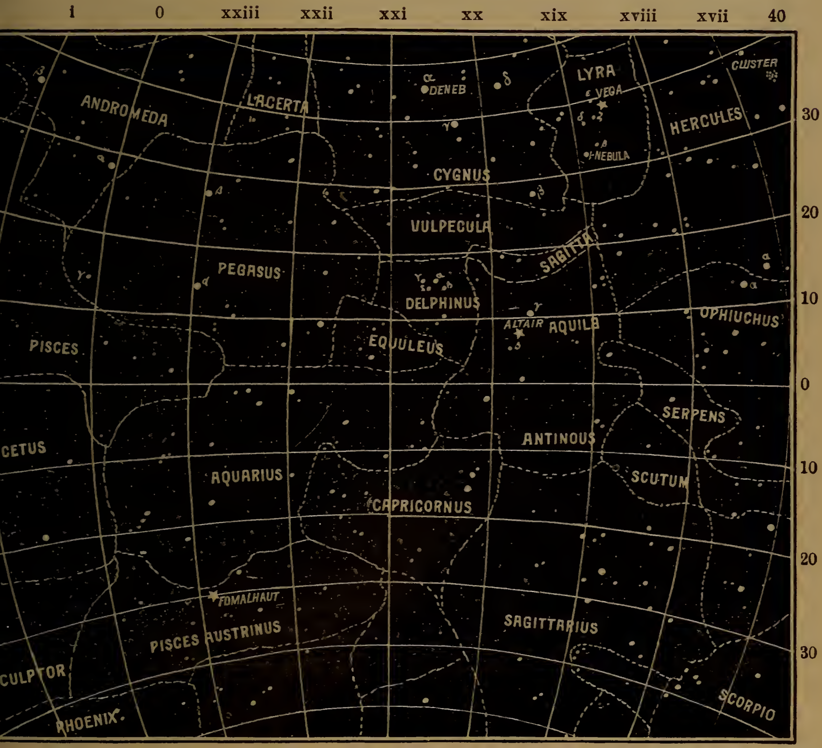

FIG. 62.—THE SOUTHERN HEAVENS IN AUTUMN.

All the constellations having now been described, a rapid review of their positions is all that is necessary.

Cygnus is in the zenith, and Lyra just west of it. Delphinus is a little west of the meridian, to the south of the zenith, and Aquila joins it to the southwest.

Hercules and Corona are near the western horizon. To the east the most conspicuous object is the "Square of Pegasus," one of the angles of which is $\alpha$ Andromedæ. Pisces joins Pegasus on the east. The bright star Fomalhaut, in *Pisces Austrinus*, is low down in the south-southeast.

This also describes the position of the heavens at 10.30 o'clock on September 1; 12.30 on August 1; and so on.[1]

The zodiacal constellations can be found on the maps. Their names have been given on page 41. The moon and all the planets will always be found in these constellations. The position of the planets should be ascertained beforehand, as, being conspicuous objects, the observer may lose time in searching for them on the charts if he mistake them for stars.

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[1] Any one who desires more familiarity with the heavens than can be gained from this general sketch should study them with the aid of a large star atlas. Heis's Star Atlas is convenient and reliable; Proctor's small Star Atlas is much cheaper. Whitall's Planisphere can be set so as to show the positions of all the stars with reference to the horizon at any time of night. Bailey's Astral Lantern is a cubical box with glass sides, within which is a lamp. The stars, with their names and magnitudes, show by transmitted light. It can also be set for any minute, and the names easily read in the dark.

# CHAPTER II.

## DOUBLE STARS.—VARIABLE STARS.—CLUSTERS AND NEBULÆ.—STRUCTURE OF THE UNIVERSE.

### Double Stars.

221. Many of the stars, when examined with a telescope, are seen to be made up of two or more parts, which are so close together that they present to the eye the appearance of a single star. Sometimes the components are of nearly equal size, and sometimes one is so faint as to be seen only with large telescopes. An instance of the former is *Castor*, and among the latter are *Sirius*, *Rigel*, and *Polaris*. Sir William Herschel, who first carefully studied these "double stars," at first supposed that they happened to be nearly in the same line of sight, though one might be much nearer to us than the other. On this supposition he measured their distance and direction from each other, hoping that the motion of the earth in its orbit would cause an apparent change in their distance apart, and that thus he could determine the parallax of the nearest one. After he had worked at this for some time he became aware that there was in some cases a connection between the two stars entirely different from what he had expected. Their distance and direction from each other changed too rapidly to be attributed to the motion of the earth alone. He finally concluded that the two components

of a double star in many cases were revolving about each other. This has been established beyond doubt by the researches of other observers. The two or more stars constituting such a group are, then, members of a common system. They revolve about their centre of gravity, just as do the sun and the earth, or the earth and the moon (Art. 113). The force of attraction exists among them, and their motions are performed in obedience to it. Several thousands of double stars are now known, and hundreds are added to the list every year. A list of such as are the most easily observed by the possessors of small telescopes is given in Appendix VI.

Those double stars in which a motion of revolution about each other has been certainly seen are called *binary stars*. When there are three or more in the group, they are called *triple* or *multiple* stars. When they are in the same line of sight without being binaries, they are said to be *optically* connected. New observations are continually placing in the list of binary stars those which were previously only known to be optically connected. It is possible, after the observations of several years, to calculate how large an orbit one of a pair of binary stars has, and how long it will take to complete it. The period of revolution for those which are determined the most accurately varies from twenty-five to one thousand years. So important is the measurement of double stars considered to be that some observatories give almost their whole attention to it. In the course of a series of years enough data will have accumulated to enable us to find the orbits of many more, and thus we shall gain additional knowledge of the condition of those distant suns.

Fig. 63 shows the orbit which one of the components of $\gamma$ Virginis makes about the other. The numbers on the diagram indicate the years when the stars were in that relative position. It will be noticed that nearly a complete revolution has been observed: at one end of the line we have the position of one of the stars in 1718, at the other its present position.

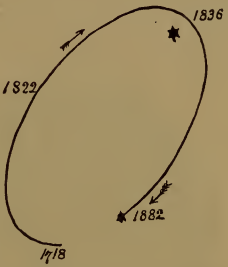

Fig. 63.—Orbit of $\gamma$ Virginis.

Figs. 64 to 67 show some of these multiple stars.

When more than two stars exist in the group, they may still be members of the same system: thus, of the stars of $\epsilon$ Lyræ, shown in Fig. 67, the two nearest each other perform their revolution in about one thousand years, the other two in about two thousand years; and each pair may revolve about the other in an orbit of immense size and in a period which is many thousands of years long. This star can be seen double by a good eye, and an opera-glass shows it easily. The components are not separable except by a telescope.

To measure double stars it is necessary to have an instrument attached to the eye end of the telescope, called a *micrometer*. This will be explained in a subsequent chapter. The two measures taken are the distance apart of the components, in seconds of arc, and the angle which a line joining them makes with the meridian through the brightest one. This angle is called the *position angle*, and is read all the way round from the north by the east from 0° to 360°. If the faint star were exactly north of the bright one, the position angle would be 0°. If it moved eastward around the bright one, the position angle would increase; when south, the angle would be 180°, and when west, 270°. It is clear that if they revolve about each other, one of these measures, or both, must change in course of time.

12 Lyncis.
Mags. 7½, 6, 6½.

ζ Cancri.
(1865.) Mags. 7, 6, 7½.

θ Orionis.
Mags. 8, 12, 7½, 6, 14, 7.

ε Lyræ.

Figs. 64 to 67.—Multiple Stars.

If we are looking at the orbit edgewise, one star will seem to move backward and forward over the other, and only the distance will vary; if we are in any other position with respect to the orbit, the angle with the meridian will also vary.

The double stars are sometimes beautifully colored, and when such is the case the colors are usually complementary[1] to each other. The larger star is most frequently red or orange, and the smaller one blue or green. Though the stars are in some instances really colored, it is probable that the complementary tints are mainly the result of contrast.

## Variable and New Stars.

Nearly all the new stars appear to remain of the same brightness night after night and year after year. A few of them, however, are perceptibly brighter at some times than at others. These are called *variable stars*. We will describe some of the most conspicuous of them.

222. *Algol.*—This star is marked $\beta$ in the constellation *Perseus*. In the autumn Perseus is in the northeast during the evening, in the winter nearly overhead, and in the spring in the northwest. Algol may be found by continuing the line joining Rigel with the Pleiades half as far beyond the latter. Usually its magnitude is $2\frac{1}{2}$. For two and one-half days it continues of this magnitude without apparent change; then for four hours it fades away, till it becomes of the fourth magnitude; here it remains for about twenty minutes, and then through four hours more gradually recovers its

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[1] Colors are *complementary* when their union produces white. When the eye notices any color, and is then quickly turned to a white or nearly white object, this object appears of a color complementary to the first. The complementary color is in this case an optical delusion.

original brilliancy. The exact period from one minimum to the next is 2 days, 20 hours, and 49 minutes. The times of its minima for the years 1882 and 1883 are contained in Appendix VIII. Only such are given as occur in the night and can be conveniently observed.

223. *Mira.*—This star is $o$ of the constellation *Cetus.* It comes to the meridian about fifty minutes earlier than Algol, and three and one-half degrees south of the equator. It is usually of the eleventh magnitude, so that it cannot then be seen by the naked eye. It gradually increases from this to the second magnitude. After first becoming visible it requires about forty days to reach its maximum, then it fades out of sight in about two months, and remains invisible for seven and one-half months, thus passing through all its changes in about eleven months. This time is variable, so that its return cannot be exactly predicted. Its maximum brightness is also variable: sometimes it is almost a first-magnitude star; sometimes at its brightest it does not exceed a fourth. It is expected to attain its greatest brilliancy in June, 1882, May, 1883, and so on; but, as the period varies from ten to twelve months, there may be some deviation from this.

224. $\eta$ *Argus.*—This star is in the Southern hemisphere, and can never be seen in latitude north of 31° north. Its variations of brightness are greater than those of any other periodic star. It goes through its changes in a period of seventy years: from a star invisible to the naked eye it increases almost to the brightness of Sirius. Its increase is not uniform, but numerous small fluctuations may be noticed along its course. The curved line of Fig. 68 shows its changes.

The horizontal lines indicate magnitudes, and the vertical lines periods of ten years. Every seventy years it goes down to the sixth magnitude. At intervening times its brightness varies as indicated by the irregular line.

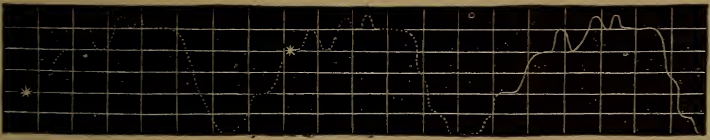

FIG. 68.

There are about one hundred and fifty known variables. The following table gives the stars in which the variations may be most easily distinguished. Those of the fifth magnitude and over can be seen and studied by the eye, for those from the fifth to the seventh magnitude an opera-glass may be employed, while those below the tenth magnitude can be followed only by the most powerful telescopes:

| Name. | Variation in Magnitude. | Period. |
|---|---|---|
| $\delta$ Libræ | 5 to 6 | $2\frac{1}{3}$ days. |
| T Cephei | $7\frac{1}{2}$ to 9 | $2\frac{1}{2}$ “ |
| $\beta$ Persei (Algol) | $2\frac{1}{2}$ to 4 | $2\frac{9}{10}$ “ |
| $\delta$ Cephei | 3.7 to 4.8 | $5\frac{1}{3}$ “ |
| $\eta$ Aquilæ | $3\frac{1}{2}$ to 5 | $7\frac{1}{3}$ “ |
| $\beta$ Lyræ | $3\frac{1}{2}$ to $4\frac{1}{2}$ | 13 “ |
| $\chi$ Cygni | 5 to 12 | 406 “ |
| R Aurigæ | 6 to 13 | 465 “ |
| o Ceti | 2 to 11 | 11 months. |
| $\eta$ Argus | 1 to 6 | 70 years. |

Many stars are known to vary their brightness slightly without any regular period having been discovered. Thus, *Betelgeuse* ($\alpha$ Orionis) is sometimes more, but usually less, bright than *Rigel* ($\beta$ Orionis).

225. *Cause of the Variation.*—We do not certainly know

the cause of the changes of brightness of variable stars. There may be a dark body like a planet revolving around the star, which, whenever it passes in front of it, cuts off a portion of its light. This is the theory which best explains the variations of such stars as Algol, which remain of the same brilliancy during most of the time, and at regular periods become fainter for a short interval. Other variables, which are *gradually* changing from one extreme to the other, are probably undergoing a real variation of brightness on their surfaces. We have already seen that the sun is, at regular intervals of about eleven years, largely covered with spots. These spots may slightly diminish its brightness, so that it can be considered a variable star with a period of about eleven years. If we suppose the spots to be greatly increased in number, so as largely to dim the surface of the sun, and this dimness to occur at regular periods, the phenomena of variable stars, as we notice some of them, would be accounted for.

226. *How to observe Variable Stars.*—The method devised by Argelander[1] of making observations on variable stars is as follows. Begin the watch a half-hour or more before the star will begin to change, and select two stars near the variable, one a little brighter and the other a little fainter. Now, if the difference between the brighter one and the variable is so slight that we could not imagine a star between the two, then the first star is said to be *one step* brighter than the variable; and if the variable is so much brighter than the other that just one star could be imagined between

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[1] Argelan′der, 1799–1875. In charge of the Observatory of Bonn, Prussia.

them, the variable would be brighter by *two steps*. If two stars could be supposed inserted between them, there is a difference of three steps; and so on. Calling the comparison stars *a* and *b*, and the variable *v*, the observation is noted thus:

1880, May 5, 10.15 P.M., *a* 1 *v* 2 *b*.

This means that *a* is one step brighter than *v*, and *v* two steps brighter than *b*. If the star is one that changes rapidly, as Algol, it should be observed every few minutes until its changes are over; if it changes slowly, as Mira, once a day is often enough. The next observation of our star may be this:

10.35 P.M., *a* 2 *v* 1 *b*;

and the next:

11 P.M., $v = b$.

If the star grow still fainter, a new and fainter comparison star should be taken, and the observations may go on, thus:

11.30 P.M., *b* 1 *v* 4 *c*;
11.55 P.M., *b* 2 *v* 3 *c*;
May 6, 12.20 A.M., *b* 3 *v* 2 *c*;
12.30 A.M., *b* 3–4 *v* 1–2 *c*;
12.40 A.M., *b* 3 *v* 2 *c*;
1 A.M., *b* 2 *v* 3 *c*;
1.30 A.M., *b* 1 *v* 4 *c*.

Here we see that the star was at its minimum about half-past twelve, when it was three or four steps fainter than *b* and one or two steps brighter than *c*. The observations should be continued till the star has come back to its usual magnitude. If the exact magnitudes of the comparison stars are found from a catalogue or elsewhere, the amount of change that the variable makes, as well as the time of minimum[1] or maximum, will also become known from the observations. The changes are frequently irregular, and these may be made more striking by laying them off in curves, as in Fig. 68, which shows the light-curve of $\eta$ Argus. The higher parts of the curve show when the star is brightest; we can see that it varies from the first to the sixth magnitude in seventy years, but that it changes irregularly.

It must be remembered that a step is the least possible difference, and that if there is room for an intermediate star the difference is two steps. A step has been found to be in practice about one-tenth of a magnitude. One should not trust himself to estimate a difference of more than four steps, but should use another closer comparison star. The condition of the sky, as clear, hazy, moonlight, etc., should be noted with the observation.

227. *New Stars.*—New or temporary stars are such as suddenly blaze out and shortly afterwards disappear. They differ from variable stars in that their increase of brightness is more striking and does not return at regular periods. The most noted of these was seen by Tycho Brahe[2] in 1572. He noticed a star of the

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[1] Minimum here means the least brightness, and maximum the greatest.

[2] A Danish astronomer, 1545 to 1601. "As a practical astronomer," says Sir David Brewster, "Tycho has not been surpassed by any observer of ancient or modern times. The splendor and number of his instruments, the ingenuity which he exhibited in inventing

first magnitude where he was certain it had not existed a half-hour before. It continued to increase till it exceeded any other star in the heavens and could be seen at mid-day; then it gradually faded away till it vanished altogether.

There are several other cases of new stars on record. One of these, which appeared in 1866 and increased till it became of the second magnitude, was examined by the spectroscope: it was found that the most of the light was due to the presence of hydrogen gas so heated as to cause the great brilliancy. We have seen that the red prominences in the sun are composed of the same gas. Hence we are led to infer that the cause of the sudden brilliancy of the star was a great outrush of burning hydrogen, which, partly by its own light and partly by heating the surface of the star, gave rise to the unusual brightness. Such an outbreak on the sun would so raise its temperature that life on the earth would instantly be destroyed. A single case is not sufficiently conclusive to prove this theory for all new stars; at all events, they are not suddenly created out of nothing, as was formerly supposed: the stars existed previously, and the brilliancy was the result of some change on the star itself. It is probable that some of these are variable stars of long period, and that we have observed only the one maximum.

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new ones, and his skill and assiduity as an observer, have given a character to his labors and a value to his observations which will be appreciated to the latest posterity." He rejected the Copernican theory because he supposed it to be contrary to the Bible.

## Clusters and Nebulæ.

228. *Clusters.*—An observer of the heavens will notice that the stars are not uniformly distributed, but are frequently collected into *clusters.* The Pleiades and Hyades are examples of these. The six stars of the former visible to an ordinary eye become transformed into a hundred in the telescope. Another illustration is Coma Berenices, which, in the evening through the spring, may be seen following Leo around the heavens. A careful observer will also notice patches of misty light, which a very small telescope will convert into stars. One of these, which may be seen on any clear

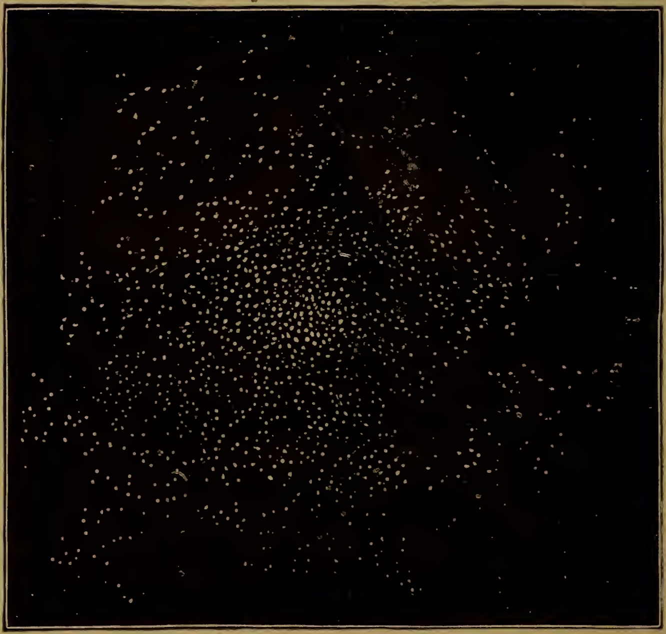

FIG. 69.—CLUSTER IN AQUARIUS.

night, is the "Beehive cluster" in Cancer. It is about half-way between Regulus and Castor, a little out of the line joining them. Another may be found in Perseus by producing the line joining γ and δ Cassiopeiæ beyond the latter a distance equal to twice their distance apart. In the telescope it is a beautiful mass of stars. Others will be found named in Appendix VII.

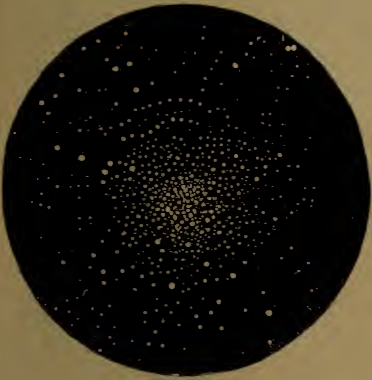

FIG. 70.—CLUSTER IN LIBRA.

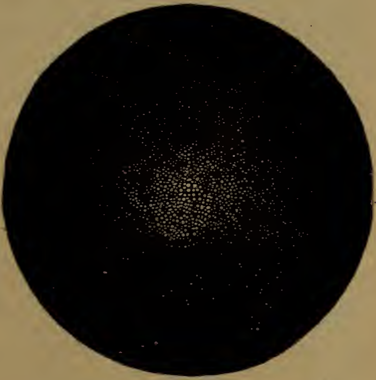

FIG. 71.—CLUSTER IN HERCULES.

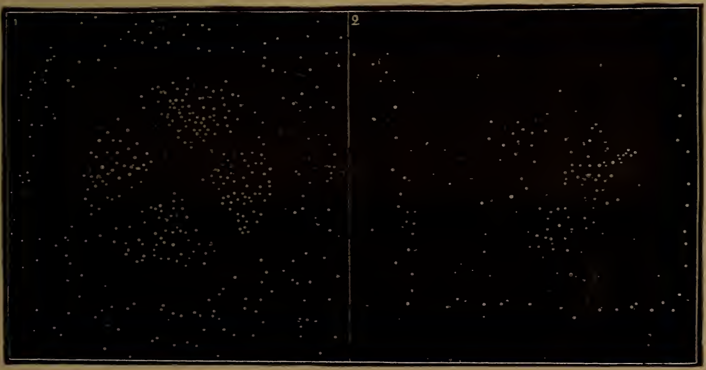

FIG. 72.—SINGULAR CLUSTERS.

Telescopes show a large number of other clusters. Many of these do not present any regular form. Some of them have a circular outline, with the stars more closely packed near the centre. The inference to be drawn from this appearance is that the cluster is in the shape of a globe; hence we should look through a greater stretch of stars near the centre than around the edges. But as such collections may constitute systems, held together by central attraction, there may also be a real condensation at the centre. The telescopic appearance of some clusters may be seen in the drawings on pages 250 and 251.

229. *Nebulæ.*—In addition to the clusters there may be seen in the telescope masses of misty light, which cannot be resolved into stars. These are *nebulæ.* Some of them are clusters so far away or so faint that the telescopic power is not sufficient to resolve them. It was thought for a time that as every increase of power resolved more and more of these into stars, when telescopes could be made great enough they would all be so resolved. But the spectroscope is able to tell from the character of the light whether it comes from a solid or a gaseous source: when directed to any of the resolvable nebulæ, it, like the telescope, gives evidence of their solid condition; but when some of the others are studied by it, it shows that they are just what they seem to be,—masses of luminous gas. Such nebulæ are not, then, collections of suns so far away that they seem to be clouds; they are entirely different from the stars; yet at the same time they give out light of their own, and are not rendered visible by reflecting the light of the suns around. They may be gradually condensing into suns, and perhaps serve to show the

FIG. 73.—GREAT NEBULA OF ORION.

early stages through which all the stars have passed. In the course of a long period of time a sun may be formed from each of them.

230. *Classification.*—There are about six thousand known nebulæ in the heavens. They are divided according to their form into five classes,—irregular, annular or elliptical, spiral, planetary, and nebulous stars. The first are the most common. The "Great Nebula of Orion" is an example. It may be seen with the naked eye on a moonless night as a faint light surrounding the star θ, the middle one of the three in the sword. The star itself is a multiple star, the four brightest components of which constitute what is called the *trapezium*[1] of Orion (see Fig. 66). From around these the nebula stretches out in irregular bands and patches, as shown in the drawing on the preceding page. It envelops the star ε in the belt and the star ι just below, and seems in an undefinable manner to cover the whole region thereabouts.

Ring nebulæ are quite rare. One in Lyra is shown in 1 and 2, Fig. 74. It is situated about midway between the stars β and γ, and can be seen with a small telescope. Sir John Herschel says, "The central vacuity is not quite dark, but is filled in with faint nebulæ, like a gauze stretched over a hoop." The other drawings of Fig. 74 show other ring nebulæ.

Elliptic nebulæ are classed with these, because they may be the same seen edgewise. The most conspicuous of these is the "Great Nebula of Andromeda," which is situated not far from β Andromedæ. It looks to the naked eye like a mass of diffused light, and has

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[1] A trapezium is a four-sided, irregular figure.

FIG. 74.—RING NEBULÆ.

FIG. 75.—GREAT NEBULA OF ANDROMEDA.

often been mistaken for a comet. The spectroscope seems to indicate that it is not gaseous, though the most powerful telescope fails to resolve it into stars. Fig. 76 shows several circular and elliptic nebulæ.

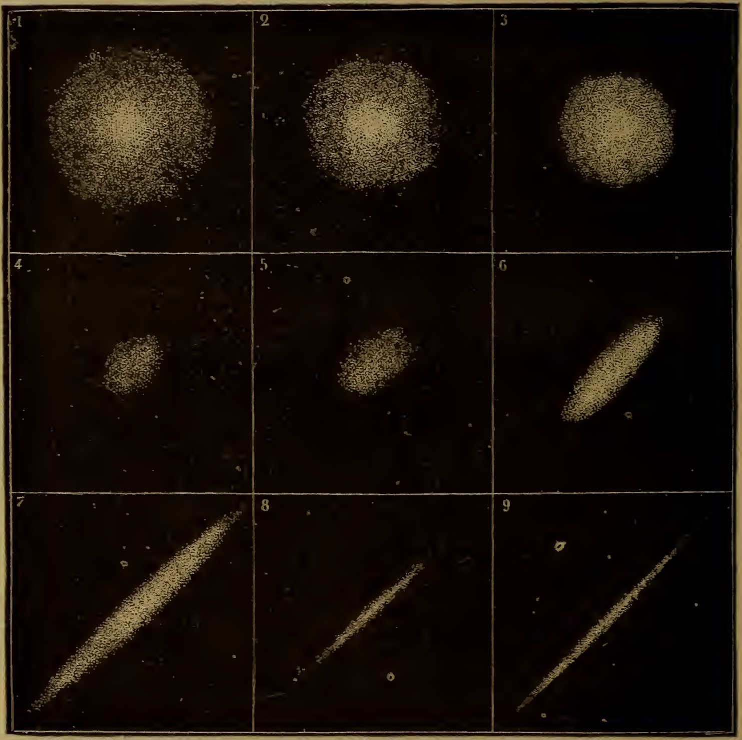

FIG. 76.—CIRCULAR AND ELLIPTIC NEBULÆ.

Spiral nebulæ can be seen as such only in the largest telescopes. Fig. 77 represents one as it appeared in Lord Rosse's great reflector.

Planetary nebulæ are so called because they resemble a planet in appearance. In the telescope a star looks like a point of light, brighter but no larger than when viewed with the eye alone. A planet, however, has its disk magnified when viewed in the telescope, so as to appear of appreciable size. A planetary nebula is uniformly bright, and often has a well-defined outline,

Fig. 77.—Spiral Nebula.

so that it might be mistaken for one of the outer planets of the solar system.

Nebulous stars are so named because they seem to be surrounded by an ill-defined nebulous atmosphere. It is noticed in a few cases of elliptic nebulæ that stars occupy positions near the two *foci*[1] of the ellipse. In other cases the stars seem to be in the centre of a neb-

FIG. 78.—DUMB-BELL NEBULA IN VULPECULA.

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[1] See page 33.

ulous mass. These arrangements are too common to be the results of chance, and it is probable that there is some physical connection between the stars and nebulæ. Such stars are often variable. A very conspicuous nebula surrounds the remarkable variable, $\eta$ Argus.

231. *Magellanic*[1] *Clouds.*—These are two nebulous objects which can be seen by the naked eye in the Southern hemisphere. When examined with a telescope they are shown to be made up of a collection of nebulæ, clusters, and single stars, crowded together in great confusion,—a kind of miniature sidereal system.

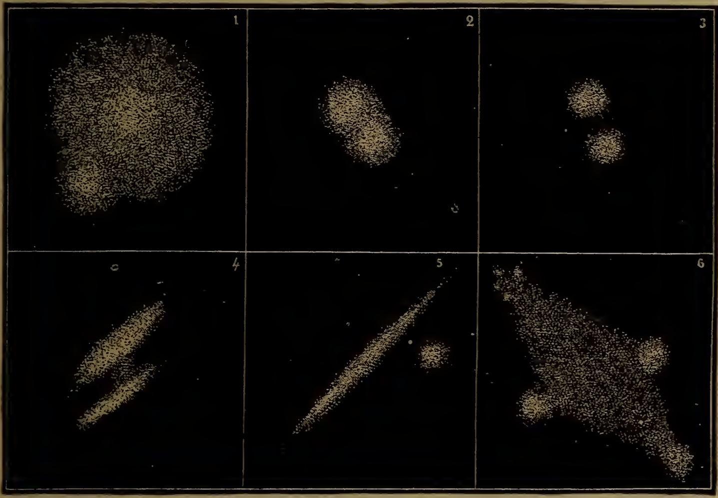

FIG. 79.—DOUBLE NEBULÆ.

232. *Variable Nebulæ.*—There are nebulæ, like stars, which vary in brightness at different times. New nebulæ have also been announced where none had been known to exist previously. We have likewise the phe-

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[1] Named from Magellan, the navigator.

nomena of double nebulæ, the parts of which may revolve about each other.

### Structure of the Universe.

233. The greatest problem which astronomers have ever attempted to solve is the determination of the shape and structure of the sidereal universe taken as a whole. We do not know that we have reached the outer bounds of the *solar* system; there may be planets outside the orbit of Neptune; there are probably an immense number of planetoids and meteors, of which we know nothing, inside its orbit. Since our information is so imperfect concerning the construction of the system in which we are, it might be expected that anything regarding the bounds of the great sidereal universe would be out of our reach. In most portions of the heavens the only effect of more powerful telescopes is to bring into view more stars and nebulæ, without seeming to pierce through the stratum to any vacuity beyond. The largest glasses ever constructed show a thousand times as many stars as we see by the eye; but they reveal also faint glimmerings of light which tell of clusters beyond their reach. If the light from the nearest of the stars is years on its way to us, the light from some of these outlying members has been coming to us for centuries. These facts suggest to us numbers which we cannot even imagine; the distance to the boundaries of the universe is inconceivable, and to tell anything of its shape or its structure may well seem a hopeless problem.

234. *Distribution of the Stars.*—There are, however, a few facts which throw a little light on the question.

Sir William Herschel, in order to aid in its solution, undertook a system of "star-gauging." This consisted in systematically going over the heavens, pointing his telescope to every part, and counting the number of stars in the field of view. By this means he found that they were not distributed uniformly over the sky, but were arranged with some regularity with reference to the Milky Way. He found that the nearer to the Milky Way his telescope pointed, the greater was the number of stars he could count in its field of view at any one time; and that the place in the heavens most barren of stars was the region that surrounded the poles of the Milky Way,—the points just 90° from it. Having ascertained with great certainty this law of distribution, he then took it for granted that the stars were distributed uniformly through space; that is, that they were all separated from one another by equal intervals. When he looked into his telescope and counted only a few stars, the inference would be that the system came to a limit soon in that direction; if the field of view was crowded with stars, it might be expected that in that direction the system extended to a great distance, star beyond star, each star separated from every other by a distance as great as that between our sun and its nearest neighbor. As he had found that the stars were strewn more closely as he approached the Milky Way, he concluded that the universe was a flattened, lens-shaped mass, having its greatest extent in the direction of the Milky Way: when, then, we look in that direction the ring of light we see there indicates the great stretch of the universe in that plane; when we look at right angles to this plane our gaze comparatively soon reaches out beyond its limits. This theory is wholly based on the assumption of the equal distribution of the stars; if it be true, as seems probable, that the stars are crowded more closely in the plane of the Milky Way than elsewhere, it may be that the universe is no more extended in that direction than in others. But whatever be the outline of the universe, considered as a whole, Herschel's investigations undoubtedly show that the greater *number* of stars are clustered near the plane of the Milky Way, and that we are situated in that plane, or near to it. The Milky Way may be such a flat disk as Herschel describes, or it may be a ring; in the latter case we must suppose it to be filled inside with a looser company of stars, of which our sun is one.

235. *Distribution of the Nebulæ.*—The nebulæ are arranged very differently from the stars. While many clusters are in and near the Milky Way, the real irresolvable nebulæ are there distributed *least* profusely. The constellation which contains the most of them is Virgo, which is situated as far from the Milky Way as possible; on all sides of this they diminish in frequency with considerable regularity. The figure on the opposite page, drawn by Richard A. Proctor, shows the Milky Way and the distribution of the nebulæ. Each dot is a nebula. It will be seen that they increase in frequency as we depart from the Milky Way.

236. *The Universe.*—So far as our knowledge of the great sidereal system extends, which is only a very little way, we may, then, consider it to be either a flat disk or ring of stars, of which the sun is one, and that its greatest extent is in the direction of the Milky Way; while on either side of this plane are groups of nebulæ, interspersed with a small number of stars. It is a very great and complicated universe. The stars in

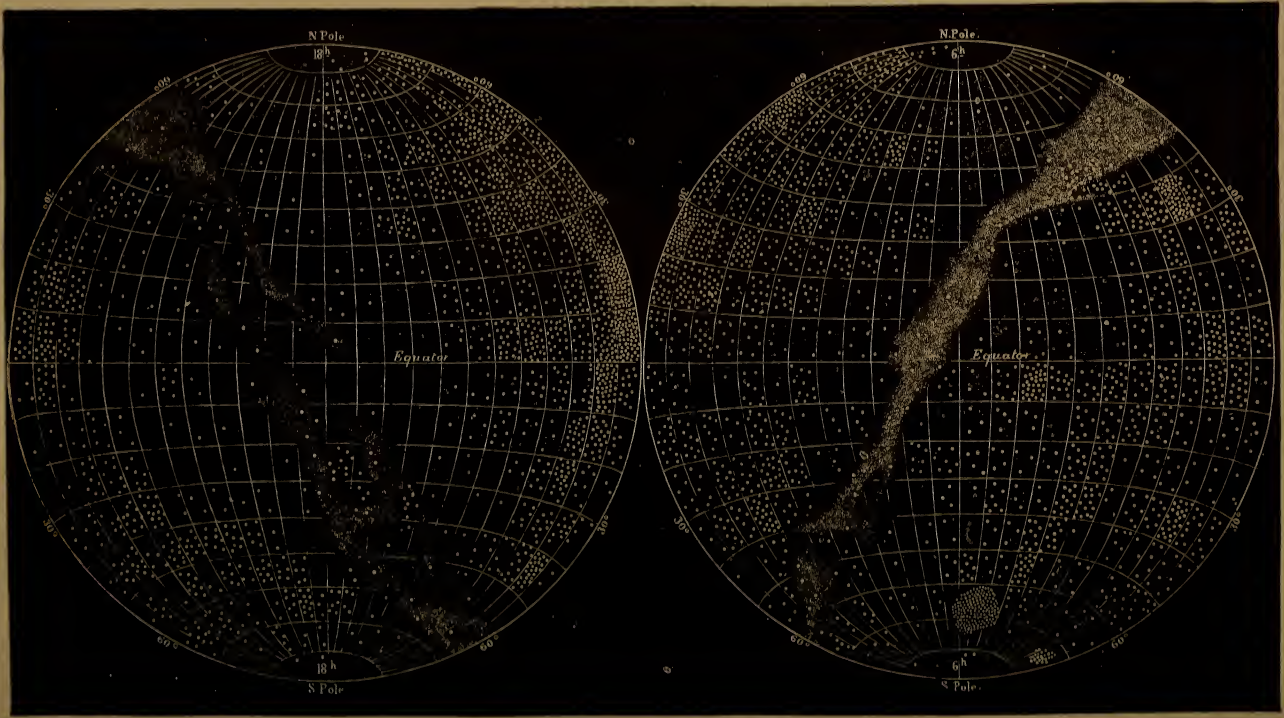

Fig. 80.—Distribution of Nebulæ.

it are moving in all conceivable directions, and, so far as can now be known, do not revolve about any common centre, as is the case with the solar system.[1] In all probability, around these suns are moving multitudes of dark worlds, while comets are speeding in all directions, messengers from one solar system to another. All is regulated by material laws, which keep every member in its place, and over all and in all rules the Great Lawgiver.

237. *The Nebular Hypothesis.*—But the question comes up, What has been the past history of the universe? Was it created just as we study it now? This is not probable. There has doubtless been a gradual growth to its present condition. Through what stages the growth has been carried we do not certainly know. There is a theory, commonly called the *nebular hypothesis*, which will account for many of the facts, but which seems to be disproved by others. As it has received a wide notoriety, we will explain it briefly here. The theory is that every star, with its attendant system of worlds, was at one time in the form of a gaseous nebula. A motion of rotation was set up in this mass. The central attraction would tend to condense it towards the centre; as it contracted in volume its velocity of rotation would increase, and the tendency of the parts around the equator of the mass to fly out from the centre would also increase. Hence there would be thrown off around the outer edge of the revolving nebula a ring of matter, and the remainder of the nebula would go on contracting, leaving the ring separated

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[1] A theory has been proposed that Alcyone, the brightest of the Pleiades, is the centre of the sidereal system. There is no satisfactory proof of this, and astronomers consider it improbable.

from it. When the contraction went on farther, a second ring would be thrown off, and the process would go on till the central mass became a sun. Fig. 81 is a fanciful picture of the appearance of the solar system at one stage of development.

The rings which had been thrown off at various times would also condense by radiating heat to the cooler space around; if the condensation was about equal all around the ring, a number of small masses would be formed, and the phenomenon of our ring of planetoids, or of the rings of Saturn, would be presented; if, however, one portion were denser than the rest, it would gradually attract the other parts to it, till the whole ring was joined in a single planetary mass. This mass might in its turn condense and throw off rings which would form the satellites.

Fig. 81.—Illustration of the Nebular Hypothesis.

We can trace the possible development further. The planets would be at a great heat, at first being gaseous, and then liquid; in course of time, by the continual radiation of heat, a crust would be formed on their surfaces which would gradually be prepared for habitation; the larger bodies, the central masses, would cool more slowly, and thus their worlds could have the benefit of their light and heat; on the other hand, the small moons would soon become cold and barren, as we know our moon to be.

The facts in support of this theory are,—

First. In our solar system the planets all revolve around the sun in one direction, and nearly in the same plane. The satellites in general move about their primaries in the same direction, and nearly in the same plane, and the planets, with the probable exception of Uranus, turn on their axes the same way. If they had ever been parts of a common revolving body, they would of necessity show this common direction of rotation.

Second. Matter in the interior of the earth is known to be in a liquid molten state. The heat increases as we descend into the earth, and the effects of heat are shown in the igneous and metamorphic rocks.

Third. We see in the heavens a number of nebulæ which seem to be in the various stages of development in this direction, and which the spectroscope now shows to be gaseous. According to the theory, these are, then, systems in process of growth.

# PART III.

## ASTRONOMICAL INSTRUMENTS.

238. *Properties of Light.*—We will now briefly consider such of the properties of light as are necessary to the correct understanding of the principles involved in the construction of the telescope and the spectroscope.

When a body is luminous it is so on account of a rapid vibration of its particles. These vibrations are conveyed by the ether. This ether fills up all the space between the different bodies of the universe, and also exists in the pores of matter; when these waves enter the eye they affect the nerve and brain in such a way as to give us the sensation of light.

Waves of light, when they pass through a substance of uniform density and transparency, move in straight lines. When they strike a smooth surface which they cannot penetrate, they are *reflected*, and bound off, making, in the opposite direction, the same angle with the perpendicular to the surface which they had before striking. As we see an object by means of the rays of light which pass from it to the eye, it appears to be in the direction from which the light comes as it enters the eye. Thus, in a mirror the contents of a room seem to lie behind the wall, because the light from them, turned back by the mirror, moves from that direction.

When these waves of light pass from one medium to another, transparent but of different density, they do not turn back, but slightly change their course. This change of course is termed *refraction*. We have shown in Chapter IV. the effect of the refraction of the different strata of the atmosphere. If the waves pass into a piece of glass at an angle, the same phenomena are noticed; the direction changes so as to agree more nearly with the perpendicular to the surface.

Another phenomenon besides refraction takes place when light passes from one transparent medium into another. The waves which make up a ray of ordinary light are of different lengths; some vibrate rapidly, and when they reach the eye alone give the sensation of blue light, and some vibrate more slowly, and give the idea of red; while between these are all the other colors of the rainbow. A ray of ordinary light contains all these colors, and when it enters obliquely a transparent medium of different density the short blue rays are turned from their course more than the longer red ones, and we see the rainbow colors. This is called *dispersion*.

239. *Velocity of Light.*—The fact that light requires a certain time to pass from one point to another was discovered by Römer[1] in 1675. He noticed that the times of the eclipses and transits of Jupiter's satellites occurred later when the earth was on the side of its orbit opposite to Jupiter than when it was nearer to him. The first one of these points is farther from Jupiter than the other by a distance equal to the diameter of the orbit of the earth. Thus, if EE′ be the earth's

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[1] Rö′mer, a German, 1644–1710.

orbit, S the sun, and J the position of Jupiter, the earth at E is nearer to Jupiter than at E′ by the distance EE′, the diameter of its orbit. He therefore rightly concluded that the reason of the lateness was the greater distance the light has to pass over in one case than in the other. This lateness amounts to about sixteen and one-half minutes. The time it requires light to pass over the space which separates the earth from the sun thus becomes known, and from this, if we know the velocity of light, we can determine the distance to the sun. Very careful investigation has shown that the time necessary for light to pass from the earth to the sun is 498 seconds. By multiplying 498 by the number of miles that light moves in one second, we obtain the distance to the sun in miles.

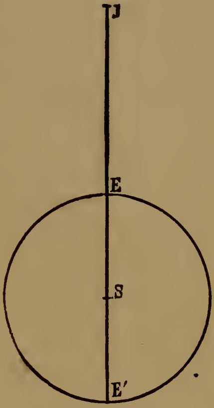

FIG. 82.

It therefore becomes a very important problem to determine the velocity of light. Several methods have been used, which are described in treatises on natural philosophy. The one which has produced the best results is that which was first suggested by Foucault,[1] and which has since been carried to a great degree of perfection by Michelson.[2] The outlines of the method are as follows. Sunlight is allowed to pass through a narrow slit and fall on a mirror which is rapidly revolving; from this it is reflected to another mirror, which turns

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[1] Foucault (foo-kō′·), a French natural philosopher, 1816–1868.

[2] Michelson, Professor at U. S. Naval Academy at Annapolis.

it back to the revolving mirror, and thence to the slit. If the light were propagated instantaneously, it would be reflected back exactly to the place from which it started; but, as it takes some time for it to pass twice between the mirrors, the revolving one has slightly changed position, and the reflected image will fall a certain distance from the slit. This small displacement is accurately measured, and from it can be obtained the time that the light requires to move from one mirror to the other. Great care, and numerous devices too intricate to explain here, were used to make the result as accurate as possible. The figures which it is believed most nearly represent the actual velocity of light are 299,940 kilometres, or 186,380 miles, per second.

The distance to the sun obtained from this is $186,380 \times 498 = 92,827,240$ miles.

240. *Telescopes.*—There are two necessary parts of every telescope,—a mirror, or lens, to collect the light and form an image of the object, and one or more lenses to magnify this image. When the first of these parts is a mirror, it constitutes a *reflecting telescope;* when a lens, a *refracting telescope.* The second part is called the *eye-piece*, because the eye is applied to it. The two parts are usually connected by a tube, to keep out side-rays.

241. *Principle of Reflectors.*—The essential part of a reflecting telescope is a concave mirror, which collects rays from all parts of the object and brings them to a focus, forming an image of the object. The eye looks at this image. As many more rays of a star can fall on a large mirror than on the eye, a faint star will look just as much brighter as the surface of the mirror ex-

ceeds the surface of the pupil of the eye, leaving out some light lost by the reflection. The largest mirror of this kind ever made is that of Lord Rosse's telescope: its diameter is six feet, and it can collect 250,000 times as much light as the unaided eye. Its *speculum*, as the concave mirror is called, was made of a combination of copper and tin, which was moulded and then ground under water till it came exactly to the proper shape. Metallic specula of this kind tarnish soon, and then have to be taken from the tube and reground, so that few of them are now made. Instead of this, one side of a large glass disk is carefully hollowed out to the proper shape and covered with a very thin coating of silver. This does not soon tarnish, and when it does the silver is easily removed and a new coating applied. Owing to the difficulty of supporting a piece of glass of very large size, reflectors of this kind have not been made over three feet in diameter.

242. *Kinds of Reflectors.*—There are three kinds of reflecting telescopes, depending on the situation of the eye-piece. The first was invented by James Gregory,[1] the second by Sir Isaac Newton, and the third by Sir William Herschel; hence their names.

In the *Gregorian* the rays, after being reflected by the large mirror, are collected on a smaller one, situated in the position of *mn*, Fig. 84, but so placed as to reflect the rays directly back to *M*. The eye is placed back of the speculum and looks through an opening in it.

In the *Newtonian* the second mirror is placed diagonally, so that the rays are reflected out at one side of the

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[1] A Scotch mathematician, 1638–1675.

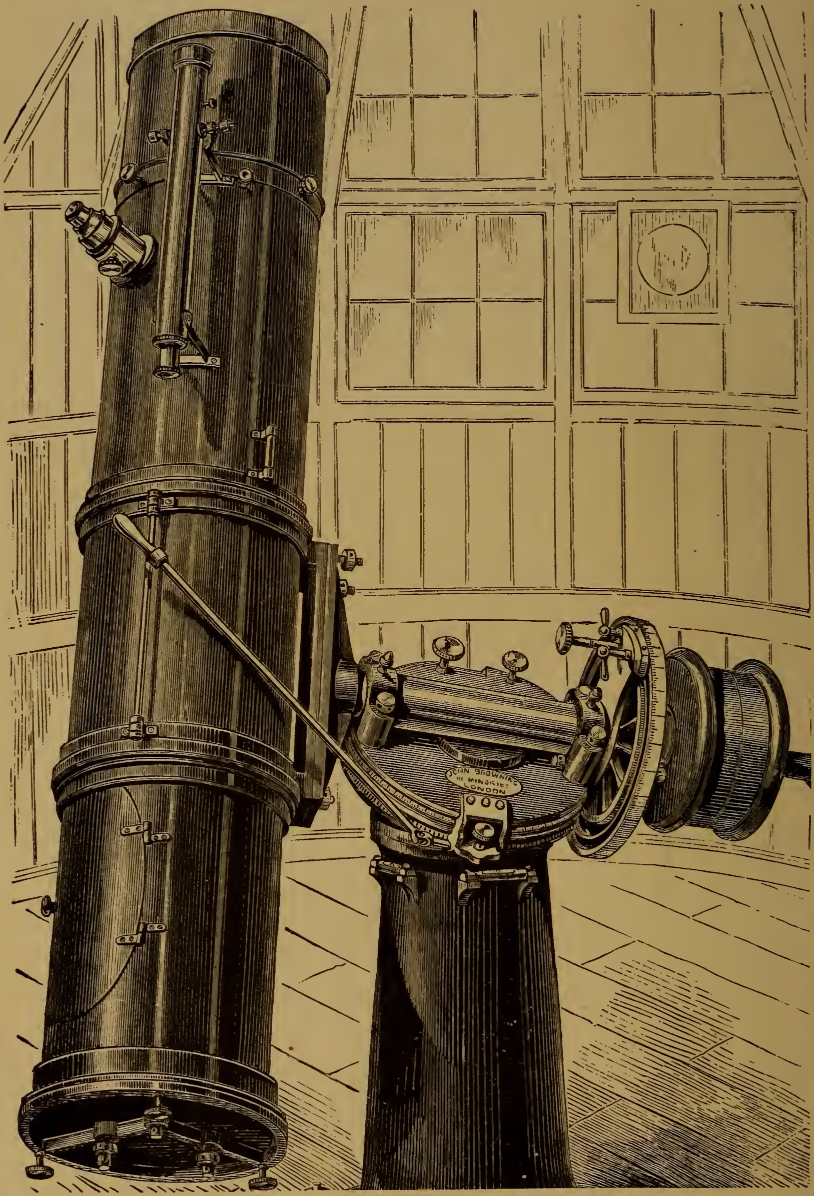

FIG. 83.—NEWTONIAN REFLECTOR EQUATORIALLY MOUNTED.

tube where the eye-piece is placed. The observer looks at right angles to the direction of the object which he wishes to view. Fig. 84 shows the course of the rays of light through a Newtonian telescope. M is the concave speculum, and *mn* the diagonal mirror, or "flat," which reflects to the eye at D.

In the *Herschelian* the large mirror is tilted so as to bring the light to a focus at one edge of the opposite end of the tube. The observer is situated here, and has his back turned towards the object he is viewing.

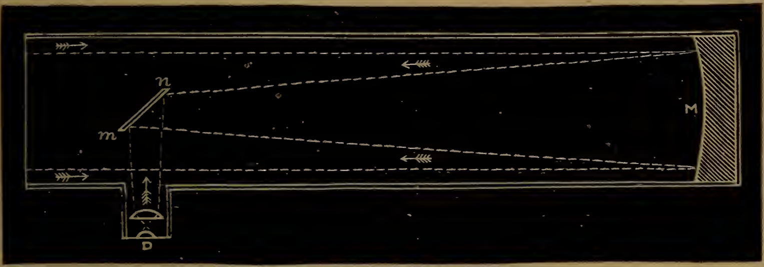

FIG. 84.—PRINCIPLE OF THE NEWTONIAN REFLECTOR.

In the first two the small mirror cuts off a portion of the light which would otherwise fall on the speculum; some light is also lost by the double reflection. In the third the observer's head cuts off some light,—less, however, than is lost in the others. The large telescope of Lord Rosse is Newtonian, as are also most of those now constructed.

243. *Principle of Refractors.*—In refracting telescopes the light is collected by means of a double convex lens of glass. The observer looks directly towards the object to be viewed, as in the common spy-glass. The large lens is called an *objective*, or *object-glass.*

When the early telescopes were made, a difficulty was experienced from the fact that the object-glass not only refracted the rays and brought them to a focus, but also dispersed them, so that the observer saw colors surrounding the object viewed. This was corrected by Dollond[1] in the following manner. He made a double convex lens of crown glass in the usual way, and combined with it a concave lens of flint glass. The flint glass unites again the different-colored rays separated by the crown glass, while from its different quality it does not counteract the refracting tendency of the convex lens. The noted opticians, Alvan Clark & Sons, of Cambridge, Massachusetts, make their lenses now as shown at A, Fig. 86, combining a double convex lens of crown with a lens of flint, of such a curvature on one side as to fit into the convexity of the crown, and flat on the opposite side. The best telescopic work is now done by refracting telescopes with their objectives arranged in this way.

The most powerful telescope in the United States is the refractor of the Washington Observatory, which has an object-glass of excellent construction, twenty-six inches in diameter. The only completed telescope larger than this is twenty-seven inches in diameter, and is at Vienna. There is, however, now in process of construction by Alvan Clark & Sons a refracting telescope of thirty inches in diameter for the Russian Observatory at Pulkowa, and one thirty-six inches in diameter for the Lick Observatory in California. Such huge glasses have to be ground with the greatest care, and require years for their completion. Other large telescopes are mentioned in Appendix II.

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[1] An English optician, 1706–1761.

244. *Eye-Pieces.*—The eye-piece is a microscope for magnifying the image formed by the speculum or objective. One lens would answer the purpose, but, to secure distinctness all around the field of view, a second

FIG. 85.—PORTABLE NEWTONIAN REFLECTOR.

lens is added. The amount of convexity of these lenses determines the magnifying power of the telescope. If nearly flat, the image is seen almost of its real size; if more convex, the rays enter the eye so as to make a larger angle with one another, and the image is much magnified.

Fig. 86 gives the course of rays through a refracting telescope. It will be seen that they cross at the focus B: hence such a telescope always inverts objects. This is a matter of no consequence with the heavenly bodies, but when terrestrial objects are to be observed it is necessary to add two more lenses to turn them over again. This is the only difference between an astronomical telescope and a common spy-glass.

FIG. 86.—ILLUSTRATION OF THE PRINCIPLE OF REFRACTORS.

245. *Micrometer.*—Very fine spider-webs are stretched across the tube in the focus. These can be seen at the same time with the image of the body we are observing. By having these movable, they can be so placed as to agree with the images of two stars which may be in the field of view, and the distance between them may be measured on some scale conveniently arranged for the purpose. Such an instrument is called a *micrometer*, and is indispensable in measuring double stars and for other purposes. It is so arranged that it can be taken off the telescope and put on at pleasure.

246. *Illuminating Power.*—The advantages of telescopes are twofold: they collect a great amount of

light, and they enable us to see a magnified image of the object. The first advantage will depend entirely on the size of the mirror or lens. This may be considered to be a huge eye, and all the light which falls on it is conveyed through the eye-piece to the retina. Hence a great advantage of a large telescope is the ability to see very faint objects. Herschel's great reflectors, which he made with his own hands, brought to his view thousands of nebulæ which were not previously known to exist. The little moons of Mars were never recognized till Prof. Hall saw them with the great refractor of the Washington Observatory.

247. *Magnifying Power.*—The focal length of the object-glass, divided by the focal length of the eye-piece, expresses the magnifying power of a telescope. The focal length of a lens is the distance from its centre to the place where the image is formed. In Fig. 86, AB represents the focal length of the lens A. We can therefore increase the magnifying power either by lengthening this distance, or by shortening the focal length of the eye-piece, which is done by making it more convex. In early times of telescope-making the first method was adopted, and the instruments of the seventeenth century were wonderfully long and unwieldy. Latterly it has been deemed better to make the telescope moderately long, and to gain power by shortening the eye-piece. If the focal length of the object-glass were forty inches, and that of the eye-piece one-half inch, the magnifying power would be $40 \div \frac{1}{2}$, or 80. Another way to find the magnifying power is the following. Point the telescope to the bright sky and focus the eye-piece, when a small circle of light is observable in the eye-piece. This is merely the light

which falls on the object-glass reduced in size by the passage through the lenses. The diameter of this circle divided into the diameter of the object-glass will give the magnifying power.

It must be remembered that the magnifying power of a given eye-piece will vary with the object-glass with which it is connected; also that there is a limit to the power that can be used with any size of aperture. If too great a power is applied, the magnified image becomes indistinct. It is like looking through a pin-hole: everything is confused. A refractor of six inches aperture cannot to advantage have a power of over 600; one of ten inches aperture, of over 1000; and so on. And this high power can be used only when the atmosphere is in a very favorable condition.

In looking over the country on a hot day there may be noticed a quivering of the objects in the horizon. This is due to the light from these objects passing through strata of air which are differently heated. This quivering is often noticed in the telescope, and the higher the magnifying power the more it interferes with distinct vision. The nights are very few when the atmosphere is so steady that a very high power can be used to advantage. Sometimes the air in and around the telescope-tube becomes heated so that nothing can be done till the observatory is completely cooled to the surrounding temperature. The temperature in the telescope-room should always be as nearly as possible the same as that outside.

248. *Equatorial Telescopes.*—Small telescopes which require to be moved from one place to another are mounted on a tripod or other light stand. In observatories it is necessary to have them permanent. All

telescopes intended for general work are mounted *equatorially*. An equatorial telescope is shown in Fig.

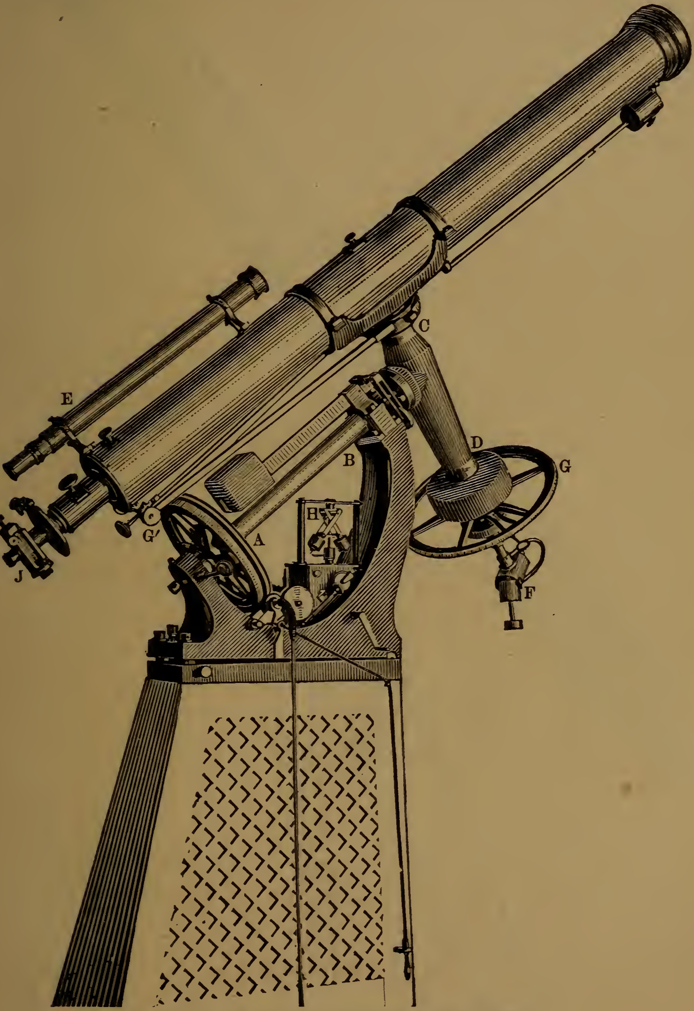

Fig. 87.—Equatorial Refracting Telescope.

87. The advantage of this mounting is that a star can be easily followed as it is carried by the diurnal motion

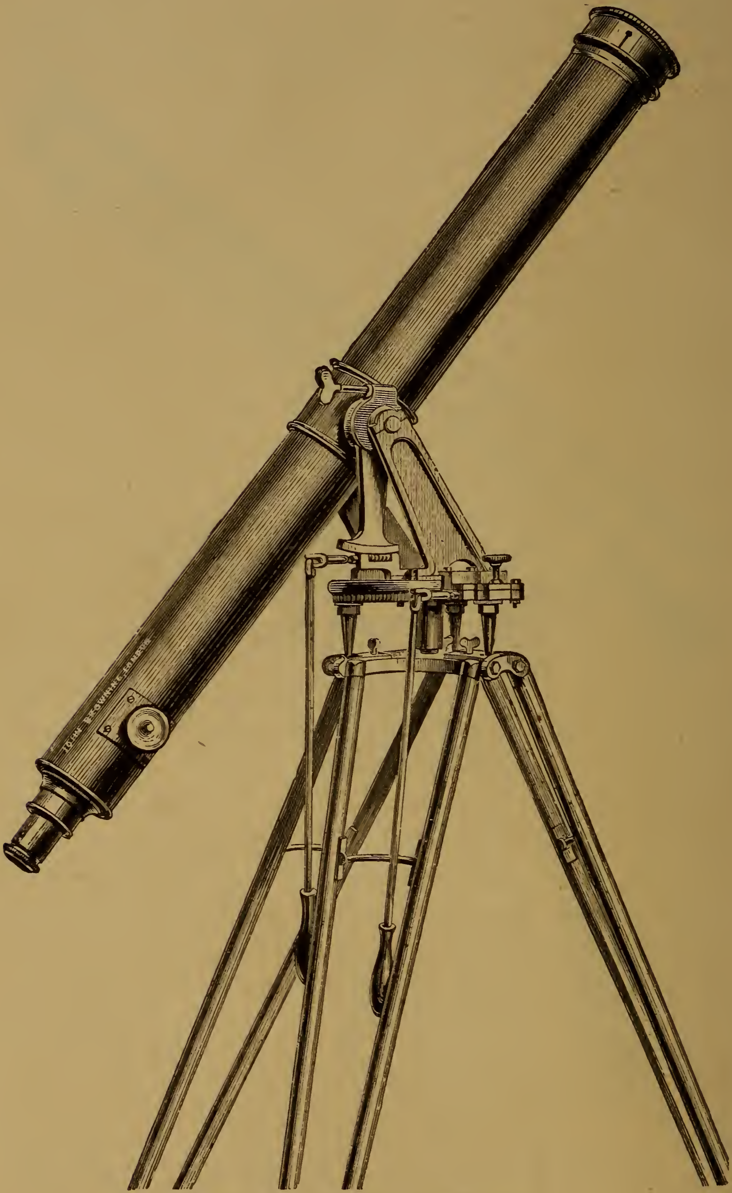

FIG. 88.—PORTABLE REFRACTING TELESCOPE.

around the earth. The mounting consists of two axes at right angles to each other: one of these is pointed directly towards the pole of the heavens, and is called the *polar axis;* the other is attached to this at one end, and is called the *declination axis.* The telescope turns on the declination axis, and with it around the polar axis: hence it can be pointed to any part of the sky. As the polar axis is parallel to the axis about which the diurnal motion of the stars is performed, the telescope pointed to a star and turned on this axis alone will follow the star from rising to setting. This turning can be done by clock-work so regulated as to move the telescope just as fast as the star moves; that is, at such a rate as to make a complete revolution in a day. The star then will keep exactly in the field of view, and, if the clock works accurately, on the same spider-line of the micrometer, so that it can be studied and measured at leisure. In the figure, AB is the polar axis, CD is the declination axis, E is the finder,[1] F is a lamp so arranged as to light up the interior of the tube so that the spider-lines can be seen at night, G and G′ are graduated circles upon which the distance of a star from the meridian and its declination may be read, H is the clock which turns the telescope, J is the eye-piece and micrometer.

249. *Transit Instrument.*—The transit instrument is a telescope mounted on a single axis which rests on two piers or posts. It is set so as to swing exactly in the

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[1] A finder is a little telescope with a large field of view, by which to find a star. As it will embrace a large circle of the heavens, the star can be easily found and placed in the centre of the field of view. It can then be seen in the large telescope. A finder is indispensable to any telescope except the smallest.

meridian; hence the axis must point east-and-west. In the eye-piece of the telescope is a series of parallel spider-lines, which are stretched across vertically, and one or two horizontal lines. The pivots on which the axis rests are ground very carefully, so as to be exactly circular and of equal size.

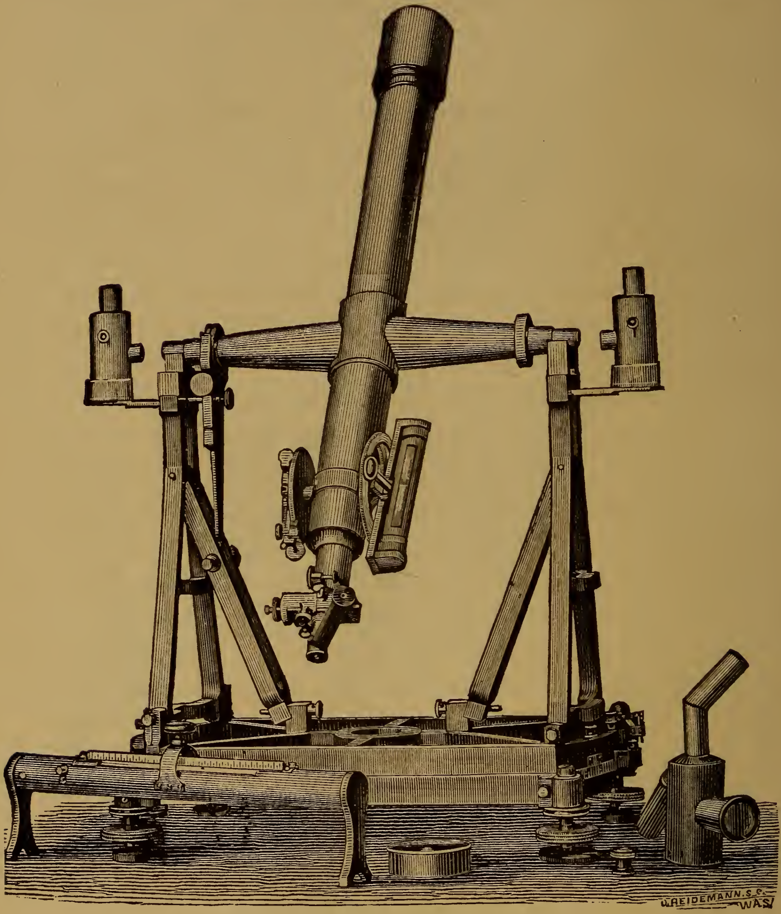

Fig. 89.—Portable Transit Instrument.

The use of the transit instrument is to record the passage of stars over the meridian, and thus find the true sidereal time. It will be remembered that when the vernal equinox crosses the meridian the sidereal clock indicates 0 h. 0 m. 0 s.; also that a star situated at this point would have its right ascension 0 h. 0 m. 0 s. If a star pass the meridian, for instance, 1 h. 27 m. after this, its right ascension is 1 h. 27 m. If this star be observed at its passage over the meridian, and the time recorded by an accurate sidereal clock, this clock will indicate 1 h. 27 m. If it do not, it is in error, and the amount of its error becomes known. We thus have the opportunity of correcting our sidereal clocks if we know the exact right ascensions of certain stars. These right ascensions are given in the Nautical Almanac. The observer fixes the telescope to the point where the star will cross, and notes the time of passage over each of the vertical spider-lines. The average of all these times will be the time when it crosses the meridian, if the instrument be accurately adjusted; if not, certain corrections must be applied. This gives him the clock time of passage. He then compares this with the right ascension of the star as given in the Nautical Almanac; the difference is the error of the clock. From the sidereal time the mean solar time can be calculated. A small transit instrument is shown in Fig. 89.

250. *Sextant.*—The sextant is an instrument for taking angles on shipboard, or in other places where a fixed telescope cannot be arranged. It is shown in Fig. 90. It consists of a graduated scale, AA, usually about 60° in length, but divided into one hundred and twenty parts. Another scale works on this, which is attached

to the arm B; on this arm is a mirror, C; another piece of glass, D, of which one-half is silvered and the other half clear, is fixed to the frame of the instrument.

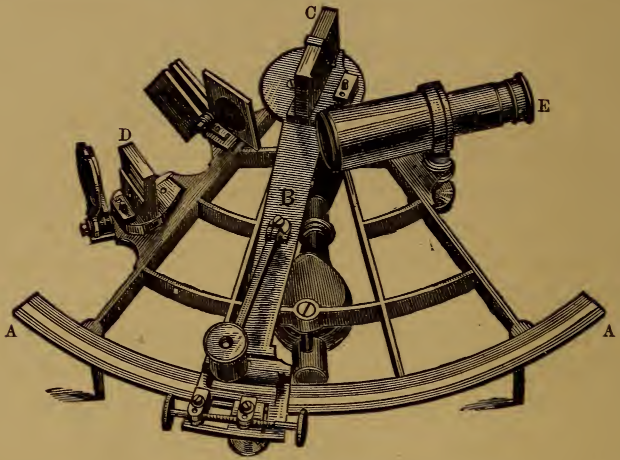

FIG. 90.—SEXTANT.

The telescope E points directly to this second piece of glass. If now it be desired to read an angle,—for instance, to know the height of a given star above the horizon at sea,—the sextant is held by the handle, so that the observer, looking through the *clear* part of the glass D, sees the horizon. Then he moves the index on the pivot till the star reflected from the mirror C and again from the *silvered* part of D agrees with the horizon. The angle is then read on the scale.

Should the observer be on land, the horizon is so broken that no definite point can be taken. Then it is necessary to read the angle between the star and its reflection from a vessel of mercury. This gives double the altitude of the star.[1]

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[1] Why is this?

251. *Spectrum Analysis.*—The phenomena connected with the dispersion of light have performed a very important part in modern astronomical research. By them we have been enabled to tell the construction of our sun, and of all the other suns which crowd our skies; we have been able to say what elements compose them, and in what form those elements exist; we have found out that the nebulæ are different in constitution from the stars; that planets shine by reflected light, and, to some extent, the character of their atmospheres; that some stars are moving towards us or away from us, and, approximately, the velocity of their motion. All this information has been contained in the rays of light which have fallen on the earth since its creation, but only within the last twenty years have we been able to understand it.

We will now explain briefly the principles on which the science of spectrum analysis is founded.

It has been known since the time of Sir Isaac Newton that light, when passed through a prism, is divided into its several parts. The violet rays are turned aside the most, and the red least. This phenomenon is seen whether the light comes to the prism from the sun or from a burning candle or from the electric light. If this light falls on the prism after passing through a *narrow slit*, it is spread out into a band of colors, which is called a *spectrum*. This is nothing more than a slice of a rainbow cut crosswise. Now, so long as the source is a glowing *solid* or *liquid*, or a very greatly condensed gas, we obtain just such a spectrum. A heated piece of lime will give us exactly the same spectrum as glowing carbon, such as we have in a candle-flame. But suppose we pass the light from a glowing *gas* in ordinary state through a slit and a prism. The spectrum now changes. Instead of a combination of colors running into one another we have narrow bright bands or lines of color, which are separated by dark intervals. Moreover, each gas has its own peculiar set of bright lines. Thus, sodium has only two yellow lines, close together, while the spectrum of iron is composed of hundreds of lines of all colors. If, then, we desire to know the elements of which any substance is composed, we may apply enough heat to vaporize these elements, allow the light to pass through a slit and a prism, and see what is the position of the bright lines formed. These must then be compared with known spectra. If we get the two sodium lines, for instance, we know sodium to exist in the substance examined.

There is one other case to be considered,—that in which light from a solid or a liquid passes through a gas before it reaches the prism. Here the gas absorbs some of the rays of the light, and it is found that it absorbs exactly the same rays that it gives out when it is itself heated to glowing. The spectrum formed is then a continuous spectrum, similar to that given out by a solid or a liquid, but crossed by a series of narrow dark lines, and these lines have exactly the same position as the bright lines which the gas forms when self-luminous. Let us suppose that light from a candle or from white-hot iron passes through sodium vapor. After emerging from the prism the spectrum would be the ordinary spectrum, except that in the yellow portion there would be two dark lines agreeing exactly in position and relative character with the bright lines previously mentioned. If, then, we have a spectrum which is crossed by dark lines, we know that the light comes from a solid or a liquid, or a very dense gas, and passes through a less bright atmosphere of gas.

252. *Fundamental Principles.*—The principles of spectrum analysis thus deduced are,—

1. A glowing solid, liquid, or compressed gaseous body gives a continuous spectrum.

2. A glowing gas under low pressure gives a spectrum of bright lines only, each element having its peculiar lines.

3. Light which comes from a glowing solid or liquid, or compressed gas, and passes through less bright gas, gives a spectrum crossed by dark lines, and these dark lines agree exactly in position and character with the bright lines given out by the same gas.[1]

253. *Application to the Heavenly Bodies.*—These principles being established by experiments with terrestrial substances, we have only to examine the spectra obtained from the light from the heavenly bodies to tell what is their constitution and composition.

The solar spectrum is continuous, but crossed by dark lines. Hence we infer that the photosphere of the sun is solid or liquid, or a gas condensed by the enormous pressure upon it, and is surrounded by an atmosphere through which the rays that reach us pass. The

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[1] As the gas which is the source of light becomes more dense and approaches a liquid in character, the lines of its spectrum broaden into bands, and when condensation is complete the bands run into one another and so form a continuous spectrum. It will thus be seen that there is no distinct line between the different kinds of spectra.

It is supposed that the change from one kind of spectrum to another is due to a change in the complexity of the molecules of the substance examined. A simple substance gives a spectrum of lines. When the complexity increases by cooling down, the spectrum changes first to a band and then to a continuous spectrum.

dark lines which can be seen in the spectrum agree with the bright lines of hydrogen, sodium, magnesium, and other substances on the earth. Hence we infer that these elements exist in the chromosphere of the sun; that is, that great quantities of sodium, etc., are burning less brightly than the sun, and the sunlight passes through these vapors before it reaches the earth.

The spectra of the stars are fainter than those of the sun, but are of the same general character. They are crossed by dark lines in the same way; the substances are not identical, and there is a slight diversity in the composition of different ones; but all that have been examined show many terrestrial elements, thus proving that all through the universe there is the same kind of material. In general the red stars present a different kind of spectrum from the yellow, and the yellow from the white. Those stars which are of the same color have the same kind of spectra. It is considered that these differences indicate different stages of star-life. Thus, Capella and our sun are of the same color, and have almost exactly the same character of spectra. We thence infer that they are in the same condition.

The spectra of the nebulæ are some of them continuous spectra. Such nebulæ are then probably solid bodies, collections of suns. Others show spectra of bright lines only. These are then, according to our second principle, masses of glowing gas, which has not yet condensed into anything like suns. The Great Nebula of Andromeda belongs to the former class; that of Orion to the latter.

The planets, since they are visible by reflected sunlight, give the same spectra as the sun, with the addition to it of some dark lines, which are made by absorption of the planet's atmosphere. The spectrum of the moon shows none of these dark lines, but is simply a fainter solar spectrum, because the moon probably has no atmosphere, and does not give out or affect in any way the sunlight which it reflects. All the comets examined show a spectrum of bright lines on top of a continuous one, indicating a solid nucleus and a large amount of *self-luminous* gas surrounding it. This gas seems to be a hydrocarbon.

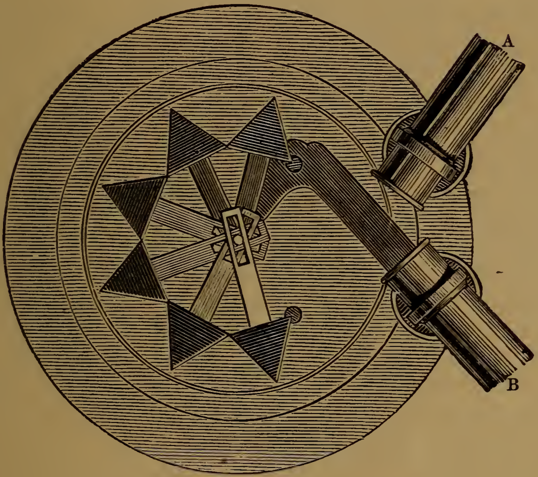

FIG. 91.—PORTION OF A SPECTROSCOPE.

254. *Spectroscopes.*—Fig. 91 shows the theory of the spectroscope. The light from the source comes in through one of the tubes after passing through a slit. It then passes through one or more prisms,—six in the figure,—each one farther separating the rays from one another. A telescope then magnifies the spectrum formed by the prisms. When we are examining a star, this whole apparatus is attached to the eye-end of a

telescope by the tube B, so that the slit shall be in the focus of the object-glass. The observer looks in at A, and sees the light of the star, which has passed around through all the prisms, separated into its primary colors, with its dark lines in their appropriate positions. The more prisms there are in the train, the more the light will be dispersed and the longer will be the spectrum, but, being spread over more surface, it will be fainter.

# APPENDICES.

## I.

## LIST OF LARGE TELESCOPES.

### I.—REFRACTORS OF OVER EIGHT INCHES' APERTURE.

| Name and Place. | Aperture, in Inches. | Maker. |
|---|---|---|
| Imperial Observatory, Vienna | 27 | Grubb, of Dublin. |
| Naval Observatory, Washington | 26 | Clark, of Cambridge, Mass. |
| R. S. Newall's Private Observatory, England | 25 | T. Cooke, of England. |
| Princeton College Observatory | 23 | Clark.[1] |
| Strasburg Observatory | 19 | Merz & Mahler, of Germany. |
| Chicago Observatory | 18.5 | Clark. |
| Private Observatory, Buffalo, N.Y. | 18 | Fitz, of New York. |
| Warner Observatory, Rochester | 16 | Clark.[1] |
| Washburne Observatory, Madison, Wis. | 15.50 | " |
| Harvard College Observatory | 15 | Merz & Mahler. |
| Royal Observatory, Pulkowa | 15 | " " |
| Royal Society, London | 15 | Grubb. |
| Lord Lindsay, Aberdeen | 15 | " |
| (Foreign Telescopes are now Omitted.) | | |
| Litchfield Observatory, Clinton, N.Y. | 13.5 | Spencer. |
| Dudley Observatory, Albany, N.Y. | 13 | Fitz. |
| Alleghany Observatory, Pa. | 13 | " |
| Rutherford's Observatory, N.Y. | 13 | Rutherford. |
| Detroit Observatory, Ann Arbor, Mich. | 12.5 | Fitz. |
| Vassar College Observatory, Poughkeepsie, N.Y. | 12.3 | Clark. |
| Morrison Observatory, Glasgow, Mo. | 12.25 | " |
| Cincinnati Observatory, Ohio | 11.25 | Merz. |
| Henry Draper's Private Observatory, Hastings, N.Y. | 11 | Clark. |
| Middletown Observatory, Conn. | 11 | " |
| Naval Observatory, Washington | 9.62 | Merz. |
| Newington, Conn. | 9.40 | Clark. |
| Shattuck Observatory, Hanover, N.H. | 9.25 | " |
| Winchester Observatory, New Haven, Conn. | 9 | " |
| Haverford College Observatory, Pa. | 8.25 | Fitz. |
| Carleton College Observatory, Minn. | 8.25 | Clark. |
| Seagrove Observatory, Providence, R.I. | 8.25 | " |

[1] Not quite completed.

### II.—REFLECTORS OF OVER TWO FEET APERTURE.

| Name and Place. | Aperture, in Inches. | Maker. |
|---|---|---|
| Earl of Rosse, Parsonstown, Ireland | 72 | Earl of Rosse. |
| Melbourne Observatory, Australia | 48 | Grubb. |
| Paris Observatory | 47 | Martin & Eichens. |
| Mr. Commons's Observatory, England | 36 | |
| Marseilles Observatory, France | 31.5 | Foucault. |
| Toulouse Observatory, France | 31.5 | " |
| Henry Draper's Private Observatory, Hastings, N.Y. | 28 | H. Draper. |
| Mr. Lassell, Maidenhead, England | 24 | Mr. Lassell. |

Clarks have in process of construction a thirty-inch glass for the Royal Observatory of Pulkowa, Russia, and a thirty-six inch glass for the Lick Observatory of California. It is understood that these glasses, without mounting, are to cost $30,000 and $50,000, respectively.

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## II.

## ASTRONOMICAL SYMBOLS.

The following are the symbols and abbreviations used in ordinary almanacs.

### SIGNS OF THE PLANETS, ETC.

☉ The Sun.
☾ The Moon.
☿ Mercury.
♀ Venus.
⊕ or ♁ The Earth.
♂ Mars.
♃ Jupiter.
♄ Saturn.
♅ Uranus.
♆ Neptune.

### THE MOON'S PHASES.

● New Moon (Conjunction).
☽ First Quarter.
○ Full Moon (Opposition).
☾ Last Quarter.

### SIGNS OF THE ECLIPTIC.

| | |
|---|---|
| Spring signs. | 1. ♈ Aries.<br>2. ♉ Taurus.<br>3. ♊ Gemini. |
| Summer signs. | 4. ♋ Cancer.<br>5. ♌ Leo.<br>6. ♍ Virgo. |
| Autumn signs. | 7. ♎ Libra.<br>8. ♏ Scorpio.<br>9. ♐ Sagittarius. |
| Winter signs. | 10. ♑ Capricornus.<br>11. ♒ Aquarius.<br>12. ♓ Pisces. |

## ABBREVIATIONS.

| | | | |
|---|---|---|---|
| ☊ | Ascending Node. | ° | Degrees. |
| ☋ | Descending Node. | ′ | Minutes of Arc. |
| ☌ | Conjunction. | ″ | Seconds of Arc. |
| □ | Quadrature. | $^h$ | Hours. |
| ☍ | Opposition. | $^m$ | Minutes of Time. |
| R. A. | Right Ascension. | $^s$ | Seconds of Time. |
| Dec. | Declination. | | |

## THE GREEK LETTERS.

In astronomy, used principally to designate the different stars in each constellation.

| Letter. | Name. | Letter. | Name. |
|---|---|---|---|
| α | Alpha. | ν | Nu. |
| β | Beta. | ξ | Xi. |
| γ | Gamma. | ο | Omi′kron. |
| δ | Delta. | π | Pi. |
| ε | Epsi′lon. | ρ | Rho. |
| ζ | Zeta. | σ | Sigma. |
| η | Eta. | τ | Tau. |
| θ | Theta. | υ | Upsi′lon. |
| ι | Io′ta. | φ | Phi. |
| κ | Kappa. | χ | Chi. |
| λ | Lambda. | ψ | Psi. |
| μ | Mu. | ω | Ome′ga. |

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## III.

## LENGTHS OF DAYS, MONTHS, AND YEARS.

$24^h$ = a mean solar day; the ordinary day.

$23^h\ 56^m\ 4.09^s$ = a sidereal day; the exact time of the earth's rotation.

29.53088 days = a mean synodical month; the common lunar month, being the time from one new moon until the next, or from one full moon until the next.

27.32166 days = a sidereal month; the time of the revolution of the moon about the earth.

365.24220 days = a tropical year; the common year, being the time from one vernal equinox until the next.

365.25636 days = a sidereal year; the time of the revolution of the earth about the sun.

## IV.

## THE MAJOR PLANETS, SUN, AND MOON.

| | Distances from the Sun. | | Mean Angular Diameter. | Mean Diameter. | Periodic Time. | Axial Rotation. | Orbital Velocity. | Velocity of Rotation at the Equator. |
|---|---|---|---|---|---|---|---|---|
| | Miles. | Times the Earth's Distance. | | Miles. | | | Miles per Second. | Miles per Hour. |
| Mercury | 35,956,000 | .39 | 8″.7 | 3,009 | Days.<br>87.97 | 24$^h$ 5$^m$ (?) | 29.6 | 393 (?) |
| Venus | 67,187,000 | .72 | 38″.1 | 7,630 | 224.70 | 23$^h$ 21$^m$ (?) | 21.6 | 1,027 (?) |
| Earth | 92,885,000 | 1 | | 7,918 | 365.26 | 23$^h$ 56$^m$ 4.09$^s$ | 18.4 | 1,040 |
| Mars | 141,528,000 | 1.52 | 17″.3 | 4,998 | 686.98 | 24$^h$ 37$^m$ 22.7$^s$ | 15 | 638 |
| Jupiter | 483,115,000 | 5.20 | 36″.5 | 89,769 | Years.<br>11.86 | 9$^h$ 55$^m$ 20$^s$ | 8 | 28,423 |
| Saturn | 885,961,000 | 9.54 | 16″.2 | 73,044 | 29.46 | 10$^h$ 14$^m$ 23.8$^s$ | 6 | 22,410 |
| Uranus | 1,781,806,000 | 19.18 | 3″.7 | 33,554 | 84.02 | Unknown. | 4.2 | |
| Neptune | 2,790,000,000 | 30.04 | 2″.6 | 37,203 | 164.78 | Unknown. | 3.4 | |
| Sun | | | 32′ 3″ | 866,400 | | 25 days. | | 4,536 |
| Moon | 92,885,000 | 1 | 31′ 26″ | 2,160 | 365.26 | 27.32 days. | 18.4 | 10 |

| | Weight, in Tons. | Mass. | Weight of One Pound at the Surface. | Density. | | Light and Heat from Sun. | Eccentricity of Orbit. | Angle between Orbit and Ecliptic. |
|---|---|---|---|---|---|---|---|---|
| | | Times that of the Earth. | | Times Density of Water. | Times Density of the Earth. | | | ° ′ ″ |
| Mercury | 393,000,000,000,000,000,000 | $\frac{1}{15}$ | $\frac{1}{2}$ | 6.8 | $\frac{6}{5}$ | 6.6 | .2056 | 7 0 5 |
| Venus | 4,763,000,000,000,000,000,000 | $\frac{3}{4}$ | $\frac{7}{8}$ | 4.8 | $\frac{6}{7}$ | 1.9 | .0068 | 3 23 29 |
| Earth | 6,069,000,000,000,000,000,000 | 1 | 1 | 5.6 | 1 | 1 | .0168 | 0 0 0 |
| Mars | 750,000,000,000,000,000,000 | $\frac{1}{8}$ | $\frac{3}{10}$ | 4.2 | $\frac{3}{4}$ | .4 | .0933 | 1 51 6 |
| Jupiter | 1,825,900,000,000,000,000,000,000 | 301 | $2\frac{1}{2}$ | 1.4 | $\frac{1}{4}$ | .04 | .0483 | 1 18 52 |
| Saturn | 546,406,000,000,000,000,000,000 | 90 | $1\frac{1}{10}$ | .7 | $\frac{1}{8}$ | .01 | .0560 | 2 29 36 |
| Uranus | 76,721,000,000,000,000,000,000 | 12 | $\frac{7}{10}$ | 1.3 | $\frac{1}{5}$ | .003 | .0464 | 0 46 28 |
| Neptune | 101,720,000,000,000,000,000,000 | 17 | $\frac{8}{10}$ | 1.1 | $\frac{1}{5}$ | .001 | .0090 | 1 46 59 |
| Sun | 1,910,278,070,000,000,000,000,000,000 | 330,000 | $27\frac{7}{10}$ | 1.4 | $\frac{1}{4}$ | | | |
| Moon | 78,000,000,000,000,000,000 | $\frac{1}{81}$ | $\frac{1}{6}$ | 3.4 | $\frac{3}{5}$ | 1 | .0549 | 5 8 40 |

## V.

## PERIODIC COMETS.

| Name. | Last Perihelion Passage. | Periodic Time. | Notes. |
|---|---|---|---|
| Encke | 1881, November. | 3.30 years. | See page 198. |
| Biela | 1852, September. | 6.62 " | See page 200. |
| Faye | 1881, August. | 7.44 " | Discovered in 1843. |
| Brorsen | 1879, March. | 5.56 " | Discovered in 1846. |
| D'Arrest | 1877, May. | 6.39 " | Faintest of all periodic comets. |
| Winnecke | 1880, September. | 5.55 " | Discovered in 1819, and not seen again till 1858. |
| Tuttle | 1871, December. | 13.78 " | Discovered in 1790, and not seen again till 1858. |
| Tempel | 1879, May. | 6.00 " | |
| Halley | 1835, November. | 76.00 " | See page 198. |
| Swift | 1880, October. | 5.40 " | Seen in 1869, but not known to be periodic until 1880. |

There are also other comets which have been calculated to move in elliptic orbits, but which have not been seen at more than one return. Denning's, 1881, has a period of about eight years, but it is not known to have been seen before that time. It is also believed that Gould's comet of 1880 is identical with the bright comet of 1843. The brightest comet of 1881 has been calculated to move in a very greatly elongated ellipse, and to have a period of about three thousand years.

## VI.

# LIST OF NOTED DOUBLE STARS.

### COMPILED FROM "HAND-BOOK OF DOUBLE STARS" OF GLEDHILL, CROSSLEY, AND WILSON.

| Name. | R. A. | Dec. | Position Angle. | Distance. | Magnitude. | Remarks. |
|---|---|---|---|---|---|---|
| | h. m. | ° ' | ° | " | | |
| 51 Piscium.......... | 0 26.2 | 6 17 | 82 | 28 | 5 9 | White, ash. |
| η Cassiopeiæ........ | 0 41.8 | 57 11 | 145 | 5.7 | 4 7.6 | Yellow, purple. Binary. |
| Polaris................ | 1 13.7 | 88 40 | 213 | 18.6 | 2 9 | Yellow, white. |
| α Piscium............ | 1 55.8 | 2 11 | 325 | 3 | 3 4 | White, blue. |
| γ Andromedæ...... | 1 56.5 | 41 46 | 63 | 10.1 | 3 5 | Yellow, blue. Binary. |
| ι Trianguli.......... | 2 5.4 | 29 44 | 76 | 3.9 | 5 6.4 | Yellow, blue. |
| ι Cassiopeiæ ........ | 2 19.2 | 66 51 | 265<br>108 | 2.1<br>7.9 | 4.2 7.1 8.1 | Triple. Binary. |
| γ Ceti.................. | 2 37.1 | 2 44 | 291 | 3 | 3.5 7 | Yellow, blue. |
| Aldebaran.......... | 4 29 | 16 16 | 35 | 114 | 1 11.2 | Red, blue. |
| Rigel.................. | 5 8.8 | —8 20 | 199 | 9.2 | 1 8 | |
| θ Orionis............ | 5 29 | —5 30 | ......... | See p. 242. | ........... | Sextuple. In nebula of Orion. |
| σ Orionis............ | 5 32.7 | —2 40 | .......... | .......... | ................ | Quadruple. |
| ζ Orionis............ | 5 34.7 | —2 | 154 | 2.4 | 2 5.7 | Yellow, red. Binary. |
| Sirius.................. | 6 39.7 | —16 32 | 50 | 10.1 | 1 10 | Small star, seen with difficulty. |
| μ Canis Majoris... | 6 50.6 | —13 53 | 342 | 3 | 4.7 8 | Yellow, blue. |
| δ Geminorum ...... | 7 13 | 22 12 | 204 | 7 | 3.2 8.2 | |
| Castor.................. | 7 27 | 32 1 | 234 | 5.5 | 3 3.5 | Binary. White. |
| 38 Lyncis............ | 9 11.4 | 37 19 | 240 | 2.9 | 4 6.7 | White, blue. |
| γ Leonis.............. | 10 13.4 | 20 27 | 112 | 3.3 | 2 3.5 | Binary. Yellow, red. |
| γ Virginis............ | 12 35.6 | —0 47 | 160 | 5 | 3 3 | Yellow. Binary. |
| ε Boötis.............. | 14 39.7 | 27 35 | 329 | 2.9 | 3 6.3 | Red, lilac. |
| ξ Boötis.............. | 14 45.8 | 19 36 | 283 | 4.5 | 4.7 6.6 | Pale-red, deep-red |
| δ Serpentis.......... | 15 29.1 | 10 56 | 186 | 3.8 | 3 4 | White, ash. |
| Antares.............. | 16 22 | —26 10 | 273 | 3 | 1.5 7.7 | Red, blue. |
| α Herculis.......... | 17 9.1 | 14 32 | 115 | 4.7 | 3 6.1 | |
| ρ Herculis.......... | 17 19.5 | 37 15 | 312 | 3.7 | 4 5.1 | White. |
| 70 Ophiuchi........ | 17 59.4 | 2 33 | 78 | 3.2 | 4 6 | Binary. |
| ε Lyræ .............. | 18 40.4 | 39 33 | 16<br>140 | 3.0<br>2.5 | ................ | See page 241. |
| β Cygni.............. | 19 25.8 | 27 42 | 56 | 34.3 | 3 5.3 | Yellow, blue. |
| ε Draconis.......... | 19 48.6 | 69 58 | 360 | 3 | 4 7.6 | |
| γ Delphini.......... | 20 41.8 | 15 42 | 272 | 11.1 | 4 5 | Golden-green. |
| 61 Cygni............ | 21 1.4 | 38 7 | 117 | 20 | 5.3 5.9 | Binary. |
| μ Cygni.............. | 21 38.9 | 28 12 | 118 | 3.7 | 4 5 | White. |
| ζ Aquarii............ | 22 22.6 | —0 38 | 333 | 3.4 | 4 4.1 | |

## VII.

# LIST OF NOTED CLUSTERS AND NEBULÆ.

### I.—CLUSTERS SEEN BY THE NAKED EYE.

Pleiades in Taurus.
Hyades in Taurus.
Præsepe in Cancer.
Coma Berenices.
Clusters in Sword-Handle of Perseus.

### II.—CLUSTERS RESOLVABLE BY TELESCOPES.

| Constellation. | R. A., 1880. | | Dec., 1880. | | Remarks. |
|---|---|---|---|---|---|
| | h. | m. | ° | ′ | |
| Cassiopeia | 1 | 38 | 60 | 38 | Seen by two-inch telescope. |
| Auriga | 5 | 44 | 32 | 32 | |
| Gemini | 6 | 1 | 24 | 21 | To naked eye, faint nebula. |
| Coma | 13 | 7 | 18 | 48 | |
| Canes Venatici | 13 | 37 | 28 | 58 | One thousand small stars. |
| Libra | 15 | 12 | 2 | 32 | Compressed cluster. |
| Scorpio | 16 | 10 | —22 | 42 | Like a comet. |
| Hercules | 16 | 37 | 36 | 41 | Just visible to naked eye. |
| Sagittarius | 18 | 29 | 24 | 0 | Bright cluster. |
| Antinous | 18 | 45 | —6 | 24 | Fan-shaped. |
| Pegasus | 21 | 24 | 11 | 38 | Bright cluster. |
| Aquarius | 21 | 27 | —1 | 22 | Compressed, and resolved with difficulty. |

### III.—NEBULÆ.

| Constellation. | R. A., 1880. | | Dec., 1880. | | Remarks. |
|---|---|---|---|---|---|
| | h. | m. | ° | ′ | |
| Great Nebula of Andromeda | 0 | 36 | 40 | 37 | See page 253. |
| Great Nebula of Orion | 5 | 29 | 5 | 29 | See page 253. Whole neighborhood nebulous. |
| Ursa Major | 9 | 39 | 12 | 50 | Planetary nebula. |
| | 11 | 8 | 55 | 40 | |
| Virgo | 12 | 20 | 13 | 36 | Many nebulæ about. |
| | 12 | 24 | 8 | 40 | |
| | 12 | 34 | 10 | 57 | |
| Canes Venatici | 13 | 25 | 27 | 49 | Spiral nebula. |
| Sagittarius | 17 | 55 | 23 | 2 | Trifid nebula. |
| Scutum Sobieskii | 18 | 14 | —16 | 15 | Horseshoe nebula. |
| Lyra | 18 | 49 | 32 | 53 | Ring nebula. See page 253. |
| Dumb-Bell Nebula in Vulpecula | 19 | 54 | 22 | 23 | See page 258. |
| Delphinus | 20 | 28 | 6 | 59 | |
| Aquarius | 20 | 58 | —11 | 50 | Planetary nebula. |

## VIII.

## EPHEMERIS OF ALGOL (β PERSEI).

The dates given below are the times of Algol's minimum to the end of 1883. The first indications of diminution of brilliancy are observable about four and one-half hours previous to the date of minimum. Only such as occur during the hours of darkness are given. At some of these Algol is in a position unfavorable for observation. During fall, winter, and spring it may be observed in the early evening. The days are astronomical days, and begin at 12 o'clock of the civil day of same date. Hence 14 hours is 2 o'clock A.M. The ephemeris is based on a minimum which occurred 1882, January 3, 11 h. 35 m. 42 sec., and the period is assumed to be 2$^d$ 20$^h$ 48$^m$ 54$^s$.

| Day. | Hour. | Min. | Sec. | Day. | Hour. | Min. | Sec. |
|---|---|---|---|---|---|---|---|
| 1882. | | | | 1883. | | | |
| September 18 | 12 | 56 | 42 | February 14 | 15 | 19 | 30 |
| " 21 | 9 | 45 | 36 | " 17 | 12 | 8 | 24 |
| " 24 | 6 | 34 | 30 | " 20 | 8 | 57 | 18 |
| October 8 | 14 | 39 | 0 | " 23 | 5 | 46 | 12 |
| " 11 | 11 | 27 | 54 | March 9 | 13 | 50 | 42 |
| " 14 | 8 | 16 | 48 | " 12 | 10 | 39 | 36 |
| " 28 | 16 | 21 | 18 | " 15 | 7 | 28 | 30 |
| " 31 | 13 | 10 | 12 | " 29 | 15 | 33 | 0 |
| November 3 | 9 | 59 | 6 | April 1 | 12 | 21 | 54 |
| " 6 | 6 | 48 | 0 | " 4 | 9 | 10 | 48 |
| " 20 | 14 | 52 | 30 | " 21 | 14 | 4 | 12 |
| " 23 | 11 | 41 | 24 | " 24 | 10 | 53 | 6 |
| " 26 | 8 | 30 | 18 | " 27 | 7 | 42 | 0 |
| December 10 | 16 | 34 | 48 | May 11 | 15 | 46 | 30 |
| " 13 | 13 | 23 | 42 | " 14 | 12 | 35 | 24 |
| " 16 | 10 | 12 | 36 | " 17 | 9 | 24 | 18 |
| 1883. | | | | June 3 | 14 | 17 | 42 |
| January 2 | 15 | 6 | 0 | " 6 | 11 | 6 | 36 |
| " 5 | 11 | 54 | 54 | " 9 | 7 | 55 | 30 |
| " 8 | 8 | 43 | 48 | " 23 | 16 | 0 | 0 |
| " 11 | 5 | 32 | 42 | " 26 | 12 | 48 | 54 |
| " 22 | 16 | 48 | 18 | " 29 | 9 | 37 | 48 |
| " 25 | 13 | 37 | 12 | July 16 | 14 | 31 | 12 |
| " 28 | 10 | 26 | 6 | " 19 | 11 | 20 | 6 |
| " 31 | 7 | 15 | 0 | " 22 | 8 | 9 | 0 |

| Day. | Hour. | Min. | Sec. | Day. | Hour. | Min. | Sec. |
|---|---|---|---|---|---|---|---|
| 1883. | | | | 1883. | | | |
| August 6 | 16 | 13 | 30 | October 17 | 8 | 36 | 0 |
| " 9 | 13 | 2 | 24 | " 31 | 16 | 41 | 30 |
| " 12 | 9 | 51 | 18 | November 3 | 13 | 30 | 24 |
| " 15 | 6 | 40 | 12 | " 6 | 10 | 19 | 18 |
| " 29 | 14 | 44 | 42 | " 9 | 7 | 8 | 12 |
| September 1 | 11 | 33 | 36 | " 20 | 18 | 23 | 48 |
| " 4 | 8 | 22 | 30 | " 23 | 15 | 12 | 42 |
| " 18 | 16 | 27 | 0 | " 26 | 12 | 1 | 36 |
| " 21 | 13 | 15 | 54 | " 29 | 8 | 50 | 30 |
| " 24 | 10 | 4 | 48 | December 13 | 16 | 55 | 0 |
| " 27 | 6 | 53 | 42 | " 16 | 13 | 43 | 54 |
| October 11 | 14 | 59 | 12 | " 19 | 19 | 32 | 48 |
| " 14 | 11 | 48 | 6 | " 22 | 7 | 21 | 42 |

# INDEX.

THE END.

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