A Short Course in Astronomy.

Kiddle.

A

SHORT COURSE

IN

ASTRONOMY

AND THE

USE OF THE GLOBES.

BY

HENRY KIDDLE, A.M.,

SUPERINTENDENT OF SCHOOLS, NEW YORK, AUTHOR OF "NEW MANUAL OF THE ELEMENTS OF ASTRONOMY."

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PREFACE.

THE design of this work is to supply a brief course of lessons in astronomy for the use of young pupils, or of those whose time and opportunities do not permit a more exhaustive study of the subject. It is based on the author's "New Manual of the Elements of Astronomy," of which, in some respects, it is an abridgment; but many parts of the work have been greatly simplified, and the arrangement of topics has been somewhat changed, so as to be adapted to a work of lower grade.

The objective plan of instruction has been followed as far as it is applicable to the subject under treatment, the pupil's attention being constantly directed to the phenomena addressed to his own observation, and the reasoning made to proceed directly from them. Section First will, it is believed, be found especially useful in the accomplishment of this object, by awakening, at the commencement, an interest in astronomical observation, as the basis of all subsequent study of the science.

Throughout the work, the arrangement of the paragraphs is adapted to the topical method of recitation—so desirable, as far as is practicable, in every branch of study, in order to train the pupil in habits of connected and logical statement.

Questions have been, however, appended at the foot of each page, in order to facilitate the more minute examination of the pupil on the text.

The *Astronomical Index* will be found useful and convenient in affording a brief summary of definitions, for final review. The *Problems for the Globe* have been placed in connection with those parts of the work to which they seemed most intimately to belong, and where they can best be studied with the view to illustrate more fully the principles laid down.

The author hopes that, by presenting the fundamental principles and most interesting facts of astronomy in this simplified and condensed form, he may aid in inducing a more general study of this useful and sublime science in the public and private seminaries throughout the country, from which it is too often excluded, to make way for subjects of far less value, both in respect to educational discipline and practical information.

NEW YORK, *January, 1871.*

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INTRODUCTION.

MATHEMATICAL DEFINITIONS.

1. *Extension,* or magnitude, may be measured in three directions; namely, length, breadth, and thickness. These are therefore called the *dimensions of extension.*

Length is the greatest dimension; Thickness, the shortest; Breadth, the other.

2. *A Line* is that which is conceived to have only one dimension.

Lines have no real existence independently of extension, or solidity. They are purely abstract or imaginary quantities: the marks called lines are only *representatives* of them.

3. *A Straight Line* is a line that does not change its direction at any point.

4. *A Curve Line* is one that changes its direction at every point.

5. *A Point* is that which is conceived to have no dimensions, but only position.

A point is represented by a dot (.).

QUESTIONS.—1. How may extension be measured? Dimensions? 2. What is a line? What is remarked of lines? 3. What is a straight line? 4. A curve line? 5. A point?

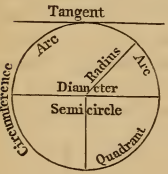
6. ***A Surface*** is that which is conceived to have two dimensions—length and breadth.

7. ***A Plane Surface, or Plane,*** is a surface with which, if a straight line coincide in two points, it will coincide in all.

That is, a straight line cannot lie partly in a plane, and partly out of it; and if applied to it in any direction, it will coincide with it throughout its whole extent. The term *plane* does not imply any limitation, or boundary, but signifies indefinite direction, without change, both as to length and breadth.

8. A plane bounded by lines is called a ***Plane Figure.***

9. ***A Circle*** is a plane figure bounded by a curve line every point of which is equally distant from a point within, called the *centre*.



10. The curve line that bounds a circle is called the ***Circumference.***

11. ***The Diameter*** of a circle is a straight line drawn through its centre from one point of the circumference to another.

12. ***The Radius*** is a straight line drawn from the centre to the circumference.

13. ***An Arc*** is any part of the circumference.

14. ***A Tangent*** is a line which touches the circumference in one point.

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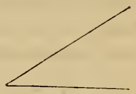
6. What is a surface? 7. A plane surface? What is remarked of it? 8. What is a plane figure? 9. A circle? 10. The circumference? 11. The diameter? 12. The radius? 13. An arc? 14. A tangent?

15. A Semicircle is one-half of a circle; a ***Quadrant*** is a quarter of a circle.

16. The circumference of a circle is supposed to be divided into 360 degrees, each degree into 60 minutes, and each minute into 60 seconds.

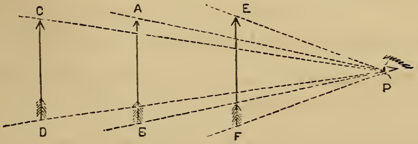
Degrees are marked (°); minutes, (′); and seconds, (″).

17. An Angle is the difference in direction of two straight lines that meet at a point, called the vertex.



ANGLE.

It is of the greatest importance that the student of Astronomy should form a clear idea of an angle, since nearly the whole of astronomical investigation is based upon it. The apparent distance of two objects from each other, as seen from a remote point of view, depends upon the *difference of direction* in which they are respectively viewed; that is to say, the angle formed by the two lines conceived to be drawn from the objects, and meeting at the eye of the observer. This is called the *angular distance* of the objects, and, as will readily be understood, increases as the two objects depart from each other and from the general line of view.



18. The Angle of Vision, or Visual Angle, is the angle formed by lines drawn from two opposite points of a distant object, and meeting at the eye of the observer.

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15. What is a semicircle? A quadrant? 16. How is the circumference of a circle divided? 17. What is an angle? Angular distance of objects?

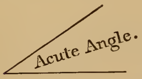
It will be easily seen that, as the *apparent size* of a distant object depends upon the angle of vision under which it is viewed, it must diminish as the distance increases, and *vice versa*.

Thus, the object A B is viewed under the angle A P B, which determines its apparent size in that position; but when removed farther from the eye, as at C D, the angle of vision becomes C P D, an angle obviously smaller than A P B, and hence the object appears smaller. At E F, the object appears larger, because the visual angle E P F is larger. The farther the object is removed, the less the divergence of the lines which form the sides of the angle; and the nearer the object is brought to the eye, the greater the divergence of the lines.

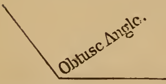
19. An angle is measured by drawing a circle, with the vertex as a centre, and with any radius, and finding the number of degrees or parts of a degree included between the sides.

20. ***A Right Angle*** is one that contains 90 degrees, or one-quarter of the circumference.

21. When one straight line meets another so as to form a right angle with it, it is said to be ***perpendicular.***



22. A straight line is said to be perpendicular to a circle when it passes, or would pass if prolonged, through the centre.



23. An angle less than a right angle is called an ***Acute Angle;*** one greater than a right angle is called an ***Obtuse Angle.***

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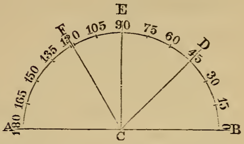
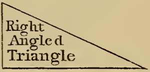
18. What is the angle of vision? Remark? Illustrate by diagram. 19. How is an angle measured? 20. What is a right angle? 21. A perpendicular? 22. A perpendicular to a circle? 23. What is an acute angle? An obtuse angle?

In the annexed diagram, the semicircumference is used to measure all the angles having their vertices, or angular points, at C. Thus B C D, containing the arc B D, is an angle of 45°; B C E, an angle of 90°; and B C F, of 120°. The points A and B are at the angular distance of 180°, or two right angles from each other.

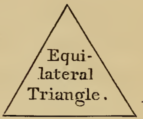


24. ***A Triangle*** is a plane figure bounded by three sides.

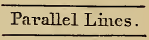


A triangle that contains a right angle is called a *Right-angled Triangle.*

A triangle having equal sides is called an *Equilateral Triangle.*

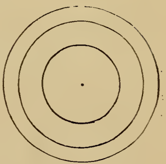


25. ***Parallel Lines*** are those situated in the same plane, and at the same distance from each other, at all points.



Parallel lines may be either straight or curved.

The circumferences of concentric circles, that is, circles drawn around the same centre, are parallel.



26. ***An Ellipse*** is a curve line, from any point of which if straight lines be drawn to two points within, called the foci, the sum of these lines will be always the same.

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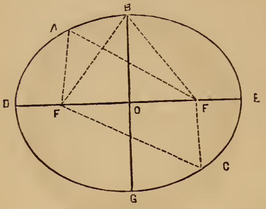
24. What is a triangle? A right-angled triangle? An equilateral triangle? 25. What are parallel lines? 26. What is an ellipse?

The curve line D B E G represents an ellipse, the sum of the two straight lines drawn to F and F, the foci, from the points A, B, and C, respectively, being always equal. This sum is equal to the longest diameter, D E.



27. The longest diameter of an ellipse is called the ***Major Axis;*** and the shortest diameter, the ***Minor Axis.***

In the diagram, D E is the major axis, and B G the minor axis.

28. The distance from either of the foci to the centre of the ellipse is called the ***Eccentricity*** of the ellipse.

It will be readily seen that the greater the eccentricity of an ellipse, the more elongated it is, and the more it differs from a circle; while, if the eccentricity is nothing, the two foci come together, and the ellipse becomes a circle.

The distance from the extremity of the minor axis to either of the foci is always equal to one-half of the major axis.

In the above diagram, F O is the eccentricity, and B F is equal to D O. The amount of eccentricity of any ellipse is ascertained by comparing it with one-half the major axis. Thus, in the diagram, O F being about one-half of O D, the eccentricity of the ellipse may be nearly expressed by .5.

29. ***A Sphere, or Globe,*** is a round body every point of the surface of which is equally distant from a point within, called the centre.

30. ***A Hemisphere*** is a half of a globe.

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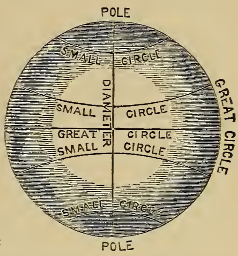
27. What is meant by major and minor axis? 28. Eccentricity? Remark? 29. What is a sphere? 30. A hemisphere?

31. ***The Diameter*** of a sphere is a straight line drawn through the centre, and terminated both ways by the surface of the sphere.



A SPHERE.

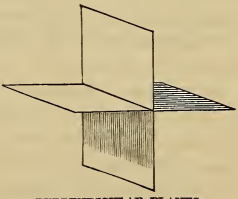
32. ***The Radius*** of a sphere is a straight line drawn from the centre to any point of the surface.

33. Circles drawn on the surface of a sphere are either ***Great Circles*** or ***Small Circles***

34. ***Great Circles*** are those whose planes divide the sphere into equal parts.

35. ***Small Circles*** are those whose planes divide the sphere into unequal parts.

36. ***The Poles of a Circle*** are two opposite points on the surface of the sphere, equally distant from the circumference of the circle.


PERPENDICULAR PLANES.

The poles of a great circle are, of course, 90° distant from every point of its circumference.

Two circles of the sphere are parallel when they are equally distant from each other at every point.

Two circles are perpendicular to each other when their planes are perpendicular, or at right angles with each other.

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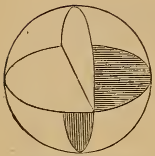
31. What is the diameter of a sphere? 32. The radius of a sphere? 33. How are circles of the sphere divided? 34. What are great circles? 35. Small circles? 36. Poles of a circle?

37. ***The Plane of a Circle,*** or of any other figure, is the indefinite plane surface on which it may be conceived to be drawn.

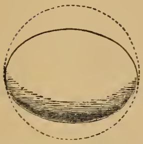


PLANES OF GREAT CIRCLES.

38. ***A Spheroid*** is a body resembling a sphere.

39. There are two kinds of spheroids: Oblate and Prolate Spheroids.

40. ***An Oblate Spheroid*** is a sphere flattened at two opposite points, called the poles.



OBLATE SPHEROID.

41. ***A Prolate Spheroid*** is a sphere extended at two opposite points.

Thus, an orange is a kind of oblate spheroid; and an egg, a kind of prolate spheroid.

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37. What is meant by the plane of a circle? 38. What is a spheroid? 39. How many kinds are there? 40. What is an oblate spheroid? 41. A prolate spheroid?

SECTION I.

GENERAL APPEARANCES OF THE HEAVENLY BODIES.

1. The Horizon.—A person standing upon an open plain, or on the deck of a vessel at sea, seems to be at the centre of a circle, the circumference of which bounds his view on all sides, both of the earth and sky; the latter rising above him like a blue dome—during the day, lit up by the sun; during every clear night, spangled all over with glittering stars, and sometimes illuminated by the silver radiance of the moon. At whatever point of the earth's surface the observer stands, he finds his view still bounded by a circle of the same size; and he everywhere seems to see an equal portion of the earth and sky. The circle which bounds our view is called the *horizon.*

2. Above this circle the sun ascends in the morning and descends below it in the evening; in the former case it is said to rise, and in the latter to set. No one will fail to observe that the sun rises and sets at nearly the same points of the horizon each morning and evening; that it passes across the heavens from one side to the other, reaching its highest point at noon; and that this point (called the *point of culmination*) is higher during the summer than during the winter.

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1. What is meant by the horizon? 2. What is said of the movements of the sun? What is the point of culmination?

3. Cardinal Points of the Horizon, &c.—In order to be able to describe the apparent motions of the sun and other bodies, it is necessary to give names to certain fixed points of the horizon. Thus, the point over which the sun is at noon is called the *south;* the point diametrically opposite to it is the *north;* that situated midway between the north and south, near which the sun rises, is called the *east;* and the point opposite to it, the *west.* Hence, if a person stand facing the north, the south will be behind him, the east on his right hand, and the west on his left. These points are called the *cardinal points* of the horizon. The intermediate points are *northeast*, *southeast*, *northwest*, and *southwest.*

4. Rising and Setting of the Sun.—A careful observation of the apparent motions of the sun will show that it does not, every day in the year, rise exactly at the east, or set at the west; but that the points of its rising and setting vary, sometimes being to the north of east and west, and at other times to the south of them. Twice, however, during the year, namely, in the latter part of March and September, it will be seen to rise exactly at the east, and to set exactly at the west.

5. Apparent Motions of the Stars.—By watching the stars, it will be discovered that they perform the same general movement as the sun; that is, they pass

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3. What are the cardinal points of the horizon? How are they determined? What names are given to the intermediate points? 4. What is observed in regard to the rising and setting of the sun? When does it rise exactly in the east and set in the west? 5. What may be discovered by observing the stars? What arcs do they appear to describe? What is meant by the *pole star?* What are *circles of daily motion?*

across the heavens from east to west. It will be seen, too, that the arcs which they may be conceived to describe are not all of equal size, those of some stars being small portions of a circle, others very large portions, while still others describe entire circles. Thus, if we look toward the south, we find that some stars rise in the southeast, pass over the heavens at a small height above the horizon, and set in the southwest; but, if we look toward the north, we observe that some stars rise in the northeast, pass nearly all around the heavens, and set in the northwest, thus describing nearly a whole circle. Still other stars will be seen to pass entirely around, never rising or setting, but apparently describing circles round a star that seems to be motionless in the heavens,—the *Pole Star.* The circles which these bodies may be conceived to describe are called *Circles of Daily Motion.*

6. It will also be observed, that, although these stars are thus constantly changing their places in respect to the horizon, each one making an entire circuit in the heavens every twenty-four hours, they do not change their relative positions. Thus, if three stars should be seen so situated as to form a triangle, the same stars would be seen, year after year, still forming the same figure, being motionless in respect to each other. On this account, these bodies have been called *Fixed Stars*, and they thus afford a standard by which we determine the motions of other bodies.

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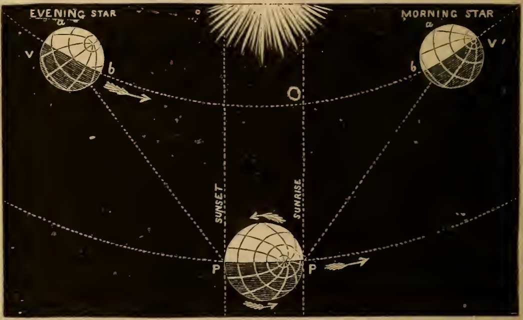
6. What also may be observed? Illustrate this. What are the stars called on this account? What do they afford?

7. Apparent Motions of the Planets.—Occasionally, bodies having the general appearance of stars are seen that do not keep the same relative position with the other stars, sometimes being near one star, sometimes another; sometimes appearing to move toward the east, sometimes toward the west, or for a short time remaining stationary in the heavens, like the other stars. These bodies are called *planets:* that is, *wandering bodies*, since they seem to move about among the stars.

8. Every one has noticed a brilliant body of this kind that appears sometimes in the west just after the sun has set, sparkling like a glittering gem in the sky. This is the planet Venus, which is familiarly known as the *Evening Star.* The same planet, after shining for some



VENUS AS MORNING AND EVENING STAR.

7. What other bodies are seen? How do they appear to move? What are they called? 8. What is the Evening Star? The Morning Star?

months in the west, gradually approaches the sun and disappears; but soon afterward we find it still shining in all its splendor in the east just before the sun rises, when it is called the *Morning Star.* It is, however, easily recognized as the same planet—the beautiful planet Venus. Thus it appears to move to and from the sun, departing only a short distance from it on one side or the other.

9. There are few persons who have not also noticed another resplendent planet, which, instead of remaining with us only a few hours, in the evening or the morning, sometimes continues in view during the whole night, rising in the east just as the sun sets, and setting in the west just as the sun rises. This planet, like the others, appears to move among the stars in a general direction toward the east, departing from and returning to the same star in about twelve years. So that, if we see it in a certain part of the heavens at any particular time, we must wait twelve years before we can again see it in precisely the same place. This splendid orb is called *Jupiter.*

10. Another planet, which shines with a remarkably red, fiery color, takes only about two years to pass from one star to the same again. To this planet has been given the name *Mars.* Still another, called *Saturn*, shines with a singularly steady light; and although, as compared with the brightest of the stars, is somewhat dull in its aspect, is yet quite a conspicuous body. Its

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9. What other planet is described? What are its apparent movements? 10. What is said of Mars? Of Saturn? How may planets be distinguished from stars?

wanderings are not so apparent as those of the other planets that have been named, since it takes nearly thirty years to pass from one star and return to it again. These are the most conspicuous of the wandering stars or planets; but others may also be seen, although with difficulty. These will be referred to hereafter. Planets may generally be distinguished from the stars by their steady light—the latter being characterized by their twinkling or scintillation.

11. The Moon—its Motions and Phases.—Of all the heavenly bodies, the moon is perhaps the most beautiful and interesting; although, in consequence of seeing it so often, we are very apt to pay but little attention to the singular phenomena which it presents. At its first appearance in the west, just after sunset, it looks like a thread of light in the blue sky, which, as twilight disappears, seems to be the partially silver edge of a dark orb, which is faintly visible. From night to night the crescent expands as the moon seems to depart further from the sun, until it is seen in the south at sunset, and then presents half of an illuminated circle. This, too, gradually widens, and, in about a week, we see its full round form clamber up the eastern slope of the sky just as the sun sets below the western horizon. After this, it rises later and later every night until it appears in the east in the morning just before sunrise, presenting the same slender crescent of light which we saw in the west on its first coming into view; and soon afterward it disappears

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11. What is said of the moon? What appearances does it present? What are its phases?

for a short time, to begin again its monthly career. These various changes of form presented by the moon are called its *Phases*.

12. Comets and Meteors.—Occasionally, beside the sun, moon, stars, and planets, we see a very singular looking body in the sky, presenting a kind of misty or cloudy aspect, and accompanied by a long train of light. Such bodies are called *Comets*. Quite frequently, also, there is seen what appears like a star falling from the sky. It darts or shoots across the heavens with amazing rapidity, and disappears almost before we can see it. Such bodies are called *Meteors*. Some of them are of great size, shine with various colors, and pass through the air followed by a long and brilliant train, and sometimes explode with a loud noise.

13. All the phenomena connected with these bodies it is earnestly recommended to the young student to watch very carefully, so as to ascertain whether the statements here made are correct. By so doing, he will, in the only efficient way, lay the foundation for a clear and extensive knowledge of the most sublime of all sciences—the science which treats of the heavenly bodies—Astronomy.

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12. What other bodies are occasionally seen? Describe their appearance.
13. What is recommended to the student? What is astronomy?

SECTION II.

THE EARTH—ITS FORM, MOTIONS, SIZE, ETC.

14. The body on which we live, named the *Earth*, is evidently a sphere or globe in form, for the following reasons:

1. The earth and sky always seem to meet in a circle, when the view is unobstructed;

2. The top of a distant object always appears above this circle before the lower parts; as the sails of a ship before its hull;

3. The elevation of the spectator causes this circle to sink, so as to show more of the earth's surface, and equally on all sides;

4. The heavenly bodies appear to move around the earth, some in large circles, some in small circles—one particular star in the heavens not appearing to have any motion at all;

5. Navigators are able to sail entirely around the earth either in an eastward or a westward direction.

15. That the earth is in motion is evident from the apparent movements of the heavenly bodies. The sun, planets, and stars all appear to pass round the earth once

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14. What is the shape of the earth? First proof? Second? Third? Fourth? Fifth? 15. What proofs are there that it is in motion? What is the direction of its rotation? What is meant by its axis?

every twenty-four hours. Now, while it is incredible that all these bodies, evidently at different distances from the earth, should revolve around it in exactly the same time, the simple supposition that the earth itself turns on its axis once every day explains all the appearances which they present. Every child has observed that when he is traveling in a steamboat or a railroad car, all distant objects appear to be moving in the contrary direction; thus, the apparent westward motion of the heavenly bodies indicates a real rotation of the earth in the contrary direction. The straight line on which the earth may be conceived to turn is called its *Axis*.

16. Latitude and Longitude.—Points are located on the surface of the earth by measuring their distances from certain established circles conceived to be drawn upon it. The position of these circles is determined by their relation to two fixed points, called the *Poles*. These points are the two extremities of the earth's axis—one being called the *North Pole*, and the other the *South Pole*. The two points where the earth's axis if extended would meet the heavens are called the *Celestial Poles*. The position of one of these (the northern) is indicated by the pole star.

17. The great circle exactly midway between the two poles is called the *Equator*. Its plane divides the earth into northern and southern hemispheres. The great cir-

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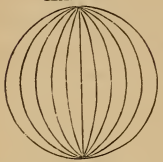
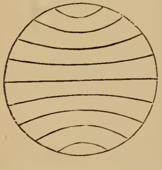
16. How are points on its surface located? How are the position of these circles determined? What are the poles of the earth? The Celestial Poles? How is the northern ascertained? 17. What is the equator? What are meridian circles? Meridians? How do they divide the earth?

cles that pass through the poles are called *Meridian Circles;* the half of a meridian circle, extending from pole to pole, is called a *Meridian.* The plane of any meridian circle must therefore divide the earth into eastern and western hemispheres.



18. The position of a place on the surface of the earth is indicated by its distance from the equator and from some fixed meridian. The distance of a place, north or south, from the equator is called its *Latitude;* its distance, east or west, from some established meridian is called its *Longitude.* For this purpose the meridian of London or Greenwich is generally used; but sometimes that of Washington or Paris. Such a meridian is called a *First,* or *Prime Meridian.*

19. Latitude is reckoned on a meridian from the equator to the poles; longitude is reckoned from the prime meridian round to the opposite meridian. Small circles parallel to the equator are called *Parallels of Latitude.* It will be easily perceived that the poles have the greatest possible latitude, namely, 90°; and that places situated under the meridian opposite the prime meridian, have the greatest longitude—namely, 180°, east or west.



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18. How is the position of a place indicated? What is latitude? Longitude? What is a first or prime meridian? 19. How is latitude reckoned? Longitude? What are parallels of latitude? What points have the greatest latitude? The greatest longitude?

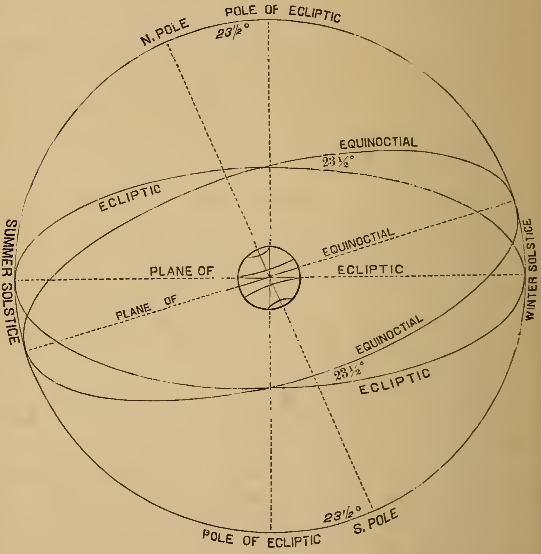
20. Dimensions of the Earth.—The size of the earth is ascertained by measuring the length of a degree on the meridian of any place; and then, as there are 360 degrees in the circumference of a circle, 360 times that length will be the circumference of the earth. The average length of a degree is a little more than $69\frac{1}{9}$ miles, and the circumference of the earth, about 24,877 miles. *Its diameter is* 7,912 *miles.* Careful observations have determined that the shape of the earth is not perfectly spherical, its diameter at the poles being about 26 miles less than at the equator. It is, therefore, a little flattened at the poles, its true form being that of an *oblate spheroid.*

21. Yearly Motion of the Earth.—This great body is not only rotating on its axis, but is also revolving around the sun. This is indicated by the apparent motions of the sun with respect to the stars, which it must be remembered are fixed points. The sun has an easterly movement among these bodies similar to that of the planets; and the time that elapses from its leaving any star until it arrives at the same again is $365\frac{1}{4}$ days. This motion of the sun we know is not real, but is occasioned by the revolution of the earth around the sun from west to east.

22. Ecliptic, Equinoctial, etc.—The great circle in the heavens in which the sun appears to revolve around

20. How is the size of the earth ascertained? What is the length of a degree on the meridian? What is the circumference of the earth in miles? Its diameter? What is the exact shape of the earth? 21. What indicates a revolution of the earth around the sun? How does the sun appear to move? What does this prove? 22. What is the ecliptic? The equinoctial? At what angle do these circles cross each other? What is this angle called? What does this prove?

the earth every year is called the *Ecliptic.* If we conceive the plane of the equator to be extended on all sides, it will cut the sphere of the heavens in a great circle, which is called the *Equinoctial;* and observation



determines that the ecliptic crosses the equinoctial, making with it an angle of 23½ degrees. This is called the *Obliquity of the Ecliptic*, and proves to us that the earth's axis is inclined to the plane of its orbit, that is, the path in which it may be conceived to revolve around the sun.

23. The two opposite points where the ecliptic crosses the equinoctial are called the *Equinoctial Points*, or *Equinoxes.* The one which the sun passes in March is called the *Vernal Equinox;* and the other, which the sun passes in September, is called the *Autumnal Equinox.*

24. The two opposite points of the ecliptic at which the sun is farthest from the equinoctial are called the *Solstitial Points*, or *Solstices.* The one north of the equinoctial is called the *Summer Solstice;* the one south of it, the *Winter Solstice.*

25. Signs of the Ecliptic, Etc.—In order to indicate the progress of the sun in the ecliptic and to define its position at any time, that circle is divided into twelve equal portions called *Signs*, each division being marked by a particular sign. The following are the signs, with their names, and the day of the month on which the sun enters each:

Spring Signs.	♈	ARIES	March 20.	VERNAL EQUINOX.
	♉	TAURUS	April 20.	
	♊	GEMINI	May 21.	
Summer Signs.	♋	CANCER	June 21.	SUMMER SOLSTICE.
	♌	LEO	July 23.	
	♍	VIRGO	August 23.	
Autumn Signs.	♎	LIBRA	September 23.	AUTUMNAL EQUINOX.
	♏	SCORPIO	October 23.	
	♐	SAGITTARIUS	November 23.	
Winter Signs.	♑	CAPRICORNUS	December 22.	WINTER SOLSTICE.
	♒	AQUARIUS	January 20.	
	♓	PISCES	February 18.	

23. What are the equinoctial points? What is the vernal equinox? The autumnal equinox? 24. What are the solstitial points? How are they distinguished? 25. How is the ecliptic divided? Name the signs. When does the sun enter each?

26. The distance of the sun from the Vernal Equinox, reckoned on the ecliptic, is called its *Longitude;* but when the distance is reckoned on the equinoctial, it is called its *Right Ascension.* The distance of the sun at any time from the equinoctial north or south is called its *Declination.* It will be obvious that the greatest declination of the sun is 23½ degrees. The same terms are also applied to the distances of the stars and planets from these circles and points. The distance of a heavenly body from the ecliptic is called its *Latitude.* Thus latitude on the earth is reckoned from the equator; but celestial latitude is reckoned from the ecliptic, while terrestrial latitude corresponds to declination.

DAY AND NIGHT.

27. The rotation of the earth on its axis causes the succession of day and night. As the earth turns, every place is brought alternately into the light and into the shade. That portion of the earth's surface which is turned toward the sun, so that its rays can shine upon it, has day; and the part turned away from the sun, being in the shadow of the earth, must have night.

28. At certain times in the year the days are equal to the nights, while at other times they are either much

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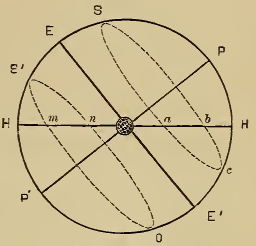
26. What is meant by the longitude of the sun? Its right ascension? Its declination? What is the greatest declination of the sun? To what other bodies are these terms applied? What is meant by the latitude of a heavenly body? What is the difference between celestial and terrestrial latitude? To what does terrestrial latitude correspond? 27. What causes day and night? To what part of the earth is it day? To what part night? 28. Why are the days sometimes longer or shorter than the nights? When do places have longer day than night? When the reverse? Illustrate by the diagram.

longer or much shorter. This is caused by the obliquity of the ecliptic, in consequence of which the sun's declination is constantly changing. When the sun is north of the equinoctial, all places in the northern hemisphere have longer day than night, and those in the southern hemisphere, longer night than day; but when the sun is south of the equinoctial, this is reversed.

In the diagram, let H H represent the horizon, P P′ the axis of the celestial sphere, E E′ the equinoctial; let also S be the sun in north declination, and S′ in south declination. It will be obvious that as the earth turns, the sun at S will appear to move in a diurnal arc, as *a* S *b*. greater than the nocturnal arc *a c b;* and at S′, the diurnal arc *m* S′ *n* will be less than the nocturnal arc *m o n;* while at E, in the equinox, the circle of daily motion described by the sun will be divided equally by the horizon.



LONGEST DAY AND NIGHT.

29. At places situated under the equator, the heavenly bodies appear to describe circles perpendicular to the horizon, and these *circles of daily motion* are all bisected by the horizon, so that the diurnal arc of the sun is constantly equal to the nocturnal arc. The days are, therefore, at places thus situated, always equal to the nights. It is also obvious that, at places under the equator, during one-half of the year, the sun is in the north when on the meridian, and during the other half in the south; while

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29. What do the heavenly bodies appear to describe at places under the equator? How does this affect the length of day and night? When is the sun vertical? What places can have a vertical sun?

on the 20th of March and the 23d of September, it is exactly overhead, or *vertical.* Since the sun's declination is never greater than $23\frac{1}{2}°$, no place whose latitude, either north or south, is beyond that limit, can have a vertical sun; and all places within these limits must have a vertical sun twice every year; that is, as the sun moves north or south, and on its return.

30. The small circles parallel to the equinoctial at the limit of the sun's declination are called the *Tropics;* that at the northern solstice is called the *Tropic of Cancer*, and that at the southern, the *Tropic of Capricorn.* These names are used because when the sun arrives at one of these circles it *turns* back and goes to the other—the word *tropic* meaning *turning.*

31. At the north or south pole there must be constant day during the whole six months the sun is north or south of the equinoctial; it being constant day at one pole while it is constant night at the other. For to a person standing at the pole the equinoctial coincides with the horizon, and therefore when the sun is north of the equinoctial it must be above the horizon of the north pole and below that of the south pole. It will also be obvious that there must be constant day and constant night alternately to all places situated within $23\frac{1}{2}$ degrees from either pole, and that its length must depend upon the distance from the pole.

[These facts can best be illustrated by means of a globe or a tellurium, which will show the different portions of the sphere and the relation of the circles of daily motion to the horizon.]

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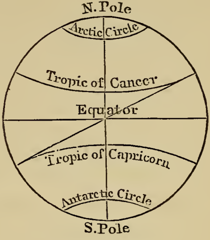
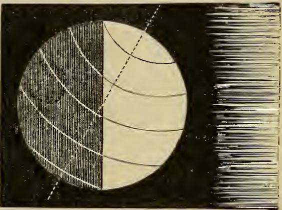
30. What are the tropics? How are they distinguished? Why is the word *tropic* used? 31. What occurs at the poles? Why? What places can have constant day and constant night?

32. The two small circles parallel to the equator, and $23\frac{1}{2}$ degrees from the poles, are called *Polar Circles.* The one round the north pole is called the *Arctic Circle;* and the one round the south pole, the *Antarctic Circle.* They serve to mark the limit at which constant day and constant night can occur.

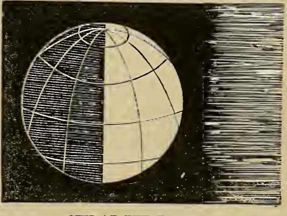


POLAR CIRCLES.

33. When the sun is at either of the *solstices*, all places in the same hemisphere with it have their longest day and shortest night; and those in the other, their shortest day and longest night. For when the sun's declination is greatest, its meridian, altitude, and diurnal arc must be greatest, and its nocturnal arc least.


SUN AT THE SOLSTICE.

34. When the sun is at either of the equinoxes, the days and nights are equal to each other in every part of the world. For, since the horizon of every place


SUN AT THE EQUINOX.

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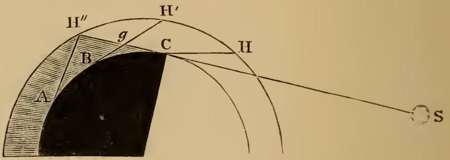
32. What are the polar circles? How are they distinguished? What do they mark? 33. What occurs when the sun is at either of the solstices? Why? 34. What occurs when the sun is at either of the equinoxes? Why?

bisects the equinoctial, the sun's diurnal arc must everywhere be equal to its nocturnal arc.

TWILIGHT.

35. When the sun is a short distance below the horizon, its rays fall on the upper portions of the atmosphere, which, like a mirror, reflect them upon the earth, and thus produce that faint light which is called *twilight*. The morning twilight is generally called the *dawn*.



Let A B C represent three places on the earth, and A H″, B H′, C H, their horizons respectively. Suppose S to represent the sun, a little below the horizon, its rays passing through the atmosphere in S C H″; at A, no portion of the visible atmosphere is illuminated, and consequently there is no twilight; at B, the part H″ *g* H is illuminated, and at C, H″ C H; twilight is produced at each of these points.

36. The duration of twilight varies greatly at different parts of the earth; it is shortest at the equator, and increases toward the poles. Near the polar circles and within them, there is constant twilight during a part of each year.

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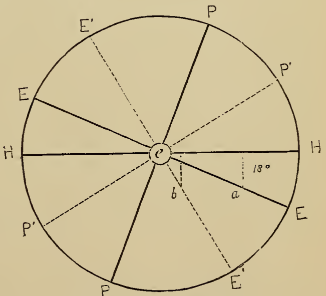
35. How is twilight caused? 36. How does its duration vary? Remark?

At the equator, the duration is 1h. 12m.; at the poles, there are two twilights during the year, each lasting about 50 days. This long twilight diminishes very much the time of total darkness at the poles; for the sun is below the horizon six months, equal to 180 days, and deducting 100 days of twilight, there remain only 80 days, or less than three months, of actual night.

37. Twilight does not cease until the sun is about 18° below the horizon.

If the earth's atmosphere were more extensive than it is, the twilight would of course be longer, since the sun would not cease to illuminate the higher portions of the atmosphere until more than 18° below the horizon; and if the atmosphere were less extensive, the reverse of this would be the case. Knowing, therefore, the depression of the sun (18°) requisite for the cessation of twilight, we can calculate the extent or height of the atmosphere.

38. If the circles of daily motion were at all places equally inclined to the horizon, the duration of twilight would everywhere be the same; since the earth would always have to turn the same amount to bring the sun 18° below the horizon; but the more oblique the circles are, the farther the earth has to turn, and hence the twilight is longer the nearer we go to the poles.



DURATION OF TWILIGHT.

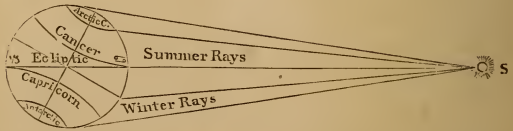
Let the large circle represent the celestial sphere,

37. When does twilight cease? Remark? 38. Why does the duration of twilight vary? Illustrate by the diagram.

e the earth in the centre; P H the altitude of the pole in one position of the sphere, and P′ H its altitude in one less oblique; E E and E′ E′ the equinoctial in each, and, of course, the direction of the circles of daily motion. In the more oblique sphere, that is, at the place in the more northern latitude, the celestial sphere, or which is the same thing, the earth, would have to turn a distance on the diurnal circle, equal to *e a*, to bring the sun 18° below the horizon; while in the other position, the sun would reach the same point of depression when the sphere had turned only *e b*. Thus we see the nearer the perpendicular the diurnal circles are, the shorter the twilight; while the more oblique they are, the longer the twilight.

THE SEASONS.

39. The seasons are caused by the inclination of the earth's axis to the plane of its orbit. For the amount of heat received at any place from the sun depends upon the direction of its rays. In summer the rays are less oblique than in winter, and consequently the heat is greater; and this is still further augmented by the greater length of the day.



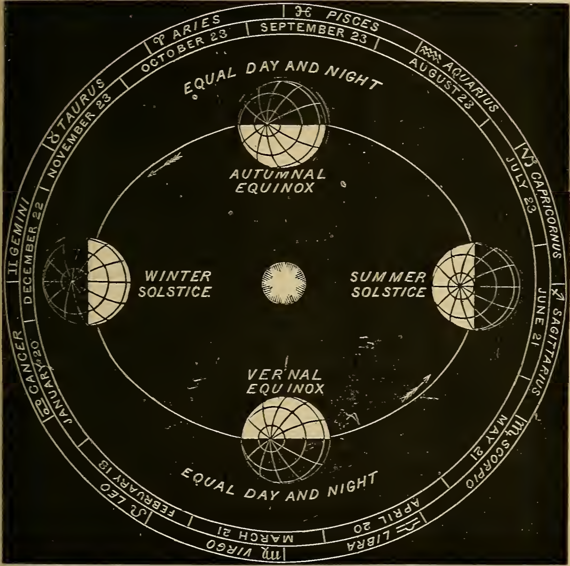
SUMMER AND WINTER RAYS.

In the annexed diagram, the effect of perpendicular and oblique rays is illustrated. It will be observed that the same quantity of

39. How are the seasons caused? Why? Why is the heat greater in summer than in winter?

rays that covers the north polar circle, when they are nearly perpendicular, covers the whole space from the antarctic circle to the equator when they are oblique.

40. The four seasons, *Spring*, *Summer*, *Autumn*, and *Winter*, are marked and limited by the arrival of the



THE SEASONS.

sun at the vernal equinox, northern solstice, autumnal equinox, and winter solstice, respectively. They are

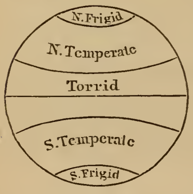
40. How are the four seasons marked and limited? Why are they regular?

regular—that is, always the same from year to year, because the axis always points in the same direction, or remains parallel to itself.

41. When the sun is at either of the solstices, summer is produced in that hemisphere which is turned toward the sun, and winter in the other, the rays falling directly on the former, and obliquely on the latter. When the sun is at either of the equinoxes, the earth's axis leans sidewise to it, and the rays are direct at the equator, and equally oblique on both sides of it. Consequently, there is neither summer nor winter; but spring in that hemisphere which the sun is about to enter, and autumn in that which it has left.

[The above statements will be understood by an inspection of the diagram on page 35.]

42. Those parts of the earth at which the sun may be vertical must have the greatest heat, and those parts at which there may be constant night must have the greatest cold; while the parts between them must have a degree of heat and cold not so extreme as either. Hence the earth's surface has been divided into five portions, called *Zones*, the boundaries of which are the tropics and polar circles.



THE ZONES.

43. These zones are called the *Torrid*, *North Temperate*, *South Temperate*, *North Frigid* and

41. What occurs when the sun is at either of the solstices? When it is at either of the equinoxes? Where is it spring? Autumn? 42 At what places must the heat be greatest? The cold? How is the earth's surface divided? 43. What names are given to the zones? State the situation of each.

South Frigid zones. The Torrid Zone includes the space between the tropics; the Temperate Zones are between the tropics and polar circles; and the Frigid Zones are within the polar circles.

THE CELESTIAL SPHERE.

44. By the Celestial Sphere is meant the concave sphere of the heavens, in which the heavenly bodies appear to be placed, the observer being at the centre within, and looking upward. The principal circle of this sphere is the horizon, which may be defined as the circle that separates the visible part of the heavens from the invisible. It is either *Sensible* or *Rational.*

45. The *Sensible Horizon* is the circle which bounds our view; and its plane touches the earth at the place where the observer stands. The *Rational Horizon* is below the sensible horizon, and parallel to it; and its plane passes through the centre of the earth. Owing to the great distance of the heavenly bodies from the earth, these two circles very nearly coincide in the heavens.

46. When, however, the observer stands at an elevation above the surface of the earth, the sensible horizon sinks below the rational horizon, and more than one-half of the heavens becomes visible. This is called the *Dip of the Horizon.*

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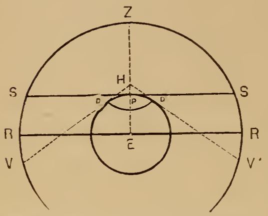
44. What is the celestial sphere? What is the principal circle of this sphere? How may it be defined? How distinguished? 45. What is the sensible horizon? The rational horizon? How do they differ? 46. What is meant by the dip of the horizon? How is it caused? Illustrate by the diagram.

This will be understood by studying the following diagram and explanation: Let the small circle, whose centre is E, represent the earth, the portion of the large circle V Z V′ a part of the celestial sphere, and P the point, or place, of the spectator. Then the tangent S P S will represent the plane of the sensible horizon, and S Z S the visible heavens. Conceive the observer to stand above the surface at H; the tangents H V and H V′ will then, at their points of contact, D and D, limit the visible part of the earth's surface, and at their extremities, V and V′, the visible heavens. S V or S V′ will be, of course, the dip of the horizon. At the point P, the visible part of the heavens is less than the invisible; but at so great an elevation as H P (represented as about 1,000 miles), the visible part would be much greater than the invisible, and a large part of the earth's surface, denoted by the arc D D, would come into view. The dip, however, at any attainable height is very small, and only an inconsiderable portion of the earth's surface can ever be seen. The line R R represents the plane of a great circle, which divides the celestial sphere into equal parts, passing through the centre of the earth, and situated at a distance from the plane of the sensible horizon equal to the semi-diameter of the earth, or nearly 4,000 miles.



SENSIBLE AND RATIONAL HORIZON.

47. The poles of the horizon are called the *Zenith* and *Nadir*. The zenith is the point directly overhead; the nadir is the point opposite to the zenith, and directly under our feet. One is, therefore, the pole of the visible, or upper hemisphere; and the other, the pole of

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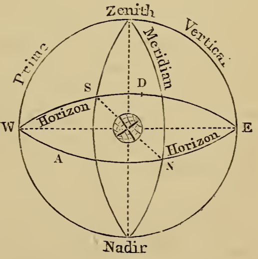
47. What are the poles of the horizon? What is the zenith? The nadir? What is the distance of each from the horizon?

the invisible, or lower. Each is obviously 90 degrees from the horizon.

48. Circles conceived to pass through the zenith and nadir, perpendicular to the horizon, are called *Vertical Circles.* That which passes through the east and west points of the horizon is called the *Prime Vertical.* That which passes through the north and south points of the horizon also passes through the poles of the earth, being the *Meridian of the Place*,—the circle which the sun crosses at noon.

49. The distance of a body east or west from the meridian is called its *Azimuth*; the distance of a body above the horizon is called its *Altitude.* The altitude and azimuth of a body serve to indicate its exact position in the visible part of the celestial sphere.

In the diagram, let N E S W represent the rational horizon; the circle passing through N S, the meridian; and that passing through E W, the prime vertical; then, if A be the position of the sun at rising, A E will be its amplitude and A N its azimuth, while its altitude will be 0°.



QUESTIONS FOR EXERCISE.

1. What is the latitude of the north pole?
2. What is the latitude of a place under the equator?

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48. What are vertical circles? What is the prime vertical? The meridian of the place? 49. What is azimuth? Altitude? What do they indicate?

3. The latitude of New York being 40½ degrees, what is its distance from the north pole? From the south pole?

4. What is the latitude of a place under the Tropic of Cancer? Under the Tropic of Capricorn?

5. What under the Arctic Circle? Under the Antarctic Circle?

6. What is the greatest latitude of a place?

7. What is the greatest altitude of a heavenly body?

8. Where is the altitude greatest? Where is it least?

9. At what points is the declination of the sun greatest?

10. At what points is its declination least?

11. What is the right ascension of the sun in the first degree of Cancer? What is its longitude?

12. What right ascension and declination has it in the first degree of Capricorn?

13. What in the vernal equinox? In the autumnal equinox?

14. What is the longitude and latitude of the sun in the summer solstice? In the winter solstice?

PROBLEMS FOR THE TERRESTRIAL GLOBE.

PROBLEM I.

To find the latitude and longitude of a place: Bring the given place to the graduated side of the brass meridian [the circle of brass that encompasses the globe], which is numbered from the equator to the poles: and the degree of the meridian over the place will be the latitude; and the degree of the equator under the meridian, east or west of the prime meridian, will be the longitude.

Verify the following by the globe:

	LAT.	LONG.		LAT.	LONG.
London, . .	51½° N.;	0°.	C. Good Hope,	34° S.;	18½° E.
Paris, . .	49° N.;	2¼° E.	Berlin, . .	52½° N.;	13½° E.
Washington,	39° N.;	77° W.	Madras, . .	13° N.;	80° E.
Cincinnati,	39° N.;	84½° W.	Santiago, .	32½° S.;	70½° W.

PROBLEM II.

The latitude and longitude of a place being given, to find the place: Find the degree of longitude on the equator, bring it to the brass meridian, and under the given degree of latitude, on the meridian, will be the place required.

EXAMPLES.

1. What place is in lat. 30° N., and long. 90° W.? *Ans.* New Orleans.
2. What place " " $42\frac{1}{2}$° N., " 71° W.? *Ans.* Boston.
3. What place " " $40\frac{3}{4}$° N., " 74° W.? *Ans.* New York.

PROBLEM III.

To find the difference of latitude or longitude between any two places: Find the latitude or longitude of both places; if on the same side of the equator or meridian, subtract one from the other; if on different sides, add them; the result will be the answer required.

EXAMPLES.

Find the difference of latitude and longitude of

1. London and Naples. *Ans.* Lat. $10\frac{1}{2}$°, long. $14\frac{1}{4}$°.
2. New York and San Francisco. *Ans.* Lat. 3°, long. $58\frac{1}{2}$°.
3. Stockholm and Rio Janeiro. *Ans.* Lat. 82°, long. 61°.

Difference of Longitude causes Difference of Time.—Since the earth turns toward the east, any place east of another place must have *later time*, because it is sooner carried, by the motion of the earth, under the sun; and as an entire rotation, or 360°, is performed in 24 hours, 15° of longitude must be equivalent to one hour of time. Thus, London is 74° east of New York; and, consequently, when it is noon at New York, it is 5 o'clock in the afternoon at London, the sun having passed the meridian five hours earlier.

Difference of Longitude may be converted into Difference of Time, by multiplying the degrees and minutes by 4; the former of which will then be minutes of time, and the latter, seconds. For since $\frac{1}{15}$ the number of degrees is equal to the number of hours, $\frac{60}{15}$ or 4 times, the degrees must be equal to the minutes; and, for the same reason, 4 times the minutes of space must be equal to seconds of time.

To convert Difference of Time into Difference of Longitude, reduce the hours to minutes, and divide by 4. For since 15 times the hours are equal to the degrees, $\frac{1}{60}$ of 15, or $\frac{1}{4}$, the minutes must be equal to the degrees.

PROBLEM IV.

To find all the places that have the same latitude as any given place: Bring the given place to the brass meridian, and observe its latitude; turn the globe round, and all places that pass under the same degree of the meridian will be those required.

EXAMPLES.

What places have the same, or nearly the same, latitude as

1. MADRID? *Ans.* Minorca, Naples, Constantinople, Kokand, Salt Lake City, Pittsburgh, New York.
2. HAVANA? *Ans.* Muscat, Calcutta, Canton, C. St. Lucas, Mazatlan.

PROBLEM V.

To find the places that have the same longitude as any given place: Bring the given place to the graduated side of the brass meridian, and all places under the meridian will be those required.

EXAMPLE.

What places have the same, or nearly the same, longitude as
LONDON? *Ans.* Havre, Bordeaux, Valencia, Oran, Gulf of Guinea.

PROBLEM VI.

A time and place being given, to find what o'clock it is at any other place : Bring the place at which the time is given to the brass meridian, set the index to the given time, and turn the globe till the other place comes to the meridian, and the index will point to the time required

NOTE.—If the place be east of the given place, turn the globe westward; if west, turn it eastward.

This problem can be performed without the globe by finding the difference of longitude.

EXAMPLES.

1. When it is noon at NEW YORK, what o'clock is it at LONDON? *Ans.* 5 o'clock P. M. (nearly).
2. When it is 10 o'clock A. M. at ST. PETERSBURG, what o'clock is it at the CITY of MEXICO? *Ans.* 1 hour 20 min. A. M.
3. When it is 9 o'clock P. M. at ROME, what o'clock is it at SAN FRANCISCO? *Ans.* Noon.

PROBLEM VII.

To find the distance between any two places : Lay the graduated edge of the quadrant over both places, so that the division marked 0 may be on one of them; and the number of degrees between them, reduced to miles, will be the distance required.

NOTE.—If geographic miles are required, multiply the degrees by 60; if statute miles, by $69\frac{1}{9}$.

EXAMPLES.

Find the distance in geographic and statute miles between

1. NORTH CAPE and CAPE MATAPAN. *Ans.* 2,100 geog. miles; $2,418\frac{8}{9}$ statute miles.
2. RIO JANEIRO and CAPE FAREWELL. *Ans.* 4,980 geog. miles; $5,736\frac{2}{9}$ statute miles.

PROBLEM VIII.

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

EXAMPLES.

1. What is the longitude of the sun June 21st? *Ans.* 90°.
2. What is it February 22d? *Ans.* 334½°.
3. What is it May 10th? *Ans.* 50°.

PROBLEM IX.

To find the right ascension of the sun: Bring the sun's place in the ecliptic to the edge of the brass meridian; and the degree of the equinoctial over it, reckoning from the first degree of Aries, toward the east, will be the right ascension.

EXAMPLES.

1. What is the right ascension of the sun October 18th? *Ans.* 203½°.
2. What is it May 2d? *Ans.* 42°.

PROBLEM X.

To find the declination of the sun: Bring the sun's place in the ecliptic to the edge of the brass meridian; and the degree of the meridian over it, reckoning from the equator, will be the declination. The declination may also be found by bringing the given day of the month as marked on the *analemma* to the meridian.

EXAMPLES.

1. What is the declination of the sun June 21st? *Ans.* $23\frac{1}{2}°$ N.
2. What is its declination Jan. 27th? *Ans.* $18\frac{1}{2}°$ S.
3. What is it April 16th? *Ans.* 10° N.

PROBLEM XI.

To find what places have a vertical sun on any day in the year: Find the sun's declination, and note the degree on the brass meridian; then turn the globe around, and all places that pass under that degree will be those required.

EXAMPLES.

1. What places have a vertical sun March 20th? *Ans.* All places under the Equator.
2. To what places is the sun vertical December 22d? *Ans.* To all places under the Tropic of Capricorn.
3. To what places is the sun vertical May 1st? *Ans.* To all in latitude 16° N.

PROBLEM XII.

To find the meridian altitude of the sun for any day of the year, at any place: Make the elevation of the north or south pole above the wooden horizon equal to the latitude, so that the wooden horizon may represent the horizon of that place; bring the sun's place in the ecliptic to the brass meridian, and the number of degrees on the meridian from the horizon to the sun's place will be the meridian altitude.

EXAMPLES.

1. Find the sun's meridian altitude at New York, June 21. *Ans.* 73°.
2. At London, Jan. 27th. *Ans.* 20°.
3. Rio de Janeiro, September 23d. *Ans.* 67°.

PROBLEM XIII.

To find the amplitude of the sun at any place, and for any day in the year: Proceed as in Problem XII.; then bring the sun's place to the eastern or western edge of the horizon, and the number of degrees on the horizon from the east or west point will be the amplitude.

EXAMPLES.

1. Find the sun's amplitude at LONDON, June 21st. *Ans.* 39¾° N.
2. At QUITO, September 23d. *Ans.* 0°.
3. At PHILADELPHIA, July 16th. *Ans.* 28° N.

PROBLEM XIV.

To find the sun's altitude and azimuth at any place, for any day in the year, and any hour of the day: Proceed as in Problem XII.; then set the index to twelve, and turn the globe eastward or westward, according as the time is before or after noon, until the index points to the given hour. Then, for a vertical, screw the quadrant of altitude over the zenith, and bring its graduated edge to the sun's place in the ecliptic; the number of degrees on the quadrant from the sun's place to the horizon will be the altitude, and the number of degrees on the horizon, from the meridian to the edge of the quadrant, will be the azimuth.

EXAMPLES.

1. Find the sun's altitude and azimuth at NEW YORK, May 10th, 9 o'clock A. M. *Ans.* Altitude, 45½°; azimuth, 72½° E.
2. At LONDON, May 1st, 10 o'clock A. M. *Ans.* Altitude, 47°; azimuth, 44° E.
3. At LONDON, March 20th, 3½ o'clock P. M. *Ans.* Altitude 22°; azimuth, 59° W.

PROBLEM XV.

To find on what two days of the year the sun is vertical at any place in the Torrid Zone : Turn the globe around, and observe what two points of the ecliptic pass under the degree of the brass meridian corresponding to the latitude of the place ; and the days opposite these points in the circle of signs will be those required.

EXAMPLES.

On what two days of the year is the sun vertical at

1. Bombay ? *Ans.* May 15th and July 29th.
2. Bahia ? *Ans.* Oct. 28th and Feb. 14th.

PROBLEM XVI.

To find the time of the sun's rising and setting, and the length of the day, at any place, and on any day in the year : Elevate the pole as many degrees as are equal to the latitude of the place, find the sun's place, bring it to the meridian, and set the index to twelve. Then turn the globe till the sun's place is brought to the eastern edge of the horizon, and the index will show the time of the sun's rising ; bring it to the western edge, and the index will show the time of the sun's setting. Double the time of its setting will be the length of the day ; and double the time of its rising, the length of the night.

Note.—The globe, of course, only shows this approximatively. A correction would also be required for refraction (see section XII.).

EXAMPLES.

At what time does the sun rise and set, and what is the length of the day and night,

1. At London, July 17th ? *Ans.* Sun rises at 4, and sets at 8 ; length of day, 16 hours ; night, 8 hours.

2. At New York, May 25th? *Ans.* Sun rises at $4\frac{3}{4}$, and sets at $7\frac{1}{4}$; length of day, $14\frac{1}{2}$ hours; night, $9\frac{1}{2}$ hours.

PROBLEM XVII.

To find the length of the longest and shortest days and nights at any place not within either of the polar circles: Find, by the preceding problem, the length of the day and night at the time of the northern solstice, if the place be north of the equator, and at the time of the southern solstice, if it be south of the equator; and this will be the longest day and shortest night. The longest day is equal to the longest night, and the shortest day to the shortest night.

EXAMPLES.

What is the length of the longest and the shortest day

1. At New York? *Ans.* Longest day, 14 hours 56 min.; shortest day, 9 hours 4 min.
2. At Berlin? *Ans.* Longest, $16\frac{1}{2}$ hours; shortest, $7\frac{1}{2}$ hours.

PROBLEM XVIII.

To find the beginning, end, and duration of constant day at any place within either of the polar circles: Take a degree of declination on the brass meridian equal to the polar distance of the place, then on turning the globe around, the two points on the ecliptic which pass under that degree will be the places of the sun at the beginning and end of constant day. Find the day of the month corresponding to each, and it will be the times required. The interval between these dates will be the duration of constant day.

Constant night is equal to constant day at a place situated under the corresponding parallel in the other hemisphere. Hence, to find the duration of constant night at a place in north latitude, find the length of constant day at a place having the same number of degrees of south latitude.

EXAMPLES.

Find the beginning, end, and duration of constant day and night at

1. North Cape. *Ans.* Constant day begins May 14th, ends July 30th; duration 77 days. Constant night begins November 25th, ends January 27th; duration, 73 days.
2. North Pole. *Ans.* Constant day begins March 20th, ends September 23d; duration, 187 days. Constant night begins September 23d, ends March 20th; duration, 178 days.

PROBLEM XIX.

To find the duration of twilight at any place not within either of the polar circles: Elevate the pole equal to the latitude, find the sun's place, bring it to the western edge of the horizon, and note the time shown by the index. Then screw the quadrant over the place, and bring its graduated edge to the sun's place; turn the globe till the sun's place is shown by the quadrant to be 18° below the horizon, and the time passed over by the index will be the duration of twilight.

EXAMPLES.

1. What is the duration of twilight at London, September 23d? *Ans.* 2 hours.
2. What is it at Dresden, April 19th? *Ans.* 2 hours, 15 min.

SECTION III.

THE SOLAR SYSTEM.

50. By means of the apparent motions of the planets, it is plainly seen that they revolve around the sun from west to east, receiving their light from that splendid luminary. The telescope reveals other bodies that revolve around the planets, and are carried with them around the sun; these are also called planets. All these bodies being dark except when illuminated by the sun, are called *opaque bodies;* while the sun, giving light of itself, is called a *luminous body.*

51. There are, therefore, two kinds of planets, namely, those that revolve around the sun only—called *Primary Planets*, and those that revolve around the primaries and with them around the sun—called *Secondary Planets*, or *Satellites.* Of the latter the moon is an example; since, as is proved by its apparent motions and phases, it revolves around the earth every month, and accompanies the latter in its annual motions around the sun.

52. Comets also revolve around the sun, but differ from planets not only in their appearance but in the direction of their motion, and the shape of their orbits.

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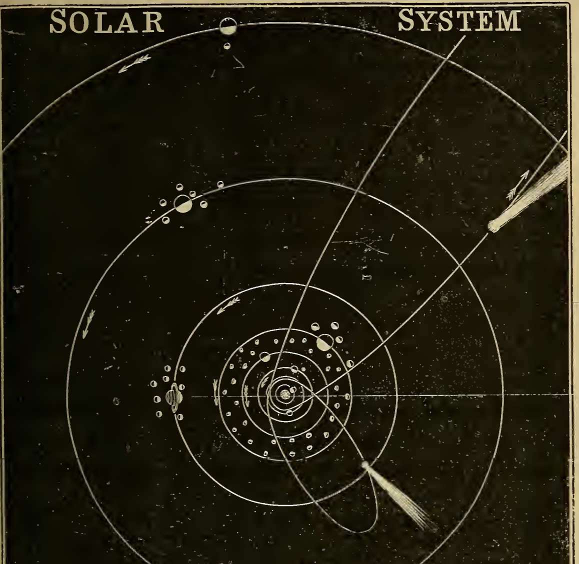
50. What do the apparent motions of the planets indicate? What does the telescope reveal? What are opaque bodies? Why is the sun called a luminous body? 51. How many kinds of planets are there? What example is given? 52. How do comets differ from planets? What is the orbit of a body?


SOLAR SYSTEM
JUPITER
COMPARATIVE MAGNITUDES
URANUS
NEPTUNE
EARTH
VENUS
MARS
MERCURY
ASTEROIDS
SATURN
SEGMENT OF SUN

For while the planets revolve from west to east, and in orbits nearly circular, comets sometimes revolve from east to west, and in very elongated orbits.

By the orbit of a body is meant the line which it may be conceived to describe in revolving around some other body.

53. It will thus be seen that the apparent motions of the sun, planets, and stars are explained by supposing, 1. That the earth is exactly or nearly a sphere; 2. That it turns on its axis once every twenty-four hours; 3. That the earth and all the other planets revolve around the sun; and, 4. That the stars are situated at an immense distance from the sun and planets, in the regions of space,—a distance so vast that their movements with respect to the earth and to each other cannot generally be discerned.

The sun with all its attendant bodies constitute the ***Solar System.***

This arrangement of the sun in the centre with the planets revolving around it, is sometimes called the *Copernican System*, from Nicholas Copernicus, who, in 1543, revived the doctrine taught by Pythagoras, a Greek philosopher, more than 2,000 years previously, that the sun is the central body, and that the earth and planets revolve around it.

Previous to Copernicus the general belief for more than two thousand years had been, that the earth is the centre of the universe, and that all the other bodies revolve around it in the following order: the moon, then the sun and planets, in their order, and then the stars. This system is very ancient, but being advocated and illustrated by Ptolemy, an eminent astronomer, who flourished

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53. How are the apparent motions of sun, planets, and stars explained? What constitutes the solar system? What is remarked of it?

at Alexandria, in Egypt, about 140 A. D., it was subsequently called the *Ptolemaic System.*

The doctrine of Copernicus, on its first promulgation in 1543, received little support, being generally rejected as visionary and absurd; but the invention of the telescope, in 1610, and the discoveries made by means of it, by Galileo and others, afforded abundant evidence of its truth.

THE PLANETS.

54. There are eight large primary planets in the Solar System, besides a great number of smaller ones, called *Minor Planets*, or *Asteroids.* The names of the larger planets are Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Of these, Mercury and Venus revolve within the earth's orbit, and are on this account called *Inferior Planets.* Mars, Jupiter, Saturn, Uranus, and Neptune, revolving beyond the earth's orbit, are called *Superior Planets.*

55. The fact that Mercury and Venus are inferior planets is shown by their never appearing but at a short distance from the sun. As already stated (Art. 8), Venus is never seen except as a morning or an evening star, and Mercury keeps always so near the sun that it is rarely seen at all. When it is visible, however, it shines with a very brilliant light in consequence of being so near the sun, twinkling like a fixed star. The other planets are known to be superior because they are seen at all distances from the sun, being

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54. How many primary planets are there? What are their names? Which are inferior? Which are superior? 55. How are Mercury and Venus known to be inferior? How are the other planets known to be superior?

sometimes seen at one point of the horizon while the sun is rising or setting at the opposite point.

56. The *Minor Planets* are very small bodies which revolve around the sun between the orbits of Mars and Jupiter. The number discovered is 112. Eighteen satellites are known to exist in the solar system; of which the earth has one,—the moon; Jupiter has four; Saturn, eight; Uranus, four; and Neptune, one.

57. All the planets in the solar system revolve in their orbits *from west to east*, except the satellites of Uranus and the satellite of Neptune, which revolve from east to west. As we view the planets, that is, looking towards the south (since the latitude of New York is $40\frac{1}{2}°$ north), the motion of the planets is from *right to left*, or the reverse direction of the hands of a clock.

MAGNITUDE OF THE SUN AND PLANETS.

58. The sun is by far the largest body in the solar system, being more than 500 times as large as all the planets taken together. Its diameter is a little more than 850,000 miles. The following are the diameters of the large primary planets in miles:

1. Jupiter, . .	85,000.	5. Earth, . .	7,912.
2. Saturn, . .	70,000.	6. Venus, . .	7,500.
3. Neptune, .	37,000.	7. Mars, . .	4,300.
4. Uranus, . .	33,000.	8. Mercury, .	3,000.

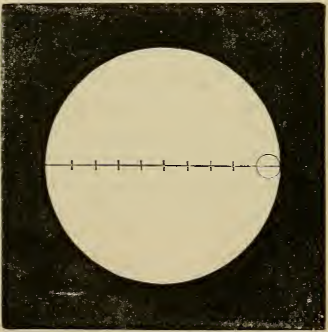
56. What are the minor planets? What is their number? How many satellites are there? How are they distributed? 57. How do the planets revolve? In what direction is this motion as we view them? 58. What is the magnitude of the sun? What is the diameter of each of the primary planets?

59. The first four of these planets, being very much larger than the remaining four, are called *Major Planets;* the others, being in the vicinity of the earth, are called *Terrestrial Planets.*

A clear idea of the comparative size of the sun and planets may be obtained by conceiving the sun to be a globe two feet in diameter. Mercury and Mars would then be of the size of pepper-corns; the Earth and Venus of the size of peas; Jupiter and Saturn, as large as oranges; and Neptune and Uranus, as large as full-sized plums.

60. The diameter of the moon is 2,160 miles; the four satellites of Jupiter, excepting one, are somewhat larger than the moon; and the eight satellites of Saturn, excepting one, are considerably smaller than the moon. Those of Uranus and Neptune also are probably smaller.

61. The *volume* of a body, by which is meant the amount of space which it occupies, depends upon its length, breadth, and thickness. Hence, the comparative volumes of spheres are as the *cubes* of their diameters. Thus, as the sun's diameter is ten times as great as that of Jupiter, the volume of the



COMPARATIVE SIZE OF SUN AND JUPITER.

59. Which are called major planets? Which terrestrial planets? Why? Illustration? 60. What is the size of the moon and of the other satellites? 61. What is meant by volume? On what does it depend? How are the volumes of bodies compared?

former is 1000 (10 × 10 × 10) times as great as that of the latter.

62. Two bodies may be equal in volume, but contain very different quantities of matter, owing to the different degrees of compactness of their substance. Thus, a piece of cork equal in bulk, or volume, to a piece of lead, evidently contains a very much less quantity of matter. The quantity of matter which a body contains is called its *Mass ;* the degree of compactness of its substance is called its *Density.*

The mass of a body depends upon its volume and density taken conjointly. Thus, if the volumes are as 2 to 3, and their densities, as 1 to 5, their masses will be as 1 × 2 to 3 × 5, or as 2 to 15 ; that is to say, the mass of the second will be $7\frac{1}{2}$ times as great as the first. To find the comparative density, therefore, of two bodies when the volume and mass of each are known, divide the relative mass by the relative volume.

63. The Terrestrial Planets are very much more dense than the Major Planets,—the average of the former being five times that of the latter. Mercury, the most dense of all the planets, is more than six times as dense as water. The density of the earth is nearly $5\frac{1}{2}$ times that of water ; the density of the sun is only about one-fourth the earth's, being about $1\frac{1}{2}$ that of water.

ORBITAL REVOLUTIONS OF THE PLANETS.

64. No portion of matter can set itself in motion ; nor, when in motion, can it stop itself. Whatever sets a body in motion, or stops it when in motion, is called *Force.*

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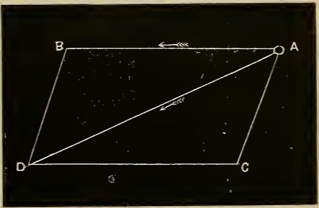
62. What is meant by the mass of a body ? Its density ? Illustration ? 63. What is said of the density of the terrestrial planets ? 64. What is force ?

65. A body when acted upon by a single force moves in a straight line; and will continue to move in the same direction and with the same velocity, until acted upon by some other force. When a force acts once and then ceases to act, it is called an *impulsive force;* when it acts constantly, it is called a *continuous force.*

Thus, the muscular force of the hand in throwing a stone, or the force of gunpowder in firing a ball from a cannon, is *impulsive;* the force of gravity by which a body falls to the ground is *continuous.*

66. When a body is impelled by two forces in different but not opposite directions, it moves in a straight line between them. This line is the diagonal of a parallelogram of which the lines that represent the direction and quantity of the forces are the sides, and is called the *resultant* of the two forces.



Thus, let A B represent the line over which the body A would pass in a certain time under the influence of one force, and A C, the line over which it would pass in the same time, if acted upon by another force; then under the simultaneous action of both forces, it will pass over the line A D in the same time, and continue to move in this line until acted upon by some third force.

67. When one of the two forces is a continuous force,

65. Distinguish between impulsive and continuous force. 66. How is a body affected by two forces? Illustrate by the diagram. 67. When does the body move in a curve line? What may this curve be? What are the forces then called?

the body is drawn, at every point, from the straight line, and, consequently, moves in a curve line; and these two forces may be so related to each other that the body will move around the centre of the continuous force in a circle or ellipse. In that case, the continuous force is called the *centripetal force;* and the impulsive force, the *centrifugal force.*

68. The *centripetal force* is that by which the body tends to approach the centre, or point around which it is revolving; the *centrifugal force* is that by which the body tends to fly off from the orbit in which it is revolving.

69. The centripetal force which acts upon the primary planets is the attraction of the sun; that which acts upon the secondary planets is the attraction exerted by their respective primaries. This arises from the general law, that *all bodies attract each other in direct proportion to their mass, and inversely as the square of their distance.*

That is, a body containing twice the quantity of matter of another body exerts twice the force; but, at twice the distance, would exert only one-fourth the force. This law is called the *Law of Universal Gravitation;* it was discovered by Sir Isaac Newton in 1665.

70. The centrifugal force must arise from an impulse given to the planets when they commenced their motions; since, without such an impulse, they would have

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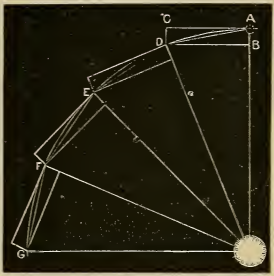
68. What is the centripetal force? The centrifugal force? 69. What acts as a centripetal force upon the planets? What is the general law? Illustration? 70. From what must the centrifugal force arise? What would result if it should be destroyed? What would result from the suspension of the centripetal force?

simply moved toward the sun and have been soon incorporated with it. And if the centrifugal force were now destroyed, the planets would all move in straight lines to the sun; while, if the attraction of the sun were suspended, they would move off into space in *tangent lines* to their orbits.



Let A B represent the amount of the centripetal, and A C that of the centrifugal force, for a given time; then completing the parallelogram, and drawing the diagonal A D, we find the point which the body when acted on by both forces will reach in that time. E, F, and G may be shown in a similar way to be the points reached by the body at the end of successive periods of time of an equal length; and thus, if the forces acted by impulses, the body would describe the broken line formed by the diagonals of the parallelograms; but as the force of gravitation is a continuous force, the revolving body describes a curve, which may either be a circle or an ellipse.

71. The three most important truths pertaining to planetary motion were discovered by Kepler about the year 1609; and hence are called *Kepler's Laws*. They are,

1. The planets' orbits are ellipses having the sun or central body in one of the foci.

2. The radius-vector of a planet's orbit passes over equal areas in equal times.

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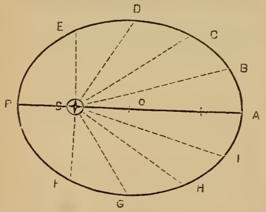
71. What is meant by Kepler's Laws? Recite them. What is meant by the periodic time of a planet?

3. The squares of the periodic times of the planets are in proportion to the cubes of their mean distances from the sun or central body.

By the *periodic time* of a planet is meant the time which it takes to revolve around the sun. The mean distance is the average distance, found by adding together its greatest and least distances and dividing by two.

72. By the *radius-vector* of a planet's orbit is meant a line which joins the planet at any point of its orbit to the body around which it is revolving. The point of a planet's orbit nearest the sun is called its *perihelion;* the point farthest from the sun is called its *aphelion.* These two points are sometimes called the *apsides.*



ELLIPTICAL ORBIT.

If S represent the sun in the focus of a planet's elliptical orbit, A will be the aphelion, P the perihelion, and A S, B S, C S, etc., the radius-vector in different positions of the planet. The planet moves in its orbit so that the spaces A S B, B S C, etc., may be equal, if described in equal times. It has therefore to move much faster in the perihelion than in the aphelion, since at the former point the spaces must be wider in order to make up for their diminished length.

73. The velocity of a planet is variable, being greatest at the perihelion, least at the aphelion, and alternately increasing and diminishing between these two points.

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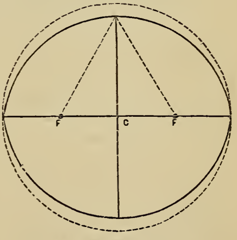
72. What is the radius-vector of a planet's orbit? What is perihelion? Aphelion? What are the apsides? 73. How does the velocity of a planet in its orbit vary? When would it be uniform? Why? In the case of what bodies is this true?

If the planets moved in circular orbits, the velocity would be uniform, since the radius-vector being constantly the same, the *arcs*, as well as the areas, described in equal times would be equal. This is the fact in the case of the satellites of Jupiter and Uranus, their orbits being almost, if not exactly, circles.

74. The *eccentricity* of the large planets' orbits is very small,—that of Mercury, which is the largest, being only about $\frac{1}{5}$, while that of Venus, the smallest, is only about $\frac{1}{145}$. The orbits of the minor planets are generally very remarkable for their great eccentricity. The eccentricity of an orbit is measured by comparing it with one-half of the major axis.

Thus, when it is said that the eccentricity of mercury's orbit is $\frac{1}{5}$, it is meant that it is $\frac{1}{10}$ of the major axis.

The annexed diagram will aid in giving the student a correct idea of the figure of the planets' orbits. This diagram represents an ellipse, the eccentricity of which is $\frac{1}{2}$, or much greater than that of the most eccentric of the minor planets. It will be apparent, therefore, that the *actual figure* of the planets' orbits is but slightly different from that of a circle. If drawn on paper, the eye could not detect the difference.



ELLIPSE—ECCENTRICITY, $\frac{1}{2}$.

75. The *mean place* of a planet is that in which it would be if it moved in a circle, and, of course, with

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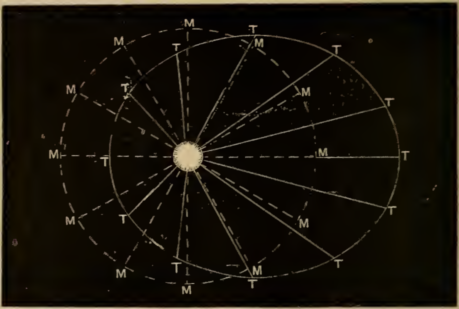
74. How great is the eccentricity of the planets' orbits? How is eccentricity measured? 75. What is the mean place of a planet? The true place? The equation of the centre? Illustrate by the diagram.

uniform velocity; the *true place* is that in which it is actually situated at any particular time. The angular distance of the true place from the mean place, measured from the sun as a centre, is called the *Equation of the Centre.*



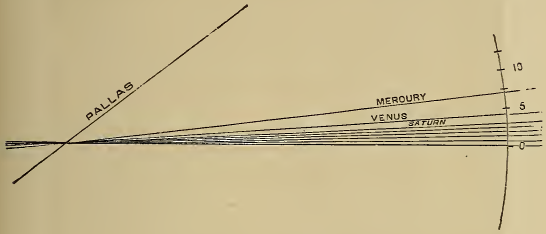
MEAN AND TRUE PLACES OF A PLANET.

In the above diagram, the ellipse represents the actual orbit of the planet, and the dotted circle the corresponding circular orbit. The points marked T represent the true places, and those marked M, the mean places of the planet. The mean place is obviously before or east of the true place, as the body moves from aphelion to perihelion, and behind, or west of it, in the other half of its revolution. The equation of the centre is the angle contained between the radius-vector and the radius of the circle.

76. The planets do not revolve around the sun all in the same plane, but in planes slightly inclined to each other. The angle which the plane of a planet's orbit

76. Do the planets revolve in the same plane? What is meant by inclination of orbit? Which planet has the greatest? Which the least? Explain by the diagram.

makes with that of the earth's orbit is called the *Inclination of its Orbit.* Of all the primary planets, Mercury has the greatest inclination of orbit (7°), and Uranus the least (46′). The Minor Planets are remarkable for a much greater inclination of their orbits than that of the other planets.



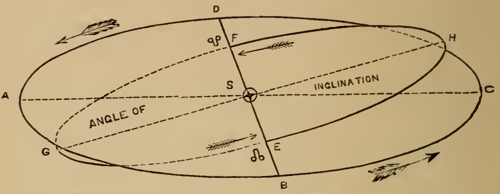
INCLINATION OF PLANETS' ORBITS.

The diagram represents the position of the plane of each orbit in relation to that of the earth. The small amount of deviation from one uniform plane will be at once apparent. These planets, however, on account of their vast distance from the sun, depart very far from the plane of the earth's orbit. Thus, Mars, although having only 2° of inclination, may be nearly 5 millions of miles from this plane; and Neptune, about 85 millions.

77. Since the planets' orbits are all inclined to that of the earth, each of them must cross the plane of the ecliptic in two points. These two points are called the *Nodes.* The point at which the planet crosses from south to north is called the *Ascending Node;* that at which it crosses from north to south, the *Descending*

77. What are nodes? Which is the ascending node? The descending node? What is the line of nodes?

Node. The straight line which joins them is called the *Line of Nodes.*



INCLINATION OF ORBITS.

The diagram represents an oblique view of the orbits of the earth and Venus. E is the ascending, and F the descending node. E F the line of nodes, and A S G the angle of inclination of the orbit. ☊ is the sign of the ascending node; ☋, of the descending node.

DISTANCES OF THE PLANETS FROM THE SUN.

78. The planets are all at immense distances from the sun, that of the nearest planet being more than 35 millions of miles.

A million is so vast a number that we can form no true conception of it without dividing it into portions. To count a million, at the rate of 5 per second, would require about 2½ days, counting without intermission, night and day. A railroad car, traveling at the rate of 30 miles per hour, night and day, would require nearly four years to pass over a million of miles.

79. The following are the mean distances expressed in approximate round numbers:

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78. How far are the planets from the sun? 79. What is the distance of each planet? Illustration? Bodé's Law?

Mercury, .	35 millions.	Jupiter, .	476 millions.
Venus, .	66 "	Saturn, .	872 "
Earth, .	$91\frac{1}{2}$ "	Uranus, .	1,754 "
Mars, .	139 "	Neptune,	2,746 "

Minor Planets, . . 260 millions (average).

Illustration.—Multiply each of these numbers expressing millions by four, and we shall find the time which an express train starting from the sun would require to reach each of the planets. In the case of the nearest planet, this period would be 140 years, and of the most remote, almost 11,000 years. A cannon ball moving at the rate of 500 miles an hour would not reach Neptune in less than 626 years.

Bodé's Law.—A comparison of the distances given above will show a very curious numerical relation existing among them, each distance being nearly double that next inferior to it. A more exact statement of this numerical relation was published in 1772 by Professor Bodé, of Berlin, although not discovered by him; it has usually been designated "Bodé's Law." Take the numbers

0, 3, 6, 12, 24, 48, 96, 192, 384;

each of which, excepting the second, is double the next preceding; add to each 4, and we obtain

4, 7, 10, 16, 28, 52, 100, 196, 388;

which numbers very nearly represent the relative proportion of the planets' distances, including the average distance of the Minor Planets. In the case of Neptune, the law very decidedly fails, and, consequently, has ceased to have the importance attributed to it before the discovery of this planet in 1846.

PERIODIC TIMES OF THE PLANETS.

80. The following are the periods of time occupied by the planets respectively in completing one revolution around the sun:

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80. What is the periodic time of each of the planets?

Mercury, .	88 days.	Jupiter, .	12 yrs. (nearly).
Venus, .	$224\frac{1}{2}$ "	Saturn, .	$29\frac{1}{2}$ "
Earth, . .	$365\frac{1}{4}$ "	Uranus, .	84 "
Mars, . .	1 yr. 322 days.	Neptune,	165 "

81. Of all the primary planets, Mercury moves in its orbit with the greatest velocity, and Neptune with the least, the velocities of the planets diminishing as their distances from the sun increase.

This is in accordance with Kepler's third law; since the ratio of the periodic times increases faster than that of the distances, the square of the former being equal to the cube of the latter. Thus if the distance of one planet is four times as great as that of another, the periodic time will not be simply *four* times as long, but *eight* times as long; that is, the square root of the cube ($\sqrt{4^3} = \sqrt{64} = 8$). Hence, as the planet has a longer time in proportion to the distance traveled, its velocity must be diminished.

82. The following exhibits the mean hourly motion of the primary planets in their orbits:

Mercury, . .	104,000 miles.	Jupiter, . .	29,000 miles.
Venus, . . .	77,000 "	Saturn, . .	21,000 "
Earth, . . .	65,500 "	Uranus, . .	15,000 "
Mars, ...	53,000 "	Neptune, .	12,000 "

Illustration.—What an amazing subject for contemplation does this table present! For example, the weight of the earth in tons is computed to be about 6,000,000,000,000,000,000,000; that is to say, six thousand million million times a million, or 6,000 × 1,000,000 × 1,000,000 × 1,000,000. Yet this body, so inconceivably vast, is rushing through the abyss of space with a velocity of 1,000

81. Which planet moves with the greatest velocity? Which with the least? Illustration? 82. State the mean hourly motion of each planet in its orbit. Illustration? How to find the hourly motion?

miles per minute, or about 15 miles during every pulsation of the heart. But the earth in comparison with the body around which it is revolving is as a *single grain* of wheat compared with *four bushels.*

To Find the Hourly Motion.—This can be done by the application of very simple principles. The orbits being nearly circles, twice the mean distance will give us the diameter, and $3\frac{1}{7}$ times the diameter will give the circumference, or whole distance traveled in the periodic time. Then finding the number of hours in this time, and dividing the whole distance by this number, we obtain the hourly motion. Thus, Mercury's mean distance is 35 million miles; then $35 \times 2 \times 3\frac{1}{7} = 220$ millions, the whole distance traveled in 88 days, or $88 \times 24 = 2112$ hours; and 220 millions $\div$ $2112 = 104{,}166$ miles.

AXIAL ROTATIONS OF THE PLANETS.

83. Besides revolving around the sun, the planets revolve upon their axes in the same direction as they revolve in their orbits; that is, from west to east. This is called their *diurnal rotation.* Proofs of the earth's rotation have already been given; that of the other planets is indicated by a regular movement of spots across their disks.

Let the pupil stand at a distance from a globe, and let it be revolved, and he will observe the marks upon it move across, and alternately disappear and reappear. The same thing must, of course, occur in our observation of the planets, if they have a diurnal motion.

84. The times of rotation of the planets respectively are as follows:

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83. What is meant by diurnal rotation? How is the rotation of a planet indicated? Illustration? 84. What are the times of rotation of the planets, respectively?

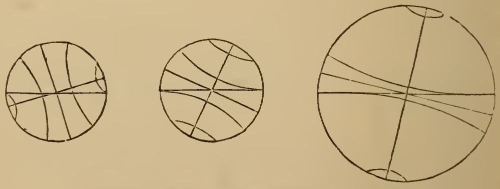
Mercury, . .	$24\frac{1}{4}$ hours.	Jupiter, . .	10 hours.
Venus, . .	$23\frac{1}{2}$ "	Saturn, . .	$10\frac{1}{2}$ "
Earth, . .	24 "	Uranus, . .	$9\frac{1}{2}$ " (?)
Mars, . .	$24\frac{1}{2}$ "	Neptune, .	(unknown.)

It will be observed that the terrestrial planets all perform their rotations in about 24 hours; but that the major planets require less than one-half that time.

85. Every planet must rotate with its axis either perpendicular or oblique to its orbit. The axes of the planets are all considerably oblique, excepting that of Jupiter, which is only 3° from the perpendicular; that of Venus is supposed to be very oblique. The angle which the axis of a planet makes with a perpendicular to its orbit is called the *Inclination of Axis.*

86. The inclination of the axis of each planet, as far as it has been discovered, is as follows:

Mercury, . .	Unknown.	Jupiter, . .	3°.
Venus, . .	75° (?)	Saturn, . .	$26\frac{3}{4}$°.
Earth, . .	$23\frac{1}{2}$°.	Uranus, . .	Unknown.
Mars, . .	$28\frac{1}{2}$°.	Neptune, .	"



INCLINATION OF JUPITER, EARTH, AND VENUS.

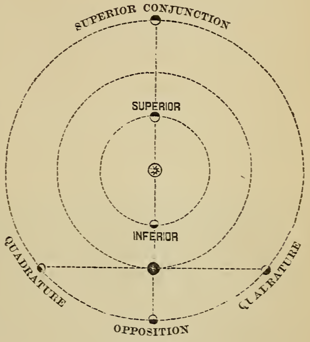
85. What is the position of the planets' axes? What is meant by inclination of axis? 86. State the inclination of each.

87. Sun's Rotation.—The sun also rotates upon an axis, but requires about 608 hours, or $25\frac{1}{3}$ days, to complete one rotation. The inclination of its axis to the plane of the ecliptic is $7\frac{1}{3}°$.

ASPECTS OF THE PLANETS.

88. The *aspects* of the planets are their apparent positions with respect to the sun and each other. The aspects most frequently referred to are *conjunction*, *quadrature*, and *opposition*.

89. A planet is said to be in *conjunction* with the sun when it is in the same part of the heavens. That is, if the sun is in the east, the planet must also be in the east, both being precisely in the same *direction*.



ASPECTS.

90. Conjunction may be *inferior* or *superior*. Inferior conjunction is that in which the planet is between the earth and the sun; superior conjunction is that in

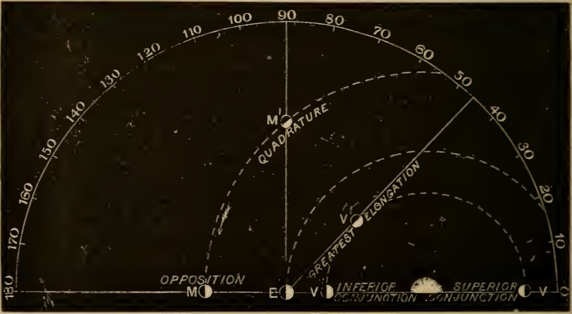
87. In what time does the sun rotate? What is the position of its axis? 88. What are aspects? Which are the most frequently referred to? 89. When is a planet in conjunction with the sun? 90. Of how many kinds is conjunction? What is inferior conjunction? Superior conjunction?

which the planet is on the opposite side of the sun from the earth.

91. A planet is said to be in *opposition* when it is in the opposite part of the heavens from the sun. That is, while the sun is in the east, the planet must be in the west. It is obvious that only the superior planets can be in opposition.

92. These aspects depend upon the angular distance of the planets from the sun (Introduction, Art. 17). In conjunction, there is no angular distance, except what is caused by the inclination of the orbits; in opposition, the angular distance amounts to 180°. The angular distance of a planet from the sun is called its *Elongation*.

93. When the elongation of a planet is 90°, it is said to be in quadrature. This position in the heavens is half-way between conjunction and opposition; but in



91. When is a planet said to be in opposition? 92. What is the angular distance in conjunction and opposition? What is elongation? 93. When is a planet in quadrature? Illustrate from the diagram.

the planet's orbit it is much nearer opposition than conjunction (see diagram, page 69).

In the diagram, the graduated semicircle cuts the sides of all the angles which have their vertices at E, and serves to measure the angular distance of each planet from the sun. V and V″ represent Venus in superior and inferior conjunction, the elongation being, at those points, 0°; while at V′, it is at its point of greatest elongation. It will be obvious from this diagram that no inferior planet can be 90° from the sun. M represents Mars in opposition, and M′ the same planet in quadrature. The aspect of M and V or V″ is opposition; of M′ and V or V′, quartile.

94. The time that elapses between two similar elongations of a planet is called its *Synodic Period.*

The term is generally applied to the interval between two successive inferior or superior conjunctions. The synodic period would be the true period of a planet's revolution around the sun, if the earth were at rest; but the earth is moving in its orbit in the same direction as the planet, with a velocity less than that of the inferior planets, and greater than that of the superior planets. Hence, the synodic period of an inferior planet is greater than the periodic time, since, after completing a revolution, it has to overtake the earth in order to reach the same relative position with the sun. The synodic period of a superior planet is generally less than its periodic time, since the earth, after performing one revolution, overtakes the planet before its revolution is completed. This is true of every superior planet except Mars.

APPARENT MOTIONS OF THE PLANETS.

95. The planets generally appear to move among the stars from west to east; but sometimes the apparent motion is from east to west. In the former case, the motion is said to be *direct;* in the latter, *retrograde.*

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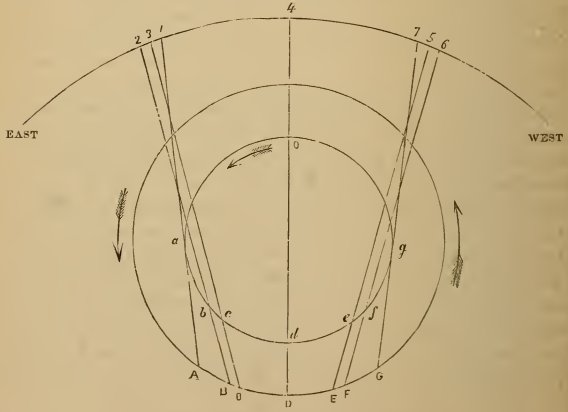
94. What is the synodic period of a planet? Why is the synodic period of an inferior planet greater than the true period? Why is that of a superior planet less? 95. What apparent motions have the planets? When is the motion direct? When retrograde? When is a planet said to be stationary?

At certain intermediate points of its course, the planet remains for a short time in the same point of the heavens, and is then said to be *stationary*.

96. An inferior planet appears stationary at two points of its synodic revolution, between its extreme elongations and inferior conjunction. This is caused by the direction of its motion at these two points, it being oblique to the motion of the earth; so that, notwithstanding the difference in their velocities, the planet and earth appear to move on together.

97. The motion of an inferior planet is retrograde while it is passing through inferior conjunction from one stationary point to the other, and direct in passing through superior conjunction between the same two points.



APPARENT MOTIONS OF VENUS AND MERCURY.

96. At what points is a planet stationary? How is this caused? 97. When is the motion of an inferior planet retrograde? Illustrate from the diagram.

Let S in the annexed diagram be the place of the sun, the inner circle the orbit of an inferior planet; the outer circle that of the earth. Let also *a*, *b*, *c*, *d*, etc., be the positions of the planet at unequal intervals of time between the points of extreme elongation, *a* and *g;* and A, B, C, D, etc., the places of the earth at the same time; while 1, 2, 3, 4, etc., represent the apparent places of the planet, as seen in the sphere of the heavens. In passing from *g*, the western point of extreme elongation, through *o*, the place of superior conjunction, to *a*, the eastern point of extreme elongation, the planet evidently must appear to move toward the east; and when it arrives at *a*, the earth being at A, it still continues to be direct for a short time; for while going from *a* to *b* its motion is so oblique that the earth passes it, so that when the latter arrives at B, the planet appears to have moved from 1 to 2. Its elongation is not, however, increased since the sun itself has moved farther to the east. While the planet is going from *b* to *c*, and the earth from B to C, the former does not appear to change its position at all; for the lines B *b* 2 and C *c* 3 are parallel, and consequently indicate no change of place among the stars, and 2 is to be considered, therefore, as identical with 3. The reason of the planet's appearing stationary, it will be seen, is that the obliquity of its motion exactly counterbalances the difference between its actual velocity and that of the earth; *b* is, therefore, to be considered the stationary point. At *d*, the planet is in inferior conjunction, having overtaken the earth, and is seen at 4, to the west of its previous position. In passing from *d* to *g* the same phenomena are presented in the reverse order; at *e* it becomes stationary, remaining so till it reaches *f*, where it ceases to be retrograde, appearing to move, while going from *f* to *g*, from 6 to 7. In going from *c* to *e*, the two stationary points, it has evidently changed its direction among the stars, not by the actual distance 3, 5, but by the angle contained by the lines 3 *c* C and 5 *e* E when produced until they meet in some point below C D E. This angle, or the arc by which it is subtended, it is obvious, is quite small; it is called the *arc of retrogradation.*

98. The motion of a superior planet appears to be retrograde for a short distance before and after opposition, and direct in the other part of its orbit. The retrogradation of the planet is caused by the greater velocity of the earth; so that as the latter body moves toward the east, it passes the other, and thus makes it appear to move toward the west. When the motion of the earth is sufficiently oblique to counteract the excess of its velocity, the two bodies move on together, and the planet appears to be stationary.

QUESTIONS FOR EXERCISE.

1. When a planet is in quadrature, what is its elongation?
2. What is its elongation when in inferior conjunction?
3. What is its elongation in superior conjunction?
4. How many degrees of elongation has it when in opposition?
5. Which of the planets can be in inferior conjunction?
6. Which can be in superior conjunction?
7. Which can be in opposition?
8. Which can be in quadrature?
9. Can the elongation of Mercury or Venus exceed 90°?
10. Can that of Jupiter?
11. What is the greatest elongation of a superior planet?
12. When Venus is in inferior conjunction, and Mars in opposition, what is their angular distance from each other? [See Fig., p. 70.]
13. What is their angular distance when Venus is in inferior conjunction, and Mars in superior conjunction?
14. How many degrees are they apart when Venus is in superior conjunction and Mars is in quadrature?
15. When the elongation of Venus is 30°, and that of Mars is 120°, what is their angular distance from each other?
16. If Venus is 50° from Mars, and the latter body is in quadrature, what is the elongation of Venus?

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98. When is the motion of a superior planet retrograde? How caused?

SECTION IV.

DESCRIPTION OF THE SUN AND PLANETS.

99. The *Sun* is the source of light and heat to all the planets, and, in connection with the atmosphere, the support of life and vegetation on the surface of the earth. The forces displayed on our planet, which spring from its exhaustless rays, are inconceivably great; and yet, it is calculated that the earth, with its limited grasp, only receives the two hundred millionth part of the whole force radiated and dispensed by this vast and splendid luminary.

100. The *apparent diameter* of the sun, or the angle which it subtends in the celestial sphere, is a little more than one-half of a degree. This is, of course, greater when the earth is in perihelion than when it is in aphelion, the variation in the apparent size of the sun affording a means of ascertaining the figure of the earth's orbit. The *real diameter* of the sun is 852,900 miles.

The greatest apparent diameter of the sun is 32′.6, and the least 31′.533; hence, the ratio is 1.034 : 1 (nearly), and one-half the difference, or .017 is about the eccentricity of the orbit.

101. The apparent diameter of the sun at each of the planets diminishes in proportion as the distance increases.

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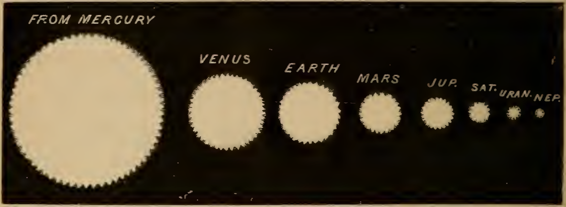
99. What is said of the sun? Of the forces derived from its rays? 100. How great is the apparent diameter of the sun? How does it vary? 101. How does it differ as seen from the other planets? How great is the sun's light at the earth?

Thus, at Mercury it is $2\frac{1}{2}$ times as great as at the earth; but at Neptune it is only $\frac{1}{30}$ as great. Various experi-



APPARENT MAGNITUDES OF THE SUN.

ments seem to show that the light of the sun at the earth is equal to that of 600,000 full moons.

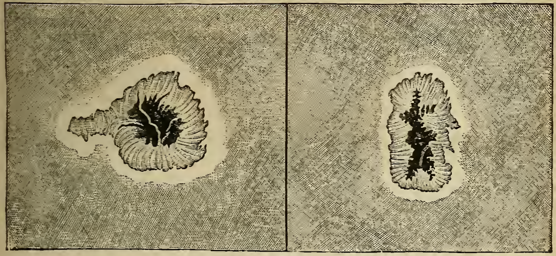
102. The distance of the sun from the earth when the latter is in aphelion is about 93 millions of miles; but when it is in perihelion the distance is only 90 millions; the mean distance, as previously stated, being about $91\frac{1}{2}$ millions.

The distance of the sun from the earth has been, from the earliest times, a subject of careful and earnest investigation with astronomers. Ptolemy and his contemporaries supposed it to be only 1200 times the radius of the earth, or less than five millions of miles. It was not until the middle of the last century that this was discovered with any degree of accuracy. The above is quite a recent determination.

103. Solar Spots.—When the disk of the sun is examined with a telescope, it is found to exhibit certain

102. What is the distance of the sun from the earth? Remark? 103. What does the sun's disk exhibit when viewed with a telescope? What is said of the position and appearance of the solar spots? What is the black portion called? The dusky border?

dark spots, which constantly vary in number, form, size, and general appearance. These spots are sometimes very numerous, being mostly confined to the region of the



SOLAR SPOTS GREATLY MAGNIFIED.

sun's equator, and some of them are of vast size. They look like irregular black patches surrounded with a dusky border or fringe. The black portion in the centre is called the *umbra* or *nucleus;* the dusky border, the *penumbra.*

104. Sometimes the sun's disk is entirely free from them, and continues so for weeks or even months; at other times, they seem to burst forth and spread over a certain part of it in great numbers. The duration of single spots is also exceedingly variable. A spot has been seen to make its appearance and vanish entirely within twenty-four hours; while others have continued for nine or ten weeks without much change of appearance.

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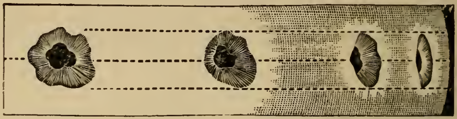
104. What changes occur in their number and appearance? What is said of their duration?

105. Various hypotheses have been advanced to account for these spots. The most recent is, that the sun is a solid or liquid mass in an intensely heated condition, surrounded by an atmosphere of vapor or burning gas; and that the disturbances in this atmosphere cause the spots, which are in fact only openings in it filled with clouds of various degrees of density.



A SPOT PASSING ACROSS THE DISK.

106. There is a general movement of the spots across the sun's disk from east to west. A particular spot first appears on the eastern limb or edge of the disk, passes across to the western limb, and then disappears, but after about two weeks reappears on the eastern limb, completing an entire revolution in about 27¼ days.

MOVEMENT OF THE SUN AND SPOTS.

105. What hypothesis is advanced to account for them? 106. How do the spots appear to move? What is the time of a complete revolution? What is inferred from this?

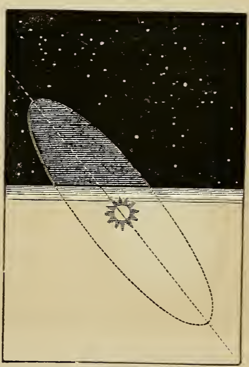
From this we infer that the sun rotates on its axis in $25\frac{1}{3}$ days.

107. A revolution of the spot must take longer than one rotation of the sun in consequence of the earth's motion in its orbit in the same direction.

[The diagram will make this intelligible. Let A be the position of the earth in its orbit at the time a spot appears at C. Now, while the sun performs a rotation, the earth moves on to B; and hence the spot must pass from C to D to become visible.]

THE ZODIACAL LIGHT.

108. Apparently connected with the sun is the singular phenomenon called the *Zodiacal Light.* This is a faint luminous appearance, of the form of a triangle or cone, seen at certain seasons of the year, in the evening at the western horizon, and in the morning at the eastern. It extends obliquely from the horizon in the plane of the sun's equator, its breadth at the horizon varying from eight to thirty degrees.



107. Why is the time of the spots' revolution greater than that of the sun's rotation? Explain from the diagram. 108. What is the Zodiacal Light? How does it extend? What is its position? Its breadth?

109. It is seen most distinctly in March and April, after sunset, and in September and October, before sunrise; because at those times the ecliptic is most nearly perpendicular to the horizon.

110. Various hypotheses have been suggested to account for it. That most generally received is, that it is a nebulous mass of the shape of a lens, encompassing the sun at its equator, and extending sometimes beyond the orbit of the earth. Some have regarded it as a vast ring of meteors circulating about the sun, some of which are constantly falling into it.

This hypothesis of a constant shower of meteoric bodies falling upon the sun has been used to account for the support of its heat; for their collision with the sun would necessarily generate an intense heat, just as iron may be heated to any degree by hammering it. It is calculated that bodies of the density cf granite falling all over the sun to the depth of 12 feet in a year, and with the velocity which they would acquire (384 miles in a second), would maintain the solar heat. If Mercury were to strike the sun, it would generate an amount of heat equal to all the sun emits in seven years; while the shock of Jupiter would supply the loss of more than 30,000 years.

MERCURY ☿.

111. Mercury is remarkable for its small size, its swift motion, and the great inclination and eccentricity of its orbit. It is, as far as is positively known, the nearest planet to the sun.

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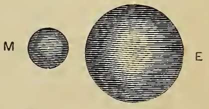
109. Where is it seen most distinctly? Why? 110. What hypotheses are advanced to account for it? Theory to account for the sun's heat? 111. For what is Mercury remarkable? Is there a planet nearer to the sun?

A planet inferior to Mercury has been supposed to exist; and in 1859, a French astronomer was thought by some to have discovered it. Later observations have not, however, confirmed, but rather disproved, its existence. The name given to this supposed planet is *Vulcan.*

112. Mercury can only be seen in the morning or evening, as it appears to keep close to the sun, never departing from it more than 28°. It is very brilliant—so much so, indeed, that the ancients called it the "Twinkler." It was called *Mercury* in consequence of the swiftness of its motion; for in the ancient mythology of the Greeks, Mercury is the messenger of the gods. The sign ☿ is supposed to represent the wand which Mercury carries in his hand.

113. Orbit.—Mercury's orbit is very eccentric; so that, in aphelion, the planet is nearly 15 millions of miles farther from the sun than in perihelion. Its inclination is about 7°, being greater than that of any of the other large primary planets.

114. Volume, Density, &c.—The diameter of Mercury being a little less than 3,000 miles, its volume is only about one-twentieth that of the earth; but its density is somewhat greater. A body that weighs a pound on the surface of the



COMPARATIVE VOLUMES OF MERCURY AND THE EARTH.

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112. When can Mercury be seen? How far does it appear to depart from the sun? Why was it called the "Twinkler?" Origin of its name? Its sign? 113. What is said of the eccentricity and inclination of its orbit? 114. What is its volume as compared with the earth? What difference in the weight of a body at the surface of Mercury?

earth would weigh less than one-half a pound at Mercury; and consequently, if we were transported to that planet, our muscular power would practically be doubled.

115. Telescopic Appearance.—When viewed through a telescope, this planet exhibits all the phases of the moon. Indications of the existence of very high mountains, and of an atmosphere of considerable extent, have been detected by some observers; but the excessive brilliancy of the planet makes it an exceedingly difficult object for telescopic observation. Sir John Herschel states that all that can be certainly affirmed of it is, that "it is globular in form and exhibits phases; and that it is too small and too much lost in the constant and close effulgence of the sun to allow the further discovery of its physical condition."

VENUS ♀.

116. Venus is the most brilliant and beautiful of all the planets, and is remarkable for its resemblance to the earth both in size and mass. By the ancients, it was called *Hesperus* or *Vesper* when an evening star, and *Phosphorus* or *Lucifer* when a morning star, these being at first supposed to be different bodies. It derives its name from Venus, the goddess of beauty; and the sign represents a mirror, with the handle at the lower side.

117. Orbit.—The eccentricity of its orbit is quite small, the difference between its aphelion and perihelion distance being less than one million of miles. Its incli-

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115. What is said of the telescopic appearance of Mercury? 116. What is said of Venus? Its name and sign? 117. The eccentricity and inclination of its orbit?

nation of orbit is only about one-half that of Mercury, being less than $3\frac{1}{2}$ degrees.

118. Sidereal and Synodic Period.—Since the sidereal or true period of this planet's revolution around the sun is nearly 225 days, its synodic period is about 585 days; because, on leaving the earth after inferior conjunction, it has to perform more than two revolutions before it overtakes it so as to be again in the same relative position with the earth and sun.

This will be evident if we consider that while the earth is completing one revolution, Venus performs one and five-eighths of another. But it has to gain an entire revolution to overtake the earth; and if it takes it $365\frac{1}{4}$ days to gain $\frac{5}{8}$, it will take it $584\frac{1}{2}$ days to gain the whole.

119. Telescopic Appearance.—The telescopic appearance of Venus is very beautiful, owing to its phases, which exactly resemble those of the moon. When it is

TELESCOPIC VIEWS OF VENUS.

in superior conjunction, its full disk is visible, which gradually diminishes until, at the time of greatest elon-

118. What is its sidereal period? Its synodical period? Why is the latter longer? How calculated? 119. What is said of its telescopic appearance? Its phases? Its apparent diameter? How are irregularities on its surface indicated? Its atmosphere?

gation, only half of the disk can be seen. After this the planet still continues to wane, until, when near inferior conjunction, it assumes the form of a slender crescent. Its apparent diameter when in inferior conjunction is more than six times as great as it is when in superior conjunction.

Very great irregularities on its surface are indicated by the jagged character of the terminator, or line bounding the illuminated part of the disk, as well as by the shading of its edge, caused by the shadows of the mountains as the sun's rays fall obliquely upon them. Like Mercury, this planet is a difficult object for observation, owing to its excessive brilliancy. There are undoubted indications that it possesses an atmosphere of considerable height and density.

120. Seasons.—The seasons of Venus are quite remarkable, owing to the great inclination of its axis. This being 75°, its tropics must be 75° from its equator, and its polar circles 75° from its poles. Hence it can have only a torrid zone, which must be 150° wide, and frigid zones extending 75° from the poles. There must be, therefore, two summers and two winters at the equator, and a summer and winter alternately at each pole during the year, the latter lasting about 112 days.

The annexed diagram exhibits the planet at each of the equinoxes and solstices. To an inhabitant of the northern hemisphere of Venus, at A the sun is in the vernal equinox; B, the summer solstice; C, the autumnal equinox; and D, the winter solstice.

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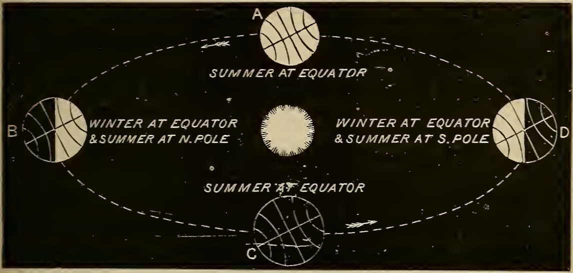
120. What seasons at Venus? How are its tropics and polar circles situated? Illustrate from the diagram.

When the sun is in the northern solstice, it will be seen that all places situated more than 15° north of the equator have constant day, and those more than 15° south of it, constant night. Hence



SEASONS OF VENUS.

there must be winter at the equator and within the south polar circle, and summer within the north polar circle. In one-fourth of the year, when the sun will have arrived at the equator, there will be equal day and night all over the planet, summer at the equator, autumn within the north polar circle, and spring within the south polar circle.

MARS ♂.

121. Mars, the fourth planet from the sun, is remarkable for its small size and the red color with which it shines among the stars. It is consequently very easily distinguished from the other heavenly bodies, and doubtless received its name on account of this red appearance, Mars being the god of war. Its sign is a shield and spear.

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121. For what is Mars remarkable? Origin of its name? Its sign?

122. Orbit.—The eccentricity of its orbit is nearly $5\frac{1}{2}$ times as great as that of the earth's, it being about 26 millions of miles nearer to the sun in perihelion than in aphelion. Its inclination of orbit is about a degree and a half.

Owing to the great eccentricity of the orbit of Mars, it sometimes, when in opposition, approaches very near to the earth; for if it is in perihelion while the earth is in aphelion, the distance is 126,300,000 − 93,000,000 = 33,300,000.

123. Seasons.—Since the inclination of its axis is nearly the same as that of the earth, the variety of seasons must be the same; but they must be nearly twice as long, because it takes Mars nearly two years to revolve around the sun. Owing to the great eccentricity of its orbit, summer in the northern hemisphere must be only four-fifths as long as in the southern; and at each of the poles there must be, alternately, constant day and constant night, each lasting nearly one of our years.

124. Telescopic Appearance.—The telescopic appearances of this planet are very interesting, exhibiting what seem to be the outlines of continents and seas, the former appearing of a ruddy or orange color, and the latter of a dusky greenish or bluish tint. Brilliant white spots are also seen alternately at the poles, evidently produced by accumulations of ice and snow during the long winters, particularly as they are seen to disappear as

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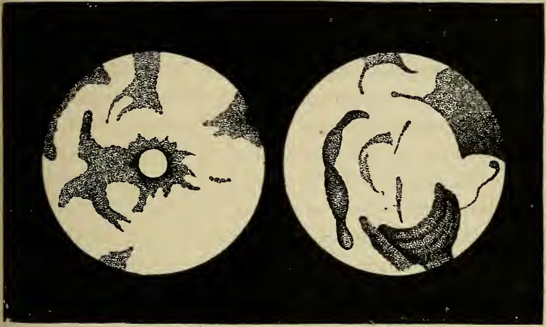
122. How great is the eccentricity of its orbit? Its inclination? 123. What seasons has Mars? Why? Why is summer shorter in the northern than in the southern hemisphere? Duration of constant day and night at the poles? 124. What does its telescopic appearance exhibit? Where are brilliant white spots? How caused? Cause of the red color of Mars? Appearance of continents and islands in the cut?

summer advances. Evidences are also presented of an atmosphere, probably equal in density to that of the earth.

No entirely satisfactory cause has been assigned for the ruddy color of this planet. It is thought by Sir John Herschel to be due to "an ochrey tinge in the general soil, like what the red sandstone districts on the earth may possibly offer to the inhabitants of Mars, only more decided." Viewed through a telescope, the redness of its hue is very considerably diminished.



NORTHERN AND SOUTHERN HEMISPHERES OF MARS.—*Mädler.*

The annexed cut does not represent any actual telescopic views of the planet, since we are never so situated as to be able to see the *whole* of either the northern or southern hemisphere at any one time. It exhibits a combination of a large number of telescopic appearances, the various dusky spots being placed together so as to show the forms of the *different bodies of water* and their relation to the continents; the latter being indicated by the white spaces. These, through the telescope, appear of a ruddy color, and give this general tint to the planet. On the earth, the continents are islands, being encompassed by the water; on Mars, it will be perceived, the bodies of water are lakes or seas, being entirely encompassed by the land.

JUPITER ♃.

125. Jupiter, the first of the major planets, is remarkable for its great size, as well as for the peculiar splendor with which it shines among the stars. It doubtless received its name on this account, Jupiter being, in the ancient mythology, the king of the gods. Its sign is supposed to be an altered *Z*, the first letter of *Zeus*, the name of Jupiter among the Greeks.

126. Orbit.—The eccentricity of its orbit is nearly three times that of the earth, but its inclination is very small, being a little more than one degree (1° 19′).

127. Figure.—The oblateness of its figure is very great, its equatorial diameter being 5,000 miles longer than its polar diameter. This is caused by the rapid rotation on its axis, which being performed in a little less than ten hours, a point on the equator of this planet moves with a diurnal velocity of 28,000 miles an hour, or 27 times as fast as at the earth.

128. Volume, Density, etc.—The volume of Jupiter is nearly 1250 times as great as the earth's; but as its mass is discovered to be only 300 times as great, its density can be only about $\frac{1}{4}$ that of the earth, or a little greater than that of water. The force of gravity at the surface of the planet is about $2\frac{1}{2}$ times as great; so that a

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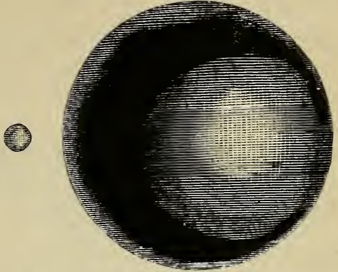
125. For what is Jupiter remarkable? Origin of its name? Its sign? 126. How great is the eccentricity of its orbit? Its inclination? 127. How great is the oblateness of its figure? How is this caused? 128. What is said of its volume, mass, and density? Force of gravity at its surface? Velocity in its orbit?

body weighing one pound at the earth's surface would weigh $2\frac{1}{2}$ pounds at Jupiter's.

This body, so inconceivably vast, is flying in its orbit with the velocity of 28,700 miles an hour, or nearly 500 miles a minute—a speed sixty times as great as that of a cannon ball. How tremendous is the exhibition of force here displayed!



COMPARATIVE MAGNITUDES OF THE EARTH AND JUPITER.

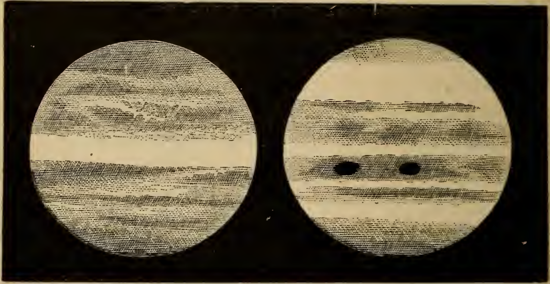
129. Telescopic Appearance.—When examined with a telescope the disk of Jupiter appears crossed by dusky streaks or belts, parallel to its equator, their general direction always remaining the same, although they constantly vary in number, breadth, and situation on the disk. Sometimes the disk is almost covered with them; while at other times scarcely any are visible.

These dusky bands or belts are supposed to be the body of the planet seen between the clouds that constantly float in its atmosphere, and are thrown into zones or belts by the great velocity of its rotation. The cloudy zones are more luminous than the surface of the planet, because they more perfectly reflect the solar light.

The belts are not equally conspicuous, there being two generally which are more distinctly observable than others, and more perma-

129. Describe its telescopic appearance. What are the belts supposed to be? Their situation and appearance?

nent. These are situated, one on each side of the equator, and are separated by a clear space somewhat more luminous than the other parts of the disk. Toward the poles they are narrower and less dark; and they imperceptibly fade away a short distance from the eastern and western edges of the disk—a phenomenon due, evidently, to the thickness of the atmosphere at those parts. Dark spots are also occasionally seen in connection with the belts.



TELESCOPIC VIEWS OF JUPITER.

In the cut are given two telescopic views of this planet; the first, from a drawing by Sir John Herschel, as it appeared September 23d, 1832; the second, by Mädler, in 1834. The two dark spots shown in the latter were employed to determine the time of the planet's rotation.

130. Satellites.—The four satellites of Jupiter are among the most interesting bodies of the solar system. They were first seen by Galileo, in 1610, a short time after the invention of the telescope, and were perceived to be satellites by their apparent movements with respect to the planet, alternately approaching it, passing behind

130. What is said of the satellites? How designated?

it, and receding from it; sometimes also passing over its disk and casting their shadows upon it.

These planets have been distinguished by particular names, but are more generally designated by the numerals I., II., III., IV., according to their order from Jupiter.

131. The orbits of these bodies are almost circular, and very nearly in the plane of the planet's equator. They therefore make only a very small angle with the plane of its orbit (about 3°).

132. Their distances from Jupiter are, respectively, 264,000 miles, 423,000 miles, 678,000 miles, and 1,188,000 miles.

Their diameters in approximate numbers are I., 2,300 miles; II., 2,070 miles; III., 3,400 miles; IV., 2,900 miles; all, excepting the second, being larger than the moon.

As seen from Jupiter these bodies present quite large disks; the apparent diameter of I. being 36′; of II., 19′; of III., 18′; and of IV., 9′. The first is therefore somewhat larger in appearance than that of the moon. The firmament of Jupiter must present a very beautiful diversity of phenomena. These various moons, all of which are occasionally above the horizon at one time, go through their phases within a few days; the first within 42 hours. To an inhabitant of the first satellite, the apparent diameter of Jupiter must be 19°; that is, about 36 times as great as the moon; while the amount of illuminated surface presented by it must be nearly 1300 times as great.

133. The *eclipses*, *occultations*, and *transits* of the

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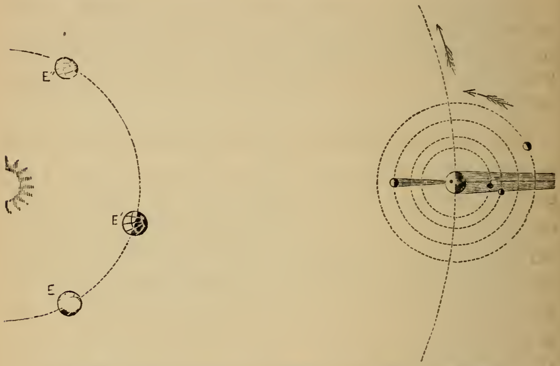
131. What is the figure of their orbits? Their position? 132. Their distances from Jupiter? Their diameters? How do they appear at Jupiter? 133. What phenomena are presented by them? What is said of their eclipses? How do the transits occur? Explain the diagram.

satellites present an endless series of interesting and useful phenomena; and the situation of their orbits causes them to occur with very great frequency.

During the transits the satellites appear like *bright* spots passing from east to west across the disk, preceded or followed by their shadows, which seem like small round dots as black as ink.



ECLIPSES, OCCULTATIONS, AND TRANSITS OF JUPITER'S SATELLITES.

In the figure, to an observer at E, I. is represented as eclipsed; II., as just passing into the shadow of the planet; III., just before a transit, the shadow *preceding;* and IV., at the point of occultation. At E′, I. has just passed behind the disk; II. is in occultation; III., a transit, both shadow and satellite being on the disk, the shadow preceding; IV., just emerging from behind the planet; at E″, I. and II. are behind the disk, III. is in transit, but the shadow follows the satellite; IV., just after an eclipse.

134. Since the occurrence of these eclipses can be exactly predicted, they serve to mark points of absolute

134. What do the eclipses mark? How is this useful?

time; so that if the precise moment at which they will occur at any particular place has been computed, and the actual time of their occurrence at any other place is noted, a comparison of the two will give the difference of time, and, of course, the difference of longitude, between the two places.

Thus, if a mariner perceives, by the nautical almanac, that the eclipse of a satellite will occur at 9 o'clock P.M., Washington time, and he notices that the eclipse does not take place till 11 o'clock P.M., he can infer that his position is 2 hours, or 30°, east of Washington.

135. Velocity of Light.—In the calculation of these eclipses, a constant variation was, for several years, found to exist between the calculated and the observed time of the occurrence, with the additional fact that the eclipse was later as Jupiter receded from the earth, and earlier as it approached the earth, being about 16½ minutes earlier in opposition than in conjunction. This is explained by supposing that light requires 16½ minutes to cross the orbit of the earth, and hence that it passes to us from the sun in 8¼ minutes. Its velocity must therefore be about 184,000 miles a second.

This theory was promulgated in 1675 by Hans Roemer, a Danish astronomer, and has been confirmed by other and more recent discoveries.

SATURN ♄.

136. Saturn is the centre of a very large and peculiar system, being attended by eight satellites and encom-

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135. What important discovery did this lead to? In what way? By whom made?
136. What is said of Saturn? Its name and sign?

passed by several rings. It shines generally with a dull yellowish light.

Saturn, in the ancient mythology, was one of the older deities, and presided over time, the seasons, etc. He was represented as a very old man carrying a scythe in one hand. The sign of the planet is a rude representation of a scythe.

137. Orbit.—The eccentricity of its orbit is a little greater than that of Jupiter, being about $\frac{1}{20}$ of its major axis. It is therefore nearly 100 millions of miles nearer to the sun in perihelion than in aphelion. The inclination of its orbit is about $2\frac{1}{2}$ degrees.

138. Figure, etc.—The oblateness of this planet is, like that of Jupiter, very remarkable, its equatorial diameter being 7,800 miles longer than the polar diameter. Its axial rotation being performed in $10\frac{1}{2}$ hours, its equatorial velocity is more than 22,000 miles an hour; and, as its density is somewhat less than that of oak wood, its figure would necessarily be very much flattened by the action of the centrifugal force.

The density of this planet is so small that, notwithstanding its immense size, a body at its surface would weigh only about $\frac{1}{5}$ more than at the surface of the earth.

139. Seasons.—As the inclination of its axis is about 27°, its seasons must be similar to those of the earth; but, in consequence of the length of its year, are nearly thirty times as long as on the earth.

140. Telescopic Appearance.—This planet, when

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137. Eccentricity and inclination of its orbit? 138. How great is the oblateness of its figure? Why? Weight at its surface? 139. What seasons has it? 140. Describe its telescopic appearance. How is an atmosphere indicated?

viewed with a good telescope, appears to be encompassed with dusky belts ; but they are far more indistinct than those of Jupiter; and instead of crossing the disk in straight lines like those of that body, they generally present a curved appearance,—an indication of the axial inclination.

Sir William Herschel inferred the existence of a dense atmosphere surrounding Saturn, both from the changes constantly occurring in the number and appearance of the belts, and the appearance of the satellites at the occurrence of occultations. The nearest was observed to cling to the edge of the disk about twenty minutes longer than would have been possible had there been no atmosphere to refract the light. Indications of accumulations of ice and snow at the poles have also been detected, similar to those of Mars.

141. Rings.—Saturn is encompassed by three or more thin, flat rings, all situated exactly or very nearly in the plane of its equator. Two of these rings are very distinctly observed, and are designated the *interior* and the *exterior ring*. The former is about 16,500 miles wide ; the latter, 10,000 miles. The distance of the interior ring from the planet is about 18,350 miles ; and the interval between these rings, about 1,700 miles. The thickness of the rings does not exceed 250 miles, and may be much less.

Within the interior ring there is a dusky or semi-transparent ring, having a crape-like appearance as it stretches across the bright disk of the planet.

Discovery of the Rings.—In his first telescopic examination of this planet, Galileo noticed something peculiar in its form. As

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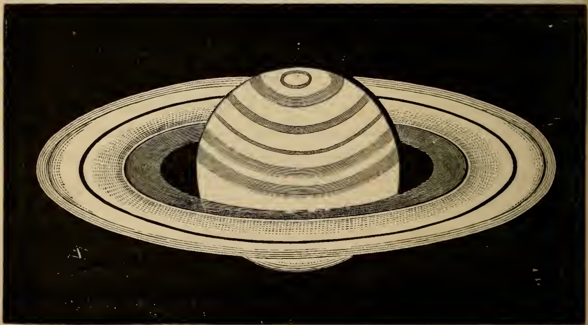
141. How many rings encompass it ? Describe them. What is said of the discovery of these rings ? By whom was the dark ring discovered ?

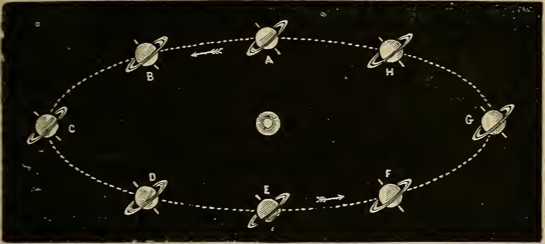
seen through his imperfect instrument, it appeared to him to have a small planet on each side; and hence he announced to Kepler the curious discovery that "Saturn was threefold;" but continuing his observations, he saw, to his great astonishment, these companion bodies (as he thought) grow less and less, and finally disappear. For fifty years afterward the true cause of the appearance remained unknown, the distortion of the planet's form being supposed to arise from two *handles* attached to it. Hence they were called *ansæ*, the Latin word for handles. Huyghens, in 1659, discovered the real cause of the phenomenon, and announced it in these words: "The planet is surrounded by a slender, flat ring, everywhere distinct from its surface, and inclined to the ecliptic." The division of the ring into two was discovered by an English astronomer in 1665. We have now certain knowledge of the existence of three rings, and some indications of several more. The dark ring was discovered by the American astronomer, G. P. Bond, in 1850.



TELESCOPIC VIEW OF SATURN.—*Dawes.*

The accompanying figure represents the planet as seen through a very powerful telescope, showing the dark ring, the division between the two main rings, and the line in the outer ring, which indicates the existence of an additional ring.

142. These rings rotate about the planet on an axis perpendicular to their plane, the time of a rotation being about $10\frac{1}{2}$ hours. As the planet revolves around the sun the rings constantly remain parallel to themselves.



SATURN IN DIFFERENT PARTS OF ITS ORBIT.

The accompanying figure represents Saturn in different parts of its orbit, the direction of the axis and the position of the plane of the rings constantly remaining the same. At A or E, the time of the planet's equinox, the plane of the rings passes through the sun, so that its edge only is illuminated, wherever the earth may be situated, which is to be conceived as revolving in a small orbit within that of Saturn. At the solstice C, the southern side of the rings is exhibited ; and at G, the northern side. At the intermediate points the rings are viewed obliquely.

143. Satellites.—Saturn is attended by eight satellites, seven of which revolve very nearly in the plane of its equator,—the orbit of the eighth, or most distant satellite, making with that plane an angle of about 12 degrees. Their names in the order of their distances from Saturn are *Mi'mas*, *Encel'adus*, *Te'thys*, *Dio'ne*, *Rhe'a*, *Ti'tan*, *Hype'rion*, and *Jap'etus*.

142. How do the rings rotate ? 143. By what satellites is Saturn attended ? Their names ?

144. The following are their periods and distances from the primary:

	Periods.	Distances.		Periods.	Distances.
1. Mimas	22½h	121,000	5. Rhea	4d 12½h	343,000
2. Enceladus	1d 9h	155,000	6. Titan	15d 23h	796,000
3. Tethys	1d 21h	191,000	7. Hyperion	21d 7h	1,006,000
4. Dione	2d 18h	246,000	8. Japetus	79d 8h	2,313,000

145. The largest of the satellites is Titan, its diameter being 3,300 miles, which is larger than that of Mercury. The diameters of the others are very much less.

That of Japetus is 1,800 miles; Rhea, 1,200; Mimas, 1,000; Tethys and Dione, 500; Enceladus and Hyperion, unknown.

146. The celestial phenomena at Saturn must present a scene of extreme beauty and grandeur. The starry vault, besides being diversified by so many satellites, presenting every variety of phase, must be spanned, in certain parts of the planet, and during different portions of its long year, by broad, luminous arches, extending to different elevations, according to the place of the observer, and receiving upon their central parts the shadow of the planet.

URANUS ♅.

147. Uranus was discovered in 1781 by Sir William Herschel. It shines with a pale and faint light, and to the unassisted eye is scarcely distinguishable from the smallest of the visible stars.

144. Their distances. etc.? 145. Which is the largest of the satellites? Its diameter? The diameters of the others? 146. Describe the celestial phenomena at Saturn. 147. By whom was Uranus discovered? Its appearance? History of its discovery?

History of its Discovery.—This planet had been observed by several astronomers previous to its discovery by Herschel, but had been mapped as a star at least twenty times between 1690 and 1771, its planetary character not having been discerned; and even Herschel, on noticing that its appearance was different from that of a star, was not aware that he had discovered a new planet, but supposed it to be a comet, and so announced it to the world, April 19th, 1781. It was, however, in a few months, evident that the body was moving in an orbit much too circular for a comet; but its planetary character was not fully established until 1783, when Laplace partly calculated the elements of its orbit.

148. Name and Sign.—It was called by its discoverer *Georgium Sidus* (George's Star); but for some time was designated *Herschel*, after its discoverer. Its present name U′ranus (in the Grecian mythology the oldest of the deities) harmonizes with the names of the other planets. Its sign is the letter H with a suspended orb.

149. Orbit.—The eccentricity of its orbit is about 82 millions of miles, or about $\frac{1}{20}$ of its major axis. Its inclination is very small, being about $\frac{3}{4}$ of a degree. Nevertheless, so vast is its distance that, at its greatest latitude, it departs more than 24 millions of miles from the plane of the ecliptic.

150. Rotation.—As the disk of Uranus presents neither belts nor spots, the period of its rotation and its axial inclination still remain unknown. It is thought, from the positions of the orbits of the satellites, that the inclination of its axis is very great; and analogy would lead

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148. Its name and sign? 149. What is the eccentricity of its orbit? Its inclination? 150. Does it rotate?

us to believe that its diurnal period is nearly the same as that of Jupiter or Saturn.

151. Satellites.—Uranus is known to be attended by four satellites, which differ from all the other planets of the solar system by revolving in their orbits from east to west.

Their orbits are inclined to the plane of that of the primary at an angle of 79°; but, as their motion is retrograde, it seems probable that the poles have been reversed in position, the south pole being north of the ecliptic, and *vice versa.* The inclination, on this supposition, would be 101°.

NEPTUNE ♆.

152. Neptune is the most distant planet known to belong to the solar system. It was first discovered by Dr. Galle, at Berlin; but its existence had been predicted, and its position in the heavens very nearly ascertained by the calculations of M. Leverrier (*lŭh-ver-re-á*) in France, and by Mr. Adams in England, these calculations being based upon certain observed irregularities in the motion of Uranus.

History of its Discovery.—The discovery of this planet was one of the proudest achievements of mathematical science in its application to astronomy, and afforded a more striking proof of the truth of the great law of universal gravitation than had previously been ascertained. After the discovery of Uranus, in 1781, it was ascertained that the planet had several times been observed by astronomers, and its place recorded as a star. These positions of the planet could not, however, be reconciled with those recorded after

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151. By what satellites is it attended? For what are they remarkable? 152. What is said of Neptune? History of its discovery?

its actual discovery; and observation soon showed that its motion was at certain points increased, and at others diminished, by some force acting beyond it and in the plane of its orbit. These facts suggested the existence of another planet, revolving in an orbit exterior to that of Uranus, and, according to Bodé's law, extending nearly twice as far from the sun. Adams and Leverrier almost simultaneously undertook to find, by mathematical analysis, where this planet must be in order to produce these perturbations. The former reached the solution of this wonderful problem first, and, in October, 1845, after three years of toil, communicated to Mr. Airy, Astronomer Royal, the result, pointing out the position of the planet and the elements of its orbit. The search for the planet was not, however, commenced until Leverrier published the result of his labors, which was found to agree so closely with that attained by Adams, that astronomers both in France and England prepared to construct maps of the part of the heavens indicated, in order to detect the planet.

In this they were anticipated by the Berlin observer, who, being informed by Leverrier of the result of his computations, and having by a fortunate coincidence just received a newly prepared star-map of the 21st hour of right ascension (the part of the heavens designated by Leverrier), immediately compared it with the stars, and found one of them missing. The observations of the following evening, by detecting a retrograde motion of this star, established its true character. It was the planet sought for, and, wonderful to relate, was found only 52′ from the place assigned by Leverrier. He had also stated its apparent diameter at 3.3″; it was found by actual measurement to be 3″. Adams's determination of the place of the supposed planet differed from the true place by about 2°.

153. Name and Sign.—The name selected for this planet, Neptune, was, in the ancient mythology, the name of the god who was supposed to preside over the sea. The sign is the head of a trident—the peculiar symbol of that deity.

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153. Its name and sign?

154. Distance.—So vast is the distance of this planet from the sun (more than thirty times the earth's distance), that only Saturn and Uranus can be seen from it,—the latter of these bodies never having an elongation of more than 40 degrees. Light requires about four hours to pass from the sun to this remote orb.

155. Orbit.—The eccentricity of its orbit is about 24 millions of miles, being considerably less than $\frac{1}{10}$ of its mean distance; and, relatively, only about one-half that of the earth. Its inclination is also very small ($1\frac{3}{4}°$).

156. Solar Light.—The apparent diameter of the sun at Neptune is about equal to that of Venus when at its greatest elongation; but its light is vastly more brilliant, being estimated as equal to that of 20,000 stars shining at once in the firmament, each equal to Venus when its splendor is greatest.

157. Satellite.—A satellite of this planet was discovered in 1846, and from observations made about the same time, another was suspected to exist, but subsequent observations have not positively detected it. The orbit of this satellite is nearly circular, and its motion is retrograde.

158. Are there Planets beyond Neptune?—This is a question which we are at present entirely unable to answer. Future generations may, with greater resources of science and mechanical skill, disclose new marvels in

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154. What is said of its distance? 155. Its orbit? 156. How does the sun appear at Neptune? What is the light equal to? 157. What is said of its satellite? 158. Are there planets beyond Neptune?

our system, and detect other bodies obedient to the dominion of its great central sun. The nearest of the stars is known to be nearly 7,000 times as far from Neptune as that body is from the sun; and it is by no means improbable, therefore, that so vast a space should contain planetary bodies reached by the solar attraction, but very far beyond the sphere of any other central luminary. It will require, however, far greater means than we possess to bring this to a practical determination.

THE MINOR PLANETS, OR ASTEROIDS.

159. The Minor Planets, or Asteroids, are a large number of very small bodies revolving around the sun between the orbits of Mars and Jupiter. The number discovered up to the present time (1870) is 112.

History of their Discovery.—The existence of so large an interval between Mars and Jupiter, compared with the relative distances of the other planets, for a long time engaged the attention and incited the researches of astronomers. Kepler conjectured that a planet existed in this part of the system, too small to be detected; and this opinion received considerable support from the publication of Bodé's law in 1772. When Uranus was discovered, in 1781, and its distance was found to conform to this law, the German astronomers became so confident of the truth of this bold conjecture of Kepler, that, in 1800, they formed, under the leadership of Baron de Zach, an association of 24 observers to divide the zodiac into sections and make a thorough search for the supposed planet. This systematic exploration had, however, been scarcely commenced, when, in 1801, Piazzi, an Italian astronomer, while en-

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159. What are the Minor Planets, or Asteroids? What is their number? Give the history of their discovery.

gaged in constructing a catalogue of stars, detected a new planet. It was called by him *Ceres*. In the next year, while looking for the new planet, Olbers discovered another, which he called *Pallas*.

The extreme minuteness of the new planets, and the near approach of their orbits at the nodes, led Olbers to suppose that they might be the fragments of a much larger planet once revolving in this part of the system, and shattered by some extraordinary convulsion. Believing that other fragments existed, and that they must pass near the nodes of those already found, he resolved to search carefully in the direction of those points; but while he was thus engaged, Harding, of the observatory of Lilienthal, discovered, in 1804, very near one of those points, a third planet, which he called *Juno*. Olbers, still further stimulated by this event to continue the investigation which he had commenced, was at length, in 1807, rewarded by discovering a fourth planet, *Vesta*, near the opposite node. From this date until 1845, no additional discovery was made. These small planets were called *Asteroids* by Herschel, from their resemblance, in appearance, to stars. In 1845. M. Hencke, an amateur astronomer of Driessen, after a series of observations continued for fifteen years with the use of the Berlin star-maps, discovered *Astræa*, the fifth of this singular zone of telescopic planets. The others have been discovered subsequently. Their names and date of discovery are given in the Appendix. [See Table.]

160. Distance.—The average distance of these planets from the sun is about 260 millions of miles. That of the nearest (Flora) is about 201 millions; that of the most distant (Sylvia) is nearly 320 millions. The entire width of the zone in which they revolve is about 190 millions of miles.

161. Orbits.—The inclination of their orbits is very diverse; more than one-third of the whole have a greater

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160. What is their average distance from the sun? That of the nearest? Of the most distant? How wide is the zone in which they revolve? 161. How great is the inclination of their orbits? Their eccentricity?

inclination than 8°, and consequently extend beyond the zodiac. The greatest is that of Pallas, amounting to $34\frac{1}{2}°$. The eccentricity of their orbits is equally variable, the greatest being more than one-third its mean distance, while the least is only .004.

These orbits are not *concentric;* but if represented on a plane surface, would appear to cross each other, so as to give the idea of constant and inevitable collisions. "If," says D'Arrest, of Copenhagen, "these orbits were figured under the form of material rings, these rings would be found so entangled, that it would be possible, by means of one among them taken at a hazard, to lift up all the rest." The orbits do not, however, actually intersect each other, because they are situated in different planes; but some of them approach within very short distances of each other—in one case less than the moon's distance from the earth.

162. Magnitude.—The largest of the Minor Planets is *Pallas*, the diameter of which is variously estimated at from 300 to 700 miles. These bodies are generally so small that it is quite impossible to measure their apparent diameters, or to say which is the smallest. The brightest of these planets is *Vesta;* the faintest, *Atalanta.* Vesta, Ceres, and Pallas have been seen with the naked eye, having the appearance of very small stars.

163. Periods.—The sidereal period of *Flora* is $3\frac{1}{4}$ years; that of *Sylvia* is about $6\frac{1}{2}$ years. The average period of the whole is about $4\frac{1}{2}$ years.

164. Origin of the Minor Planets.—The theory of Olbers has already been alluded to; it supposes that

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162. What is their magnitude? 163. What is the period of Flora? Of Sylvia? The average period? 164. What is said of the origin of the Minor Planets?

these little planets are the fragments of a much larger one, which by an extraordinary catastrophe was, in remote antiquity, shivered to pieces. This theory, however, has not been generally accepted, since it is highly improbable, being supported by no analogous facts.

THE MOON.

165. The Moon, although one of the smallest bodies in the solar system, is, to us, next to the sun, the most conspicuous, interesting, and important, on account of its close connection with our own planet, and the effects which it produces upon it.

166. Orbit.—The orbit of the moon is elliptical; the point nearest to the earth being called the *Perigee*, and the point farthest from it, the *Apogee*. Its mean distance from the earth is 238,800 miles; and it is 26,000 miles nearer to us in perigee than in apogee.

Its eccentricity is, therefore, 13,000 miles, or about .055 of its mean distance. This is more than three times as great, in proportion, as that of the earth.

167. The positions of the apogee and perigee in space are determined by noticing when the moon's apparent diameter is greatest and when it is least. Careful observations of this kind show that these points shift their positions, and that the line of apsides completes a circuit from west to east in a little less than nine years

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165. What is said of the moon? 166. Its orbit? What is perigee? Apogee? The moon's mean distance from the earth? Its eccentricity? 167. What change takes place in the position of the apogee and perigee? What is this called?

(Sy. 310½d.). This is called the *Progression of the Apsides.*

168. The inclination of the moon's orbit to the plane of the ecliptic is about $5\frac{1}{7}°$; consequently, it crosses this plane in two points, called the *Moon's Nodes.* The line of nodes revolves from *east to west* once in about $18\frac{1}{2}$ years.

169. Diameter.—The mean apparent diameter of the moon is a little more than half of a degree, being about the same as that of the sun. From this, its distance from the earth having been previously determined, is found its real diameter, which is 2,162 miles. Its volume is therefore somewhat more than $\frac{1}{50}$ of the earth's.

170. Phases of the Moon.—The phases of the moon are the different portions of her illuminated surface which she presents to the earth as she revolves around it. When she first becomes visible in the west, she is seen as a slender crescent; but from evening to evening her form expands as her angular distance eastward from the sun increases, until when in quadrature, or 90° from the sun, half of her disk is visible. When she has departed so far to the east that she rises just as the sun sets, the whole of her disk is seen, and she is said to be *full.* After this she becomes the waning moon, rising later and later, and growing less and less, until she may be seen in the east as a bright crescent just before sun-

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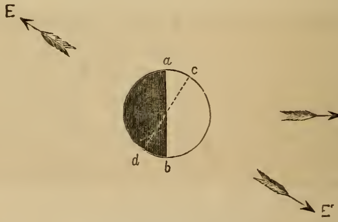
168. What is the inclination of the moon's orbit? What are the nodes? How does the line of nodes move? 169. What is the moon's apparent diameter? Its real diameter? Its volume? 170. What are the phases of the moon? Describe the moon's apparent motions and phases.

rise. A short time after this she disappears, and then becomes visible again in the west.

171. When the moon is in conjunction, the dark side being turned toward us, she is called *new moon;* when she is in quadrature and shows half of her disk, she is called *half-moon;* when she is in opposition, she is called *full moon.* When she is in quadrature after conjunction, she is said to be in her *first quarter;* when in quadrature after opposition, in her *last quarter.*

When she is between conjunction and quadrature she assumes the crescent form, and is then said to be *horned;* when she is between opposition and quadrature, she exhibits more than one-half of her disk, but not the whole, and is said to be *gibbous.*



MOON HORNED AND GIBBOUS.

In the annexed figure, the partially darkened circle represents the moon; S, the direction of the sun; E, the direction of the earth on one side of the moon, and E′, its direction on the opposite side. Then *a b* will represent the line which separates the illuminated from the darkened hemisphere of the moon; and *c d*, that

171. When is it new moon? Full moon? First quarter? Last quarter? When is the moon said to be horned? When gibbous?

which separates the hemisphere turned toward the earth from that turned away from it. At E, *a c* being the only part of the disk visible, the moon appears horned; while at E′, *b c* being visible, the form is gibbous.

172. We can, therefore, find the time of a revolution of the moon by observing the phases. If the earth were at rest, the time from one new or full moon to the next would be exactly the period of a revolution; but as the earth is constantly advancing in her orbit, when the moon has completed a revolution, she has to move still farther in order to come into the same relative position with the earth and sun. The time from one new moon to the next is 29½ days. This is the synodic period, and is called a *synodical month*, or *lunation.* The sidereal period is 27⅓ days.

SIDEREAL AND SYNODICAL REVOLUTION.

In the figure, let A B represent the advance of the earth in its orbit, while the moon completes a synodic revolution, that is, moves from C, the position of inferior conjunction, till she arrives at the same relative position with the sun at E. But when she reaches this point, she has completed a sidereal revolution, and has also moved from D to E, a distance, it will be seen, equal in angu-

172. How can the time of a revolution of the moon be found? What is the synodic period? The sidereal period? Why is the former longer than the latter?

lar measurement to A B; since the arc A B bears the same proportion to the earth's orbit that E D does to that of the moon.

173. Owing to the constant advance of the moon in her orbit, she rises and, of course, arrives at the meridian and sets, about 50 minutes later each successive day.

This is the average interval of time between the successive risings of the moon; for since she moves through the ecliptic in $29\frac{1}{2}$ days, her daily advance is equal to about $12\frac{1}{5}°$; but a place upon the earth's surface moves 15° in one hour, and hence requires nearly 50 minutes to overtake the moon. If the moon's orbit or the ecliptic, since the inclination is very small, always made the same angle with the horizon, this would be the constant interval; but, in consequence of the obliquity of the ecliptic, this angle continually varies during each lunation.

174. Harvest Moon.—This is the full moon that occurs in high latitudes, near the time of the autumnal equinox, in September and October, when she rises but a little later for several successive evenings, and thus affords light for collecting the harvest.

By means of the globe, it may be easily shown that the ecliptic is most oblique to the horizon in the signs Pisces and Aries, and least so in Virgo and Libra; so that when the moon is in the former signs, in this latitude, she rises only about half an hour later, but when in the latter, more than an hour. This difference is, however, only noticed when the moon happens to be *full* while in Pisces or Aries, and thus rises, for several evenings, in the higher latitudes, but a few minutes later. These full moons must occur, of course, in September and October, when the sun is in the opposite signs, Virgo and Libra. In the former month, the full moon in

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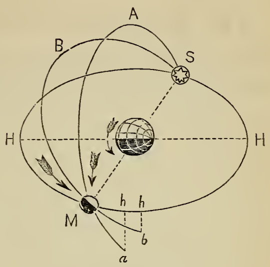
173. How much later does the moon rise each day? Why? Why is it not always the same? 174. What is harvest moon?

England is called the *Harvest Moon;* in the latter, sometimes, the *Hunter's Moon.*

Let H S H M represent the horizon; S, the position of the sun at sunset; M, the full moon just rising; S A M, the part of the equator, and S B M, the part of the ecliptic above the horizon, the sun being in Libra, the autumnal equinox, and the moon in Aries, the vernal equinox. Since the *southern* half of the ecliptic lies *east* of Libra, it will be evident that in or near this position the ecliptic must make the smallest angle with the horizon; and consequently, while the moon makes her daily advance in her orbit, M *b*, she only descends below the horizon a distance equal to *h b;* while, if her orbit made a greater angle with the horizon, as S A M, she would, by advancing through the equal arc M *a*, descend below the horizon a distance equal to *h a.*



HARVEST MOON.

175. Observations with the telescope show that the moon always presents very nearly the same hemisphere to the earth. This proves that it rotates on its axis once during each sidereal month, or $27\frac{1}{3}$ days.

The unassisted eye is able easily to perceive that the dusky spots on the disk of the moon constantly keep in the same relative position and present the same appearance; and this could not occur if she rotated so as to present in succession different hemispheres to the earth. Just as we infer a rotation of the sun from the apparent motion of the solar spots, so we know that the moon rotates during one revolution around the earth, by the observed fact that

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175. What does an observation of the moon show? What does this prove? Explain this.

the lunar spots have no apparent motion; since, if the moon performed no rotation, the spots on its disk would move across it from west to east, keeping pace with the moon's motion in the ecliptic, and completing one apparent revolution in $29\frac{1}{2}$ days.

176. Librations of the Moon.—As the orbit of the moon is elliptical, her velocity is not uniform—sometimes exceeding that of her rotation, and at other times exceeded by it. In consequence of this, a small portion of the hemisphere turned away from the earth becomes visible alternately at the eastern and western limbs. This is called the *libration in longitude*. A portion of her surface is also exhibited alternately at each pole, caused by the inclination of her axis to the plane of her orbit. This is called the *libration in latitude.*

177. Seasons.—Owing to the small inclination of the moon's axis to the plane of the ecliptic (1° 31′), she can have but very little change of seasons, and that not constant, because her axis does not always point in the same direction; for the lunar solstices and equinoxes change places with each other every $9\frac{1}{4}$ years.

178. Telescopic Appearances of the Moon.—The moon's disk when viewed through a telescope presents a diversified appearance of dusky and bright spots; the latter being evidently elevated portions of the surface, and the former, plains or valleys. Mountains are indicated by the bright spots that appear scattered over the

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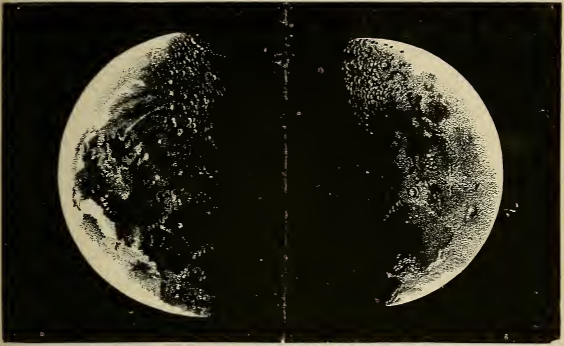
176. What are librations? How is the libration in longitude caused? The libration in latitude? 177. What seasons has the moon? Why? 178. What does the moon's disk exhibit when viewed through a telescope? How are mountains indicated? Of what form are they?

disk and beyond the terminator, and by the shadows cast upon the surface of the moon when the sun shines obliquely upon these elevations. These mountains are



PHOTOGRAPHIC VIEWS OF THE MOON.—*De La Rue.*

of various forms, many of them being very lofty, of a circular form, and inclosing an extensive area, sometimes 60 miles in diameter. These are called *Ring Mountains.* Others, called *Crater Mountains*, inclose hollow spaces, which often contain a central mound. Some of the lunar mountains are evidently over 20,000 feet high.

179. Appearances indicate that the moon has very little, if any, atmosphere ; and that its surface is as devoid of water as of air.

When viewed with a telescope, the surface of the moon appears entirely unobscured by any clouds or vapors floating over it ; and when the moon's edge comes in contact with a star, the latter is

179. Has the moon an atmosphere ? How is this indicated ?

immediately extinguished; whereas, if there were an atmosphere, it would, from the effect of refraction, rest on the edge for a short time; that is, it would be visible when a short distance actually behind the moon. Observations of this kind have been made with so much nicety, that it is believed that an atmosphere two thousand times less dense than that of the earth could not have escaped detection. If any atmosphere therefore exists, it must be rarer than the attenuated air in the exhausted receiver of the most perfect air-pump.

180. Are there People in the Moon?—This question has often been discussed, but idly; since no positive evidence can be adduced on one side or the other. The distance of the moon is too great for us to detect any artificial structures, as buildings, walls, roads, etc., if there were any; and certainly, without air or water, no animals such as inhabit our own planet could exist there. But the Almighty Creator can place animals and intelligent beings in any part of the universe, and accommodate them to the peculiar circumstances of their abode; and it would perhaps be strange if He had left even our little satellite without an intelligent witness of His infinite power and beneficence.

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180. Are there people in the moon?

SECTION V.

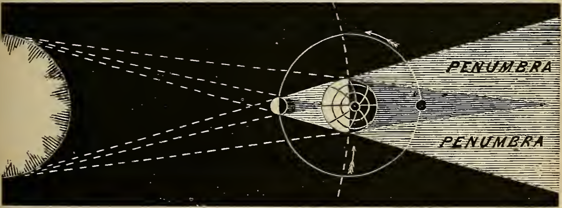
ECLIPSES.

181. An Eclipse is the concealment or obscuration of the disk of the sun or moon by an interception of the sun's rays. Eclipses are, therefore, either *Solar* or *Lunar.*

A solar eclipse is caused by the passage of the moon between the earth and sun so as to conceal the sun from our view.

A lunar eclipse is caused by the passage of the moon through the earth's shadow.

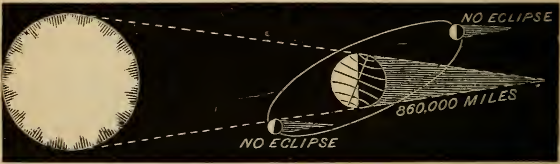
By a shadow is meant simply the space from which the light of a luminous body is wholly intercepted by the interposition of some *opaque* body. Since light proceeds from a luminous body in straight lines, and in all directions, the darkened space formed behind the earth or moon must be *conical;* that is, of the form of a cone, circular at the base and terminating at a point; since the sun or



181. What is an eclipse? Of how many kinds are eclipses? What is a solar eclipse? A lunar eclipse? What is meant by the shadow? Its form? What is it sometimes called? What is the penumbra?

luminous body is larger than either of the opaque bodies. The shadow is sometimes called by its Latin name, *umbra.* Besides the totally darkened space called the *umbra*, there is formed on each side a space from which the light is only partially excluded; this is called the *penumbra.* The relations of the umbra to the penumbra will be understood by inspecting the annexed diagram.

182. If the moon moved exactly in the plane of the earth's orbit, a solar eclipse would occur at every new moon, and a lunar eclipse at every full moon; but as the moon's orbit is inclined to that of the earth, an eclipse can only happen when the moon is at or near one of its nodes.



When the moon is new or full at a considerable distance from its node, it is too far above or too far below the plane of the ecliptic to intercept the sun's rays from the earth, or to pass within the limits of the earth's shadow. It will be easily understood that no eclipse can occur unless the sun, earth, and moon are situated exactly or nearly in the *same straight line.* [See Figure.]

183. The distance, either side of the node, within which an eclipse can occur, is called the *Ecliptic Limit.* The solar ecliptic limit extends about 17° on each side

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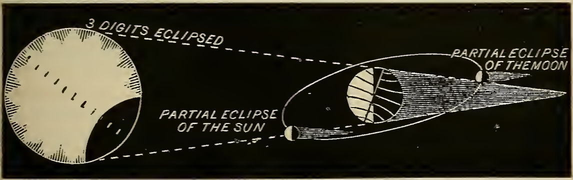
182. Why does not an eclipse occur at every new and full moon? 183. What is the ecliptic limit? The extent of the solar ecliptic limit? The lunar ecliptic limit? Which eclipses are the more frequent? Why? What is the greatest number of eclipses that can happen in a year? The least number?

of the node; the lunar ecliptic limit, only 12°. Eclipses of the sun are, therefore, more frequent than those of the moon. The greatest number of eclipses that can happen in a year is seven,—five of the sun and two of the moon, or four of the sun and three of the moon. The least number is two, both of which must be of the sun.

184. Solar eclipses do not actually occur as often as lunar eclipses at *any particular place;* because the latter are always visible to an entire hemisphere, whereas the former are only visible to that part of the earth's surface covered by the moon's shadow or its penumbra.

185. When the whole of the sun's or moon's disk is concealed, the eclipse is said to be *total;* when only a part of it is concealed, it is said to be *partial.*

In order to measure the extent of the eclipse, the apparent diameters of the sun and moon are divided into twelve equal parts, called *Digits.*



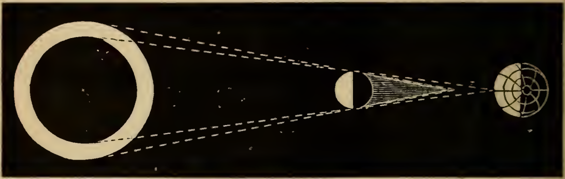
A PARTIAL ECLIPSE OF THE SUN AND MOON.

The conditions of a total and a partial eclipse will be apparent from the explanations already given. When the centres of the sun

184. Which are the most frequent at any place? Why? 185. What is a total eclipse? A partial eclipse? What are digits? 185. What is an annular eclipse?

and moon coincide, that is, when the latter is exactly at the node, the eclipse is said to be *central.* A central eclipse of the moon must, of course, be total; but a solar eclipse may be central without being total; since sometimes the shadow of the moon does not reach the earth. The moon, when this is the case, covers only the central part of the sun's disk, leaving a ring of luminous surface around the opaque body.

186. An *annular eclipse* is an eclipse of the sun, which happens when the moon is too far from the earth to conceal the whole of the sun's disk, leaving a bright ring around the dark body of the moon.



AN ANNULAR ECLIPSE.

187. The phenomena connected with a total eclipse of the sun are of a peculiarly interesting character, and have been observed by astronomers with great attention and industry.

To an ignorant mind, this occurrence must be the occasion of very great awe, if not actual terror. A universal gloom overspreads the face of the earth as the great luminary of day appears to be expiring in the sky; the stars and planets become visible, and the animal creation give signs of terror at the dismal and alarming aspect of nature. Armies about to engage in battle have thrown down their arms and fled in dismay from the seeming anger of heaven.

186. What is an annular eclipse? 187. Describe the phenomena connected with a total eclipse of the sun.

188. An *occultation* is the concealment of a planet or star by the interposition of the moon or some other body.

The occultation of a planet or star by the moon is a very interesting and beautiful phenomenon. From new moon to full moon, she advances eastward with the dark edge foremost, so that the occulted body disappears at the dark edge and re-appears at the enlightened edge. In the other part of her orbit this is reversed. The former phenomenon is of course the more striking, the star or planet appearing to be extinguished of itself.

189. Transits.—When the latitude of Mercury or Venus, at the time of inferior conjunction, is less than the semi-diameter of the sun, a *transit* must occur, the planet appearing on the sun's disk like a small, round, and intensely black spot, and moving across it from east to west.

It appears to move across the disk from east to west for the same reason that the solar spots appear to move in that direction (Art. 106). The planet's velocity being faster than the earth's, the planet passes the earth actually from west to east, but in a direction opposite to the diurnal motion of that part of the earth on which the observer stands; hence the apparent motion is *westward*, since east is in the direction of the rising sun, and this must be the point toward which any place on the earth turns.

190. The transits of Venus are of great interest and importance, because they afford a means of determining the distance of the sun from the earth. The next transit will occur in December, 1874.

The transits of Jupiter's satellites are among the most interesting celestial phenomena.

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188. What is an occultation? Describe the phenomenon. 189. When does a transit of Mercury or Venus occur? Describe the phenomenon. 190. Why are these transits of great interest?

SECTION VI.

TIDES.

191. Tides are the alternate rising and falling of the water in the ocean, bays, rivers, etc., occurring twice in about twenty-four hours. The rising of the water is called *Flood Tide;* the falling, *Ebb Tide.* They are caused by the unequal attraction of the sun and moon upon the opposite sides of the earth.

Since the attraction of gravitation varies inversely as the square of the distance, the sun and moon must attract the water on the side nearest to them more than the solid mass of the earth; while on the side farthest from them, the water must be attracted less than the solid earth; hence, there must be a tendency in the water to rise at each of these points; it being drawn away from the earth at the point toward the sun or moon, and the earth being drawn away from it at the other point. At the points 90° from these, the effect of the attraction is just the reverse; for since it does not act in parallel lines, it tends to draw together the two sides of the earth, and thus compresses the water so as to cause it to recede, and hence increases its tendency to rise at the other points.

Thus at A [see diagram, page 121] the water is attracted by the sun more than the earth, and at B less; while at C and D the attraction squeezes in the water, as it were, so as to make it recede still more, and thus to augment its rising at A and B. It will be obvious that the attraction of the moon acts so as to disturb the water just as that of the sun does; hence, in the position represented in the dia-

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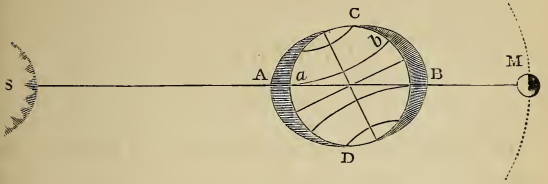
191. What are tides? What is flood tide? Ebb tide? How are tides caused? Explain by the diagram.

gram, when the moon is in opposition, the action of both the sun and moon is exerted upon the same points, A B and C D; and it



will also be obvious that if the moon were in conjunction, that is, on the same side of the earth as the sun, the effect would be the same, because the same points would be acted upon.

192. Similar tides, therefore, occur simultaneously on opposite sides of the earth; namely, flood tides on the side turned toward and on that turned from the sun or moon, and ebb tides at the two points 90 degrees distant.

193. Since the moon is so much nearer to the earth than the sun is, its attraction on the opposite sides is much more unequal, and consequently its disturbing action is greater. At the mean distance of the sun and moon from the earth, the disturbing or tidal force of the moon is about $2\frac{1}{3}$ times that of the sun.

194. When the sun and moon are on the same or opposite sides of the earth, they unite their attractions, and thus raise the highest flood tides at the points under or opposite them, and the lowest ebb tides at the points 90° from these. Such tides are called *Spring Tides;*

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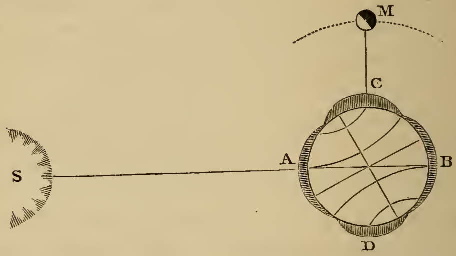
192. When do similar tides occur? 193. Which has the greater disturbing force—the sun or the moon? Why? 194. What are spring tides? How are they caused? When do they occur?

they occur at every new and full moon, or a short time afterward.

195. When the moon is in quadrature, its tidal force is partly counteracted by that of the sun, since the two forces act at right angles with each other; and consequently the water neither rises so high at flood, nor descends so low at ebb tide. Such tides are called *Neap Tides;* they occur when the moon is in either of the quarters.



The annexed diagram represents neap tide. The effect of the sun at A and B, and of the moon at C and D, is to equalize the height of the water all over the earth. The pupil must understand in inspecting these diagrams, that the actual effect of the sun or moon is not, by any means, so great as is represented. It is, in fact, but a few feet, while the earth's diameter is nearly 8,000 miles.

196. In the northern hemisphere, the highest tides occur during the day in summer, and during the night in winter. In the southern hemisphere the reverse of this is the case.

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195. What are neap tides? How caused? When do they occur? Explain by the diagram. 196. When do the highest tides occur in the northern hemisphere? In the southern hemisphere? Explain by the diagram.

This will be apparent from an inspection of the diagram on page 121. The greatest tidal elevation of the water is of course at A and B, and diminishes north and south of these points. At *a* the elevation of the water is obviously greater than at *b*; but *a* is the position of a place in the northern hemisphere at noon and in summer, since the north pole is turned toward the sun, and *b*, its position at midnight; so that the tide is higher during the day than during the night, in this season. Conceive the pole turned the other way, and it will be at once seen that the reverse is true in winter.

197. The tides do not rise at the same hour every day, but generally about 50 minutes later; because, as the moon advances in her orbit, the same place on the earth's surface does not come again under the moon until about 50 minutes later than on the previous day.

The interval which elapses from the moon's passing the meridian of a place until it returns to the same again is generally 24h. 50m. 28s.; the interval, therefore, between two successive tides is 12h. 25m. 14s.

198. The tide does not generally rise until two or three hours after the moon has passed the meridian; because, on account of its inertia, the water does not immediately yield to the action of the sun or moon.

By *inertia* is meant the resistance which matter of every kind makes to a change of state, whether of rest or motion; that is, it cannot put itself in motion, neither can it stop itself. The tides are not only retarded by inertia, but, to some extent, by the friction on the bed of the ocean or the sea, or the sides of rivers and confined channels.

199. The tides that occur in rivers, narrow bays, or

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197. How much later do the tides rise from day to day? Why? What is the interval between two successive tides? 198. Why does not the tide rise when the moon is on the meridian? What is inertia? 199. How are the tides of rivers, etc., caused? What are primitive tides? Derivative tides?

other bodies of water at a distance from the ocean, are not caused by the immediate action of the sun and moon, but arise from the movement of the great ocean tide wave, urging the water into these contracted inlets. The tides of the ocean are called *Primitive Tides;* those of rivers, inlets, etc., are called *Derivative Tides.*

200. The average height of the tide for the whole globe is about $2\frac{1}{2}$ feet; and this is the height to which it rises in the ocean. The height, however, at any particular place depends upon its situation; the highest tides occurring in narrow bays, and arms of the sea running up into the land. Lakes have no perceptible tides.

The highest tides in the world take place in the Bay of Fundy, the mouth of which is exposed to the great Atlantic tide wave. At the head of the bay the ordinary spring tides rise to the height of 50 feet, while special tides have been known to rise as high as 70 feet. In New York, the height of the tide is, at its maximum, about 8 feet; in Boston, 11 feet. On the other hand, at some places there is scarcely any tide at all. An instance of this is found at a point on the south-eastern coast of Ireland, the tide stream being diverted to the opposite shore by a promontory at the entrance of St. George's Channel.

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200. What is the average height of the tide for the whole globe? Why does it vary at different places? When are the tides highest? Tides in lakes? Mention the height at some particular places.

SECTION VII.

COMETS.

201. Comets are bodies of a nebulous or cloudy appearance that revolve in very eccentric orbits, and are generally accompanied by a long and luminous train called the *Tail*. The head of the comet consists almost always of a bright and apparently solid part in the centre, called the *Nucleus*, and a nebulous substance, called the *Coma*, which envelops it. The tail extends on the side from the sun.

The name *comet* is derived from this nebulous appearance which the ancients fancifully likened to hair [in the Greek, *comē*], and hence called these bodies *comētæ* or *hairy bodies*. When the luminous train precedes the comet, it is sometimes called the *beard*.

The appearance of comets is not uniform, the same comet changing very much at different times. Some comets have no nucleus, others, no tails; while still others have several tails.

These bodies when at a long distance from the earth and sun are distinguished from planets by the size and position of their orbits, and the direction of their motions. Uranus was for some time thought to be a comet, and was recognized as a planetary body only after its orbit had been proved to be almost circular, and nearly in the plane of the ecliptic.

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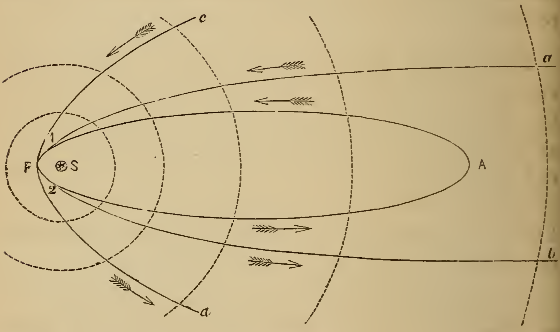
201. What are comets? Of what does the head of a comet consist? On which side is the tail? From what is the name *comet* derived? Appearance of comets? How distinguished from planets?

202. Comets either revolve around the sun in elliptical orbits, or move in curve lines of other forms. The elliptic comets may be considered as belonging to the solar system; the others, as only visitants of it, since they come from distant regions of space, move around one side of the sun, and then pass swiftly away in paths that never return into themselves, but are constantly divergent.



ORBITS OF COMETS.

In the diagram these different kinds of paths are represented. The smaller one is an elliptic orbit of very great eccentricity, A being the aphelion, and P the perihelion. *a* P *b* and *c* P *d* are paths that do not return into themselves. The former is a curve, called by mathematicians a *parab'ola*; the latter is called a *hyper'bola.* The greater divergency of the latter will be obvious; also, that the elliptic and parabolic curves coincide from 1 to 2, and

202. What is the shape of comets' orbits? To what do elliptic comets belong? Other comets? Explain the different kinds of orbits.

thus that these two orbits would be undistinguishable between these two points. The motion indicated by the arrows is direct.

203. In order to identify a comet, or ascertain that it is the same which has previously appeared, we must know, 1. The longitude of the perihelion of its orbit; 2. The longitude of its ascending node; 3. Its inclination to the ecliptic; 4. Its eccentricity; 5. The direction of the comet's motion; and 6. Its perihelion distance from the sun. These facts are called the *Elements of its Orbit.*

204. Elliptic Comets.—The elliptic comets are divided into two classes; those of short periods and those of long periods. The former are seven in number, and have all reappeared several times, their identity being satisfactorily established by an entire correspondence of their elements. The most noted of these is the comet of Encke, the period of which is about $3\frac{1}{3}$ years, nineteen returns of it having been recorded.

The others are *De Vico's*, the period of which is $5\frac{1}{2}$ years; *Winnecke's*, $5\frac{1}{2}$ years; *Brorsen's*, $5\frac{3}{5}$ years; *Biela's*, $6\frac{3}{5}$ years; *D'Arrest's*, $6\frac{3}{5}$ years; *Faye's*, $7\frac{1}{2}$ years. These comets are named after the distinguished astronomers who first discovered them, or determined their periods and predicted their returns.

205. These comets have comparatively small orbits, the mean distance of each being less than that of Jupiter, and all revolving within the orbit of Saturn. The

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203. How is a comet identified? What are the elements of a comet's orbit? 204. How are the elliptic comets divided? How many comets of short period are there? Which is the most noted? Its period and returns? 205. What is said of this class of comets?

inclination of their orbits is comparatively small; and they all revolve from west to east. They are not conspicuous objects, but have been generally visible only with the aid of a telescope.

206. With the exception of a few comets, the periods of which have been computed to be about 75 years, all the remaining elliptic comets are thought to be of very long periods, some more than 100,000 years.

The comet of 1744 is estimated to require nearly 123,000 years to complete one revolution; that of 1844, 102,000 years; and the great comet of 1680, about 9,000 years. The period of a comet cannot, however, be ascertained with precision during one appearance, since only a very small part of its orbit is described during the short time it remains visible. There is, consequently, considerable uncertainty in these determinations. To the great comet of 1811, the two periods of 2,301 and 3,065 years have been assigned.

207. Orbits of Comets.—Of all the comets whose orbits have been ascertained, about one-half are direct, that is, they revolve from west to east; the remainder are retrograde. Their inclinations are very diverse, some revolving within the zodiac, others at right angles with the ecliptic.

About three-fourths of all the comets have their perihelia within the orbit of the earth; and nearly all the others, within the orbit of the nearest asteroid. Only one is situated more than 400,000,000 miles from the sun. Some comets, on the other hand, come into close proximity to the sun. The great comet of 1680 approached within 600,000 miles of it; and that of 1843 was less than 75,000 miles. The *aphelion* distances of some of these comets are inconceivably great. The comet of 1811 recedes to a distance from the

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206. Of the other elliptic comets? Give some examples. 207. In what direction do comets move? The inclination of their orbits?

sun equal to 14 times that of Neptune, or more than 40,000 millions of miles; the greatest known (that of 1844) must be nearly 400,000 millions of miles.

208. The Velocity of Comets as they move through their perihelia is amazingly great. That of 1680 was 880,000 miles an hour; and that of 1843, about 1,260,000 miles an hour, or 350 miles per second. The latter body swept around the sun from one side to the other in about two hours.

209. The Number of Comets is supposed to be very great. From the earliest period up to the present time more than 800 have been recorded, of which nearly 300 have had their orbits computed, and of the latter 54 have been identified as returns of previous comets.

Since it is only within the last 100 years that optical aid has been made available in searching for comets, it is supposed that the actual number of comets that have come within view, in both hemispheres, is not less than 4,000 or 5,000. M. Arago estimates that the greatest possible number in the solar system cannot exceed 350,000.

210. The Size of Comets, including both envelope and nucleus, very much exceeds that of the largest planet; the nucleus is, however, comparatively small, the diameter of the largest measured being about 8,000 miles (that of 1845).

211. The Masses and Densities of the comets must be inconceivably small; since, notwithstanding their

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208. The orbital velocity of comets? 209. The number of comets? 210. Their size? 211. Masses and densities? Remark?

great magnitudes, they move among the planets and their satellites without in the least, as far as it can be observed, affecting their motions; although they are themselves greatly disturbed by the attractions of the planets.

Their densities are, without doubt, many thousand times less than atmospheric air. Stars are seen very clearly through the nebulous coma and train of a comet, notwithstanding that the light has to pass sometimes through millions of miles of the substance.

212. The Tails of comets are often of immense length, and are generally of a bent or curved form, extending on the side from the sun and nearly in a line with the radius-vector of the orbit. The tail increases in length as the comet approaches the sun, but attains its greatest dimensions a short time after the perihelion passage, and then gradually diminishes.

In respect to magnitude, the tails of comets are the most stupendous objects which the discoveries of astronomers have presented to our contemplation. That of the comet of 1680 was more than 100,000,000 miles in length; while the comet of 1843 presented a train 200,000,000 miles long, which was shot forth from the head of the comet in the incredibly short space of twenty days. The increase of the tail and the decrease of the head of the comet as it approaches the sun, are among the most striking phenomena presented by these bodies.

REMARKABLE COMETS.

213. Comet of 1680.—This was the comet that Newton subjected to the calculations by which he showed

212. Their tails? Remark? 213. What account is given of the comet of 1680?

that these bodies revolve in one of the conic sections, and that they are retained in their orbits by the same

GREAT COMET OF 1680.

force that binds the planets to the sun. It was very remarkable for its splendor, and for the extent of its train, which stretched over an arc of 70° in the heavens, and reached the amazing length of 120,000,000 miles. With the exception of the comet of 1843, it approached nearer to the sun than any other known, and moved through its perihelion with a velocity of 880,000 miles an hour.

214. Halley's Comet. This comet derives its name from Sir Edmund Halley, a celebrated English astronomer, who calculated its orbit and predicted its return. It appeared in 1682, and Halley noticing a close resemblance in its elements to those of 1531 and 1607,

HALLEY'S COMET, 1835.

214. What account is given of Halley's comet?

concluded that the comets of these years were different appearances of the same comet, and ventured to predict its reappearance in 1758 or 1759. This prediction was realized by the return of the comet in March, 1759; and it again appeared in 1835. These different appearances, it will be observed, were about 75 years apart; and others of an earlier date have also been recognized.

215. Encke's Comet is remarkable for its short period and frequent returns. Its period and elliptic orbit were determined by Professor Encke at its fourth recorded appearance in 1819. Its last return took place in 1868. This comet has generally appeared without any luminous train; but in 1848, it had a tail about 1° long, turned from the sun, and a shorter one directed toward that luminary. In its latest returns it has been very faint and difficult of observation.


ENCKE'S COMET.

216. Lexell's Comet.—This body is particularly noted for the amount of disturbance which it has suffered in passing among the planets. From observations made in 1770, Lexell calculated its period to be about

215. What account is given of Encke's comet? 216. Of Lexell's comet? What is determined by calculation in respect to it?

5½ years; and it was a large and bright object. It has, however, never been seen since, its orbit having, without doubt, been entirely changed by planetary disturbance.

It is proved by calculation that it must have returned in 1776, but was so situated as to be continually hid by the sun's rays; and also, that in 1779 it passed so near Jupiter, that its orbit must have been greatly enlarged, so that it no longer comes near the earth. On July 1st, 1770, its distance from the earth was less than 1,500,000 miles.

217. Comet of 1744. —This was the finest comet of the 18th century, and, according to some observers, had six tails spread out in the form of a fan. Euler calculated its elliptic orbit, and assigned to it a period of 122,683 years. Its motion was direct.

COMET OF 1744.

218. Biela's Comet.—This is one of the elliptic comets of short period; its perihelion lying just within the orbit of the earth, and its aphelion a little beyond that of Jupiter. The orbit of this body nearly crosses the actual path of the earth; and in 1832, Olbers calculated that it would come within 20,000 miles of the earth, so that the latter body would be enveloped in its mass. The earth, however, did not reach the node until one month after the comet had passed it.

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217. What is said of the comet of 1744? 218. Of Biela's comet?

In 1845, this comet became elongated in form and finally separated into two comets, which traveled together for more than three months; their greatest distance apart being about 160,000 miles. The two parts were again seen at the next return of the comet in 1852, but the interval had increased to 1,250,000 miles. Neither part has been seen since.

COMET OF 1811.

219. Comet of 1811.—This comet was very remarkable for its unusual magnitude and splendor. It was attentively observed by Sir William Herschel, who describes it as having a nucleus 428 miles in diameter, which was ruddy in hue, while the nebulous mass surrounding it was of a bluish-green tinge. Its tail was of peculiar form and appearance, extending about 25°, with a breadth of nearly 6°.

The investigation of its elements by Argelander is the most complete ever made. He assigns it a period of more than 3,000 years, and estimates its aphelion distance at 40,121 millions of miles.

220. Comet of 1843.—This comet was also remarkable for its size and brilliancy, it being visible in some parts of the world during the day time. It had a tail

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219. What account is given of the comet of 1811? 220. Of the comet of 1843?

60° long, and approached within a very short distance of the sun,—about 75,000 miles from its surface. Its period

GREAT COMET OF 1843.

is variously estimated at from 175 to 376 years. Its motion is retrograde.

221. Donati's Comet.—This is the great comet of 1858, named after Donati, by whom it was first seen at Florence. As it approached its perihelion it attained a very great magnitude and splendor, and was particularly distinguished for the magnificence of its train. Its period has been estimated at nearly 1,900 years.

222. Recent Comets.—About thirty comets have appeared since that of Donati, the elements of which have been calculated. The most remarkable were the comet of 1861, described as one of the most magnificent on record, having a tail 100° long; and that of 1862, which was very interesting for the peculiar phenomena which it presented of luminous jets, issuing in a continuous series from its nucleus.

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221. What account is given of Donati's comet? 222. Recent comets?

SECTION VIII.

METEORS OR SHOOTING STARS.

223. Meteors or Shooting Stars are small luminous bodies that move rapidly through the atmosphere, followed by trains of light, and quickly vanishing from view. They sometimes appear in numbers so great as to seem like showers of stars.

224. These star-showers are found to occur at certain periods. Every year, about November 14th, there is a larger fall than usual of meteors; but about every 33 years, it has been noticed, there is a great star-shower. Those which occurred in November, 1866–7, had been predicted from observations of previous events of the kind. Thus a star-shower occurred in November, 1832–3, also in 1799; and there are eighteen recorded observations of the phenomena from 1698 to 902, all corresponding in period to that mentioned above.

Great Star-showers.—The shower of 1799 was awful and sublime beyond conception. It was witnessed by Humboldt and his companion, M. Bonpland, at Cumaná, in South America, and is thus described by them:—"Toward the morning of the 13th of November, 1799, we witnessed a most extraordinary scene of shooting meteors. Thousands of *bolides* and falling stars succeeded each

223. What are meteors? 224. At what periods do star-showers occur? How many recorded observations of star-showers are there since 902? Give some examples of great star-showers.

other during four hours. Their direction was very regularly from north to south; and 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 bolides or falling stars. All the meteors left luminous traces, or phosphorescent bands behind them, which lasted seven or eight seconds." The same phenomena were seen throughout nearly the whole of North and South America, and in some parts of Europe. The most splendid display of shooting stars on record was that of November 13th, 1833, and is especially interesting as having served to point out the periodicity in these phenomena. Over the northern portion of the American continent the spectacle was of the most imposing grandeur; and in many parts of the country the population were terror-stricken at the awfulness of the scene. The ignorant slaves of the southern States supposed that the world was on fire, and filled the air with shrieks of horror and cries for mercy. The shower of 1866 was anticipated with great interest; and in New York and other places arrangements were made to announce the occurrence, during the night of November 14th, by ringing the bells from the watch-towers. The display, however, was not witnessed in this country, but in England was quite brilliant; as many as 8,000 meteors being counted at the Greenwich observatory. Another shower of less extent occurred in November, 1867.

225. Meteoric Epochs are particular times of the year at which large displays of shooting stars have been observed to occur at certain intervals. The principal of these are November 13th–14th, and August 6th–11th.

Three others have been established with considerable certainty; namely, in January, April, and December, and still others indicated, that are doubtful. There are 56 meteoric days in the year; those in August and November being the richest.

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225. What are meteoric epochs? Which are the principal ones? What others are there? Meteoric days?

226. Meteors are supposed to be small bodies collected in rings or clusters, and revolving around the sun in eccentric orbits. They appear to resemble comets in their nature and origin, and, like those bodies, sometimes revolve from east to west.

227. Origin of Meteors.—The immense velocity of these bodies, which is about equal to twice that of the earth in its orbit, or 36 miles a second, and the great elevation at which they become visible, the average being 60 miles, indicate that they are not of terrestrial, but *cosmical*, origin; that is, they emanate from the inter-planetary regions, and being brought within the sphere of the earth's attraction, precipitate themselves upon its surface. Moving with so great a velocity through the higher regions of the air, they become so intensely heated by friction that they ignite, and are either converted into vapor, or, when very large, explode and descend to the earth's surface as meteoric stones, or *aerolites*. The brilliancy and color of meteors are variable; some are as bright as Venus or Jupiter. About two-thirds are white; the remainder, yellow, orange, or green. Their number is inconceivably great.

228. Fire Balls are large meteors that make their appearance at a great height above the earth's surface, moving with immense velocity, and accompanied by luminous trains. They generally explode with a loud

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226. What are meteors supposed to be? What do they resemble? 227. Of what origin are they? How is this indicated? How are meteoric stones or aerolites produced? What is said of the brilliancy of meteors? Their colors? Their number? 228. What are fire balls?

noise, and sometimes descend to the earth in large masses. There are very remarkable occurrences of this kind on record.

229. The Composition of Aerolites is nearly always the same, iron being the principal ingredient. Some of these masses are of immense size; one, a mass of iron and nickle, found in Siberia, weighs 1,680 lbs. At Buenos Ayres there is a mass partly buried in the ground, $7\frac{1}{2}$ feet in length, and supposed to weigh about 16 tons.

230. The November Meteors are supposed to revolve around the sun in an orbit of considerable eccentricity, inclined to the plane of the ecliptic in an angle of $17\frac{1}{2}°$, and extending at its aphelion somewhat beyond the orbit of Uranus, its perihelion being very nearly at that of the earth. They move in a ring of unequal width and density, the thickest part crossing the earth's orbit every 33 years, and requiring nearly two years to complete the passage.

231. The elements of this orbit correspond almost precisely with those of the comet which made its appearance in January, 1866; so that it seems probable that the comet is a very large meteor of the November stream. The elements of the orbit of the August meteors have been found, in a similar manner, to coincide with those of the third comet of 1862; showing that

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229. What is the composition of aerolites? 230. What is the orbit of the November meteors? How do they move? 231. To what does this orbit correspond? What is inferred from this?

the comet and these meteors belong to the same ring. This seems also to be true of the first comet of 1861 and the April meteors.

232. The point from which the November meteors seem to radiate is in the constellation Leo; because, as the earth at that time of the year is moving toward that point, they appear to rush from it. Their velocity appears to be double that of the earth, although only equal to it; because they move in an opposite direction and almost in the same plane. When the earth plunges into the meteoric stream a great star-shower occurs.

233. Physical Origin.—Meteors are supposed by some to be small fragments of nebulous matter detached in vast numbers from larger masses, such as are seen in the regions of the stars, or from that of which the solar system is supposed to have been originally formed, their origin being precisely the same as that of the comets, which indeed may be considered as, in reality, only meteors of vast size. It is also probable that, like Biela's comet, others have been divided and subdivided so as finally to be separated into small fragments moving in the orbit of the original comet and thus constituting a meteoric ring or stream.

234. The following general conclusions with regard to meteors in the solar system have been suggested: 1. Biela's comet in 1845 passed very near, if not through,

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232. From what point do the November meteors seem to proceed? Why? Why is their velocity double that of the earth? 233. What are meteors supposed to be?

the November stream, and was probably divided in this way; 2. The rings of Saturn are dense meteoric streams, the principal or permanent division being due to the disturbing influence of the satellites; 3. The asteroids are a stream or ring of meteors, the largest being the Minor Planets which have been discovered.

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234. What general conclusions have been suggested?

SECTION IX.

THE STARS.

235. The Stars are luminous bodies like the sun, but situated at so vast a distance from the earth that they seem like brilliant points, and always in nearly the same positions with respect to each other. They are readily distinguishable from most of the planets by their scintillation or twinkling, which is caused by the irregularities in density, moisture, etc., of the different strata of the atmosphere through which the rays of light pass.

236. The distance of the nearest star is found by calculation to be more than 20 trillions of miles,—a distance so vast that light, traveling at the rate of 184,000 miles a second, requires more than $3\frac{1}{2}$ years to reach us from that remote luminary. Other stars are known to be more than twenty times as distant.

237. The stars are divided into classes according to their apparent brightness, the brightest being distinguished as stars of the first magnitude, the next of the second, and so on. Stars of the first six magnitudes are visible to the naked eye; but the telescope reveals the existence of others so feeble in light as to be classed as of the seventeenth magnitude.

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235. What are the stars? How may they be distinguished from the planets? What causes the scintillation? 236. What is the distance of the nearest star? How distant are other stars known to be? 237. How are the stars divided? Which are visible to the naked eye? Remark?

This classification is based merely on appearance, and therefore indicates nothing as to the real magnitudes of the bodies in question. The average brightness of stars of the first magnitude is one hundred times as great as that of stars of the sixth; but Sirius, the brightest star in the heavens, is more than three times as bright as an average star of the first magnitude.

238. The whole number of stars visible to the naked eye appears to be very great,—almost countless. There are, however, in the northern hemisphere only 2,400; and in both hemispheres, about 4,500. Viewed through the telescope, these numbers swell into millions.

239. The Constellations.—To facilitate the naming and location of the stars, the heavens are divided into particular spaces, represented on the globe or map as occupied by the figures of animals or other objects. These spaces and the groups of stars which they contain are called *Constellations*. Thus there are the constellations *Aries*, the Ram; *Leo*, the Lion; *Gemini*, the Twins, etc.

240. The general position of a star is defined by stating in what part of the figure it is situated; as, the *eye of the Bull*, *the heart of the Lion*, etc. Its exact position is, of course, only to be defined by its right ascension and declination, or longitude and latitude. This system of grouping the stars into constellations is supposed to be very ancient. Ptolemy counted only forty-eight constellations; but, since his time, the number has been augmented to 109.

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238. Number of the visible stars? 239. What are constellations? Give examples. 240. How is the position of a star defined? Antiquity of the system?

241. The most conspicuous stars of each constellation have particular names, as *Sir'ius*, *Arctu'rus*, *Reg'ulus*, etc.; but the most general designations are the letters of the Greek alphabet, α (*alpha*) being given to the brightest star, β (*beta*) to the next, and so on. When the twenty-four letters of this alphabet are exhausted, the Roman letters are used, and subsequently the Arabic numerals, the latter being applied according to the positions of the stars in the constellation, the most eastern being designated 1, which is thus the first star to cross the meridian.

The Greek Alphabet.—The following are the letters of the Greek alphabet, with their names. It will be convenient for the student to become familiar with them, as they are very frequently employed.

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

In the literal designations the letter is followed by the Latin name of the constellation, in the genitive or possessive case. Thus, α *Centauri* means the brightest star of Centaurus; β *Tauri*, the second star of Taurus; γ *Andromedæ*, the third star of Andromeda, etc.

242. The constellations are distinguished as Northern, Zodiacal, and Southern, according to their positions in the heavens with respect to the ecliptic. The zodiacal

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241. What stars have particular names? What is the general mode of designation? 242. How are the constellations distinguished? What is the situation of the zodiacal constellations? Why do they not correspond to the signs?

constellations have the same names as the signs, but are situated about 28° to the east of them, so that *Aries*, although the first sign of the ecliptic, is the second constellation of the zodiac. This is caused by the *Precession of the Equinoxes.*

243. Precession.—By precession is meant the gradual falling back of the equinoctial points from east to west. In other words, the sun, in his apparent annual revolution around the earth does not cross the equinoctial always at the same points, but at every revolution crosses a little to the west of where it crossed previously. The amount of precession is about 50 seconds every year, an entire revolution of the equinoxes requiring a period of nearly 26,000 years.

244. This movement of the equinoxes is the result of the spheroidal form of the earth. For since the excess of matter at the equator is situated out of the plane of the ecliptic, the attraction of the sun and moon acts obliquely upon it, and thus tends to draw the planes of the equinoctial and ecliptic together; which tendency, by

243. What is precession? What is its amount? 244. How is it caused? Explain by the diagram.

the rotation of the earth on its axis, is converted into a sliding movement, as it were, of one circle upon the other, both preserving very nearly the same inclination.

This is illustrated in the annexed diagram. The attraction of the sun acting obliquely upon the protuberance, or excess of matter, at E and E′, tends to draw it toward the plane of the ecliptic; and this it would finally accomplish were the earth's rotation suspended; so that the plane of the equator would be made to coincide with that of the ecliptic. But the effect is a sliding of the equator over the line of the ecliptic, and thus a change of the points of intersection.

245. Since the equator moves round on the ecliptic, the poles of the earth must revolve around those of the ecliptic, and consequently change their apparent position among the stars. Hence, the star which is now so near the north celestial pole will not always be the pole-star; but in about 13,000 years, that is, one-half the period of an entire revolution, will be 47° from it. The apparent places of all the stars undergo a constant change, for the same reason,—their right ascensions and declinations increasing or diminishing according to their situation.

246. *The following are the names of the principal constellations and of the brightest stars in each. The student should be familiarized with their situations by pointing them out on the globe or on a planisphere.*

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245. What change occurs in the position of the pole-star? In the apparent places of the stars? 246. What are the names of the principal Northern Constellations? Of the Zodiacal Constellations? Of the Southern Constellations? Name the principal stars in each. Name the constellations that are on the meridian nearly at the same time as each of the Zodiacal Constellations.

NORTHERN CONSTELLATIONS.

Name.	Meaning.	Brightest Stars.
Androm'eda	*The Chained Princess*	Alpheratz, Mirach, Almaach.
Aq'uila	*The Eagle*	Altair.
Auri'ga	*The Charioteer*	Capel'la.
Bo-o'tes	*The Bear Hunter*	Arctu'rus.
Ca'nes Venat'ici	*The Hunting Dogs.*	
Cassiope'ia	*The Queen in her Chair*	Sche'dar, Caph.
Ce'pheus	*The King*	Aldera'min.
Clyp'eus Sobies'kii	*Sobieski's Shield.*	
Coma bereni'ces	*Berenice's Hair.*	
Coro'na Borea'lis	*The Northern Crown*	Alphac'ca.
Cyg'nus	*The Swan*	Arided, Albir'eo.
Delphi'nus	*The Dolphin*	Svalocin.
Dra'co	*The Dragon*	Ras'taben.
Her'cules	*Hercules*	Ras Algethi.
Leo Minor	*The Lesser Lion.*	
Lyra	*The Harp*	Vega.
Peg'asus	*The Winged Horse*	Markab, Scheat.
Perseus et Caput Medu'sæ	*Perseus and Medusa's Head*	Al'genib, Algol.
Sagit'ta	*The Arrow.*	
Serpens	*The Serpent.*	
Taurus Poniatow'skii	*Poniatowski's Bull.*	
Trian'gulum	*The Triangle.*	
Ursa Major	*The Great Bear*	Dubhe, Merak, Alioth, Mizar.
Ursa Minor	*The Lesser Bear*	Polaris.
Vulpec'ula et Anser	*The Fox and the Goose.*	

ZODIACAL COMBINATIONS.

Aries	*The Ram*	Hamal (*a* Arietis).
Taurus	*The Bull*	Aldeb'aran, Alcy'one.
Gemini	*The Twins*	Castor, Pollux.
Cancer	*The Crab.*	

Name.	Meaning.	Bright Stars.
Leo	*The Lion*	Reg′ulus, Deneb′ola.
Virgo	*The Virgin*	Spica, Vindem′iatrix.
Libra	*The Balance*	Zuben el Genubi, Zuben el Chamali.
Scorpio	*The Scorpion*	Antares.
Sagittarius	*The Archer.*	
Capricornus	*The Goat.*	
Aquarius	*The Water-bearer.*	
Pisces	*The Fishes.*	

SOUTHERN CONSTELLATIONS.

Argo Navis	*The Ship Argo.*	
Canis Major	*The Great Dog*	Sir′ius.
Canis Minor	*The Lesser Dog*	Procy′on.
Centaurus	*The Centaur.*	
Cetus	*The Whale*	Menkar, Mira.
Corona Australis	*The Southern Crown.*	
Corvus	*The Crow*	Alchiba, Algorab.
Crater	*The Cup.*	
Crux	*The Cross.*	
Erid′anus	*The River Po*	Acher′nar.
Hydra	*The Water Serpent*	Alphard, or Cor Hydræ.
Lepus	*The Hare*	Arneb.
Lupus	*The Wolf.*	
Monoc′eros	*The Unicorn.*	
Ophiu′cus	*The Serpent Bearer*	Ras Alhagus.
Orion	*The Hunter*	Betelgeuse, Rigel, Bellatrix.
Phœnix	*The Phœnix.*	
Pis′ces Austra′lis	*The Southern Fish*	Fom′alhaut

TABLE SHOWING THE POSITIONS OF THE CONSTELLATIONS IN THE HEAVENS.

NOTE.—Each line in this table represents about 30° of right ascension.

NORTH DECLINATION.				SOUTH DECLINATION.	
90°—50°	50°—25°	25°—0°	ZODIAC.	0°—25°	25°—50°
Cassiopeia	Andromeda Triangulum		*Pisces* *Aries*	Cetus	Phœnix
	Perseus		*Taurus*	Lepus Orion	Eridanus Columba
	Auriga	Canis Minor	*Gemini*	Canis Major Monoceros	Argo
			Cancer		
Ursa Major	Leo Minor		*Leo*	Hydra Crater	
	Canes Ven.	Coma Ber.	*Virgo*	Corvus	Centaurus
Ursa Minor	Bootes Corona Bor.	Serpens	*Libra*		Lupus
Draco	Hercules	Taurus Pon.	*Scorpio*	Ophiuchus	
	Lyra	Sagitta Aquila	*Sagittarius*	Clyp. Sobiesk.	Corona Aus.
Cepheus	Cygnus	Delphinus Pegasus	*Capricornus* *Aquarius*		

Each column of this table contains the constellations as they are arranged from west to east; and each line read from *left* to *right*, gives the constellations, from north to south, that are on or near the meridian at the same time. By knowing the time that each zodiacal constellation comes to the meridian, remembering that these constellations are about 30° east of the signs, and that those are on the meridian at midnight which are opposite to the sun's place at noon, the student with a little consideration will be able to find the position of the constellations at any hour and on any evening during the year. The position at any time of the evening can easily be deduced from that at midnight by reckoning for each hour 15°, toward the east if the time is earlier, and toward the west, if later.

The following is a list of the most noted or conspicuous of the stars, with their names and situations:

LIST OF PRINCIPAL STARS.

Name.	Situation.	R. A.	Dec.
Sirius	Nose of the Great Dog	100°	$16\frac{1}{2}$° S.
Canopus	The Ship Argo	95°	$52\frac{1}{2}$° S.
Arcturus	Knee of Bootes	212°	20° N.
Betelgeuse	Shoulder of Orion	87°	$7\frac{1}{2}$° N.
Rigel	Foot of Orion	77°	$8\frac{1}{3}$° S.
Capella	Goat of Auriga	77°	46° N.
Vega	One of the strings of the Harp	278°	39° N.
Procyon	The Little Dog	113°	$5\frac{1}{2}$° N.
Achernar	The River Po	23°	58° S.
Aldebaran	Eye of the Bull	67°	$16\frac{1}{4}$° N.
Antares	Heart of the Scorpion	245°	26° S.
Altair	Neck of the Eagle	300°	$8\frac{1}{2}$° N.
Spica	Sheaf of Virgo	200°	$10\frac{1}{2}$° S.
Fomalhaut	Southern Fish	343°	$30\frac{1}{4}$° S.
Regulus	Heart of the Lion	150°	$12\frac{1}{2}$° N.
Deneb	Tail of the Swan	309°	45° N.
Alpheratz	Head of Andromeda	$\frac{1}{2}$°	$28\frac{1}{2}$° N.
Dubhe	Great Bear	164°	$62\frac{1}{2}$° N.
Castor	Heads of Gemini	112°	32° N.
Pollux	Heads of Gemini	114°	$28\frac{1}{4}$° N.
Pole-Star	Tail of the Little Bear	$18\frac{1}{2}$°	$88\frac{2}{3}$° N.
Alphard	Heart of Hydra	140°	8° S.
Ras Alhagus	Head of the Serpent-bearer	262°	$12\frac{1}{2}$° N.
Markab	Wing of Pegasus	345°	$14\frac{1}{2}$° N.
Scheat	Thigh of Pegasus	345°	$27\frac{1}{2}$° N.
Algenib	Wing of Pegasus	2°	$14\frac{1}{2}$° N.
Algol	Head of Medusa	45°	$40\frac{1}{2}$° N.
Denebola	Tail of the Lion	176°	15° N.
Alphecca	Northern Crown	232°	27° N.
Benetnasch	Tip of the Great Bear's Tail	206°	50° N.
Alderamin	Breast of Cepheus	318°	62° N.
Vindemiatrix	Right Arm of Virgo	194°	$11\frac{1}{2}$° N.
Cor Caroli	The Hunting Dogs	193°	39° N.
Alcyone	The Pleiades	55°	$23\frac{3}{4}$° N.

PROBLEMS FOR THE CELESTIAL GLOBE.

PROBLEM I.

To find the place of a constellation or star on the globe: Bring the degree of right ascension belonging to the constellation or star to the meridian; and under the proper degree of declination will be the constellation or star, the place of which is required.

NOTE.—The student should be exercised in finding the places of all the principal stars laid down in the list according to this rule. The place of a planet or comet may also be found by this rule when its right ascension and declination are given.

PROBLEM II.

To find the appearance of the heavens at any place, the hour of the day and the day of the month being given: Make the elevation of the pole equal to the latitude of the place; find the sun's place in the ecliptic, bring it to the meridian, and set the index to 12. If the time be before noon, turn the globe eastward; if after noon, turn it westward till the index has passed over as many hours as the time wants of noon, or is past noon. The surface of the globe above the wooden horizon will then show the appearance of the heavens for the time

NOTE.—The student must conceive himself situated at the centre of the globe looking out.

PROBLEM III.

To find the declination and right ascension of any constellation or star: Proceed in the same manner as to find the latitude and longitude of a place on the terrestrial globe.

247. The Galaxy, or Milky Way, is that faint luminous zone which encompasses the heavens, and which, when examined with a telescope, is found to consist of myriads of stars. Its general course is inclined to the equinoctial at an angle of 63°, and intersects it at about 105° and 285° of right ascension. Its inclination to the plane of the ecliptic is consequently about 40°. Its appearance is not uniform, some parts being exceedingly brilliant; while others present the appearance of dark patches, or regions comparatively destitute of stars.

The number of stars in the Milky Way is inconceivably great. Sir William Herschel states that on one occasion he calculated that 116,000 stars passed through the field of his telescope in a quarter of an hour, and on another that as many as 258,000 stars were seen to pass in 41 minutes. The total number, therefore, can only be estimated in millions.

248. The prevailing theory with regard to the Milky Way is, that it is an immense cluster of stars having the general form of a mill-stone, split at one side into two folds, or thicknesses, inclined at a small angle to each other; that all the stars visible to us belong to this system; and that the sun is a member of it and is situated not far from the middle of its thickness, and near the point of its separation.

The fact that the Milky Way is composed of vast numbers of stars was conjectured by Pythagoras and other ancient astronomers, but was not positively discovered till Galileo directed his telescope to the heavens. The hypothesis that it is a vast cluster

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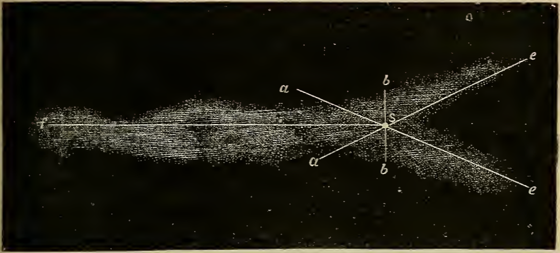
247. What is the galaxy or milky way? Its general course? Its appearance? The number of stars that compose it? 248. What is the prevailing theory in regard to it? History of the hypothesis?

of which the sun and visible stars are members was first suggested by Thomas Wright in a work entitled the "Theory of the Universe," published in 1750. This subject received a careful and prolonged investigation by Sir William Herschel, the results of which he published in 1784, and which seems to establish the hypothesis mentioned in the text. This opinion he arrived at by taking observations at different distances from the zone of the Galaxy, and counting the stars within the field of view. On the supposition that the stars are uniformly distributed throughout the system, the number thus presented would indicate the extent of the cluster in the direction in which they were seen; and in this manner some general idea of its form would be obtained.



SECTION OF THE GALACTIC STRATUM.

The annexed figure represents the general form of a section of this vast cluster, S being the position of the sun.

249. Proper Motion of the Stars.—The stars do not always remain precisely in the same places with respect to each other, but in long periods of time perceptibly change their relative positions, some approaching each other, and others receding. This apparent change of position is called their *proper motion.*

249. What is meant by the proper motion of the stars?

250. Herschel, finding that in one part of the heavens the stars are approaching each other, while in the opposite part their relative distances are increasing, arrived at the conclusion that the change in the position of the stars is caused by a motion of the solar system in space. For, evidently, if we are in motion, the stars toward which we are moving will open out, while those from which we are receding will appear to come together. Careful observations of this kind indicate that the system is moving toward a point in the constellation Hercules; and it is estimated that the velocity of the motion is about 160 millions of miles in a year. The central sun has been thought by some to be Alcyone, the principal star of the Pleiades.

251. Multiple Stars are those which to the naked eye appear single, but when viewed through a telescope are separated into two or more stars. Those that consist of two stars are called *double stars*. They differ very greatly in their distance from each other, their separation in some cases requiring the most powerful telescopes, while in others the slightest optical aid is sufficient. The members of double stars are generally quite unequal in size, and

1. POLE-STAR; 2. RIGEL; 3. CASTOR; 4. γ VIRGINIS.

250. What conclusion did Herschel arrive at? What does observation indicate? What star is supposed to be the central sun? 251. What are multiple stars? Double stars? How do they differ?

very often exhibit the beautiful phenomenon of different colors.

252. Binary Stars are double stars one of which revolves around the other, or both revolve around their common centre of gravity.

The discovery of this connection between the constituents of double stars was, perhaps, the grandest of Sir William Herschel's achievements. It was announced by him in 1803, after twenty-five years of patient observation, which he commenced with a view to discover the stellar parallax by noticing whether any *annual* change in the relative positions of double stars existed. To his astonishment, he found from year to year a regular progressive movement of some of these bodies, indicating that they actually revolve one round the other in regular orbits, and thus that the law of gravitation extends to the stars. These stars are called *Binary Stars*, or *Systems*, to distinguish them from other double stars which, although perhaps at immense distances from each other, appear in close proximity, because, as viewed from the earth, they are very nearly in the same visual line, and therefore are said to be *optically double*.

253. The observations of Herschel resulted in the discovery of about 50 binary stars; but since his time the number has been very greatly increased. Most of the double stars are believed to be binary systems. A very careful scrutiny of these bodies and their changes in position has shown that they revolve in elliptical orbits of considerable eccentricity and in periods greatly varying in length.

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252. What are binary stars? How discovered? 253. Their number? Their orbits?

254. Stars that appear double when viewed through a glass of low power are often separated by one of higher power into triple, quadruple, or other multiple stars.

θ ORIONIS. TRAPEZIUM OF ORION.

Thus, ε Lyræ, with very slight optical assistance, is resolved into two stars, each of which is a close double star; and θ Orionis (Theta of Orion) consists of four bright stars, two of which have companion stars, thus forming a *sextuple star.* From the configuration of the four principal stars, this is sometimes called the *Trapezium of Orion.*

255. Variable Stars are those which exhibit periodical changes of brightness. The number of such stars discovered up to the present time (1870) is about 120. They are sometimes called *Periodic Stars.*

One of the most remarkable of these stars, and the first noticed (by Fabricius in 1596), is Mira—*the wonderful*—in the Whale. It appears about 12 times in 11 years; remains at its greatest brightness about a fortnight, being equal to a star of the 2d magnitude; decreases for about 3 months, and then becomes invisible, remaining so 5 months, after which it recovers its brilliancy; the period of all its changes being about 331⅓ days.

Algol, in the Head of Medusa, is another remarkable variable star of a very short period, it being only 2d. 20h. 49m. It is commonly of the 2d magnitude, from which it descends to the 4th magnitude in about 3½ hours, and so remains about 20 minutes, after which, in

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254. Into what are some double stars separated by the telescope? Give examples.
255. What are variable stars? Their number? What are they sometimes called? What examples are given?

3½ hours, it returns to the 2d magnitude, and so continues 2d. 13h., when similar changes recur.

256. Cause of Variable Stars.—Several hypotheses have been suggested to account for these interesting phenomena. One is that these bodies rotate, and thus present sides differing in brightness, or obscured by spots similar to those which are seen on the solar disk; another, that their light is obscured by planets revolving around them; and a third, that their light is diminished by the interposition of nebulous masses, since it has been observed that during their minimum brightness they are often surrounded by a kind of cloud or mist. No one of these hypotheses is entirely satisfactory, and hence we must conclude that the true cause of the variability of these stars is unknown.

257. Temporary Stars are those which suddenly make their appearance in the heavens, sometimes shining with very great brilliancy; and, after a while, gradually fade away, either entirely disappearing or remaining as faint telescopic stars. The latter are properly called *New Stars.*

Several instances are on record in ancient times. The star of 1572 was a very remarkable one. It appeared first as a star of the first magnitude, blazing forth with the lustre of Venus, and visible even at noon. It lasted from November, 1572, to March, 1574. In 1604, a very splendid star shone forth in the constellation Ophiuchus, and lasted 15 months. Another in the same constellation appeared in 1848, which still remains as a telescopic star. Lastly, a new star was seen in May, 1866, in Corona Borealis. It first

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256. What is the cause of variable stars? 257. What are temporary stars? Mention some instances.

appeared of the second magnitude, and of a pure white color; but in a week had changed to the fourth, and soon after to the ninth.

258. Cause of Temporary Stars.—No satisfactory hypothesis has as yet been advanced to account for these phenomena. Some have supposed that these stars are revolving in elliptical orbits of great eccentricity so that they sometimes approach very near us and then recede to great distances; but this is rendered improbable by the sudden changes in brilliancy; since, to pass from the first to the second magnitude, it has been computed would require six years, if the star moved with the velocity of light; whereas, that of 1572 underwent this change in one month, and that of 1866 diminished to the extent of five magnitudes in the same time. Another hypothesis is, that extensive conflagrations take place on the surface of these bodies, which in their progress give rise to the observed changes in color and brightness, and at their extinction leave the body in an obscure state.

259. Numerous instances are on record of stars formerly known to exist which have entirely disappeared from the heavens. These are called *Lost* or *Missing Stars.*

Some of the instances mentioned by early astronomers, of lost stars, may be the result of erroneous entries; but those of later times cannot possibly be accounted for in this way. Revolving in orbits, they may have passed

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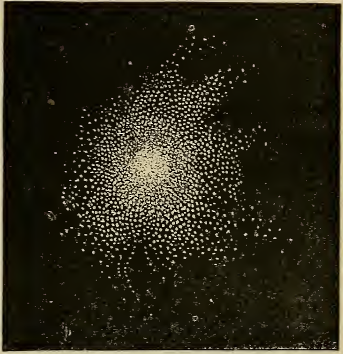
258. What is the supposed cause of them? 259. What are lost or missing stars? How accounted for?

beyond the reach of the most powerful telescope; or they be obscured by the interposition of great nebulous masses, and thus are only concealed for a certain period, which however may comprise hundreds, or even thousands of years.

260. Star Clusters.—These are dense masses of stars so crowded together, and so far distant, that they present a hazy, cloud-like appearance, similar to that of the Milky Way. Collections of stars visible as such to the naked eye, although considerably crowded, are called *Star-groups*. Such are the *Pleiades*, the *Hyades*, and the group which constitutes the constellation Berenice's Hair.



CLUSTER IN HERCULES.—*Sir J. Herschel.*

Among star-clusters, a very small number are sufficiently bright to be distinguished by the naked eye; but generally they require a telescope to render them visible.

The annexed cut represents a peculiarly magnificent object of this kind, situated between *Eta* and *Zeta* in the constellation Her-

260. What are star clusters? Star groups? Example?

cules. On a very clear night, it is visible to the naked eye as a small nebulous spot or faint star. In the telescope its appearance is considerably changed by several outlying branches, while its condensation at the central portions is quite a striking feature. Very many objects of a similar character are visible in different parts of the heavens.

261. The number of stars contained in these clusters is very great. According to Arago, many clusters contain at least 20,000 collected in a space the apparent dimensions of which are scarcely a tenth as large as the disk of the moon. The clusters are not equally distributed over the heavens, but are most numerous in the Milky Way; while globular clusters most abound in that region of the Galaxy which is contained between Lupus and Sagittarius in the southern hemisphere.

These globular clusters are supposed to be held together by their motions and mutual attractions. That there must be a real condensation is obvious from a simple glance at such an object as that depicted in the figure on page 159; since the increase of brightness toward the centre is far too great to be explained on the supposition that the stars are equally distributed, but appear closer together at the centre, because the visual line traverses there a much greater portion of the mass.

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261. What is the number of stars contained in these clusters? Their distribution?

SECTION X.

NEBULÆ.

262. **Nebulæ** are certain faintly luminous appearances in the heavens, resembling specks of cloud or mist, some just visible to the naked eye, but the greater part only to be discerned with a telescope. They resemble in their general apects the distant star-clusters, but their physical structure appears to be very different.

Their distance from us must be immense, since they constantly maintain very nearly the same situation with respect to each other and to the stars. Their magnitudes also must be inconceivably vast.

The first of these objects mentioned in the annals of astronomy was discovered in 1612, by Simon Marius, a German astronomer. This was the nebula situated in the girdle of Andromeda. In 1656, Huyghens discovered the great nebula in Orion. The labors of Sir William Herschel, directed to the investigation of this department of astronomy for more than twenty years, enabled him in 1802 to publish a catalogue of 2,500 nebulæ and clusters; and the subsequent researches of his son, Sir John Herschel, in the southern hemisphere, has increased this number to more than 5,000. Very great additions, however, have been made to our knowledge of these interesting objects by the labors of Lord Rosse, aided by the largest reflecting telescope ever constructed.

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262. What are nebulæ? Their distance from us? Example?

263. Nebulæ are distinguished from clusters by not being resolved into stars when viewed through the most powerful telescopes, presenting the appearance of diffuse luminous substances, filling vast regions of space, and differing in form, and degree of condensation.

Herschel at first thought all nebulæ resolvable into stars; but his subsequent investigations convinced him that this was an error; and he accordingly divided these objects into *resolvable* and *irresolvable nebulæ;* the first being those vast star-clusters which exhibit a nebulous, or cloudy aspect, because of their comparatively crowded condition and great distance from us; and the second, according to his conceptions, *immense aggregations of self-luminous matter*, of great tenuity, but gradually condensing into solid bodies like the sun and stars.

Many of the irresolvable nebulæ of Sir William Herschel having been resolved by the great telescope of Lord Rosse, or having given indications of being resolvable into stars, the opinion came to be almost universally entertained that *all nebulæ* are star-clusters, some so distant that light requires millions of years to pass from them to us. But the more recent researches by means of the analysis of light, have proved that these luminous masses consist of *gaseous* not *solid* matter; so that Herschel's hypothesis would seem to be established. These diffuse and attenuated substances constitute thus a peculiar class of objects in the starry heavens, and are the *nebulæ* defined in the text, although some astronomers still continue to classify them with the clusters which have a nebulous appearance.

264. Nebulæ may be divided, according to their form, into the following six classes: *Elliptic*, *Annular*, *Spiral*, *Planetary*, *Stellar*, and *Irregular Nebulæ.*

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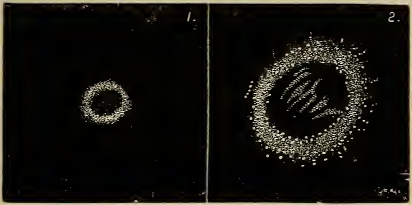
263. How are they distinguished from clusters? Herschel's hypotheses? What has been proved by recent researches? 264. How may nebulæ be divided?

265. Elliptic Nebulæ are such as have the elliptical or oval form. They are quite numerous, and of various degrees of eccentricity. The one already referred to in Andromeda is an example. There is another in the same constellation, near the star Gamma, which is represented in the annexed figure.

ELLIPTIC NEBULA IN ANDROMEDA.

266. Annular Nebulæ are such as have the form of a ring. These are very rare, the heavens affording only four examples.

The most remarkable one is found in Lyra, situated between the stars *Beta* and *Gamma*, and may be seen with a telescope of moderate power. It is slightly elliptical and has the appearance of a



ANNULAR NEBULA IN LYRA.—1. *Sir John Herschel;* 2. *Lord Rosse.*

flat oval ring, the opening occupying somewhat more than one-half of the diameter. The central portion, when viewed through a powerful telescope, is not altogether dark, but is crossed with faint

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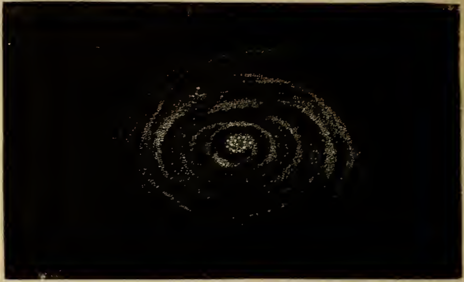
265. What are elliptic nebulæ? Examples? 266. What are annular nebulæ? Examples?

nebulous streaks, compared by some to gauze stretched over a hoop. The telescope of Lord Rosse shows fringes of stars at its inner and outer edges. The other annular nebulæ are two in Scorpio, and one in Cygnus.

267. Spiral Nebulæ are such as have the form of one or more spirals or coils; in some cases presenting the appearance of continuous convolutions, or whorls; in others, of great spiral arms or branches projecting from a central nucleus.



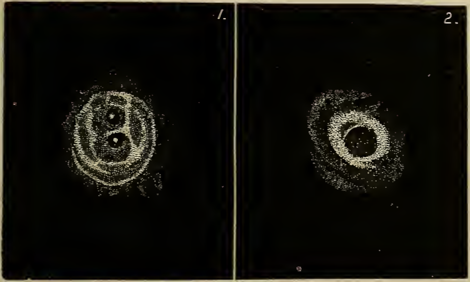
SPIRAL NEBULÆ IN LEO.—*Lord Rosse.*

The discovery of nebulæ of this remarkable form is due to Lord Rosse, no indication of it whatever having been afforded by the great telescope of Sir William Herschel. The grandest object of this kind is found in Canes Venatici. Brilliant spirals, unequal in size and brightness, and apparently overspread with a multitude of stars, diverge from the central nucleus, the whole suggesting the idea of a rotary movement of considerable rapidity, and the play of forces at which the imagination is startled when it contemplates the immensity of space filled by this wondrous object.

268. Planetary Nebulæ are those which, in their cir-

267. What are spiral nebulæ? By whom discovered? Example? 268. What are planetary nebulæ? Examples?

cular or slightly elliptical form, their pale and uniform light, and their definite outline, resemble the larger and more distant planets of our system.



PLANETARY NEBULÆ. 1, IN URSA MAJOR; 2, IN ANDROMEDA.

One of the most striking of this class is found in Ursa Major (near β), the light of which, in Sir John Herschel's drawing, is quite uniform; but when seen through Lord Rosse's telescope, it presents the appearance depicted in the annexed cut (No. 1). The disk is about 3′ in diameter, and exhibits a double luminous circle with two dark openings, each containing a bright but partially nebulous star. No. 2 in the same figure, represents a nebula near κ (*Kappa*) in Andromeda, which, though perfectly round in Herschel's drawing, appears in Lord Rosse's like a luminous ring surrounded by a wide nebulous border. In the illustration on page 166, 1 and 2 are representations of planetary nebulæ.

269. Stellar Nebulæ are those which appear to envelop one or more brilliant spots or points, resembling stars surrounded by a nebulous border or ring. Some of these are called *nebulous stars.* If the nebula is cir-

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269. What are stellar nebulæ? What are some of them called? Where is the star situated? Examples?

cular, the star occupies the centre of it; but some that are elliptical have two stars situated at the foci of the ellipse.

In the above cut, No. 5 represents a remarkable nebulous star in Cygnus. The star is of the 11th magnitude, and is at the centre of a perfectly circular nebula of uniform light, and about 15′ in diameter. No. 4 is a stellar nebula in Sobieski's Shield, of an elliptic form, and having two stars at the foci of the ellipse. These stars are described by Sir John Herschel as of a gray color. No. 3 is the representation of a nebula bearing a resemblance to a comet. It is found in the tail of Scorpio. There are several other instances of such nebulæ, which from their appearance are called *conical* or *cometary nebulæ*. In the case of each, the stellar or bright point is at one extremity of the nebulous mass.

270. Irregular Nebulæ are such as have no symmetry of form and scarcely any distinctness of outline, and are also remarkable for the diversity of brightness which they exhibit at different parts.

Arago remarks of these diffuse masses of nebulous matter, that "they present all the fantastic figures which characterize clouds carried away and tossed about by violent and often contrary winds." The most remarkable of these objects are the following:

1. *The Crab Nebula in Taurus.*—This singular object has an elliptic outline in ordinary telescopes, but in Lord Rosse's great reflector it presents an appearance which has been fancifully likened to a crab or lobster with long claws.

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270. What are irregular nebulæ? What examples are given?

2. *The Great Nebula in Orion.*—This is probably the most magnificent of all the nebulæ. It is very irregular in form; of immense extent, covering a surface more than 40′ square; and consists of patches varying considerably in brightness. Near the famous sex-

CRAB NEBULA IN TAURUS.—*Lord Rosse.*

tuple star θ Orionis, already described, it is very brilliant; but other portions are quite dim, and some absolutely black. It was thought that portions of this nebula had been resolved into stars by the telescopes of Lord Rosse and Prof. Bond; but recent observations have proved conclusively the gaseous nature of this object.

3. *The Great Nebula in Argo.*—This is another very irregular and extensive nebula, covering a space equal to five times the disk of the moon. It contains a singular vacancy of an irregular oval form near the centre, and not very far from the variable star *Eta*. "It is not easy," says Sir J. Herschel, "to convey a full impression

of the beauty and sublimity of the spectacle which this nebula offers as it enters the field of the telescope, ushered in as it is by so glorious a procession of stars, to which it forms a sort of climax." This nebula is remarkably destitute of any indications of resolvability.

DUMB-BELL NEBULA.—*Herschel.*

4. *The Dumb-bell Nebula.*— This object is found in Vulpecula, and derives its name from its singular appearance as viewed through a telescope of moderate power. In Lord Rosse's telescope it assumes a form of less regularity, and appears to consist of innumerable stars mixed with a mass of nebulous matter. These may be only centres of condensation.

5. *The Magellanic Clouds.*—These are situated in the southern hemisphere and not far from the pole, and are called sometimes *Nubecula Major and Minor*, or the *Greater and Lesser Cloudlets.* The former is in Dorado; the latter in Toucan. These objects are distinguished for their great extent, the larger one covering a space of about 42 square degrees, and the smaller being of about one-fourth that extent, but of greater brightness.

DOUBLE NEBULA.—*Lord Rosse.*

271. Double Nebulæ are those which indicate by their close proximity to each other that they have a physical connection. More than 50 of such objects have been discovered, the component nebulæ of which are not more than 5′ apart.

The annexed cut represents an object of this kind, found in Gemini. It is composed of two rounded masses, terminated by brilliant appendages and enveloped in a nebulous mass, the whole surrounded by light luminous arcs resembling fragments of a nebulous ring.

272. Variable Nebulæ are those which undergo changes in apparent form and brightness.

Several instances of such changes have been positively ascertained by Struve, D'Arrest, Hind, and other distinguished astronomers. The great nebulæ in Orion and Argo have exhibited undoubted variations of a marked character.

273. Structure of the Universe.—The universe has been supposed, by many modern astronomers, to consist of an infinite number of star-clusters similar to the galaxy, and situated at inconceivably immense distances from it and from each other. In view, however, of the recent discoveries as to the nature of the nebulæ proper, this hypothesis cannot be considered as established ; and the true structure of the universe remains a problem to be solved.

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271. What are double nebulæ? Their number? Describe the one in Gemini. 272. What are variable nebulæ? What instances are mentioned? 273. What is said of the structure of the universe?

SECTION XI.

TIME.

274. The apparent motions of the sun and stars, caused by the real motions of the earth, afford standards for the measurement of time. The time which elapses between a star's leaving the meridian of a place until it returns to it again is called a *sidereal day.*

This is the time of one complete revolution of the celestial sphere, and is the exact period of one rotation of the earth on its axis. It is an absolutely uniform standard, having undergone not the slightest appreciable change from the date of the earliest recorded observations. Indeed, it is the only absolutely uniform motion observed in the heavens.

275. A Solar Day is the period which elapses from the sun's leaving the meridian of a place until it returns to it again.

As the sun is constantly changing its place among the stars, owing to the annual revolution of the earth, this period must be longer than a sidereal day; for the sun having moved toward the east during the time of a rotation, the earth must turn farther in order to bring the place again into the same relative position with the sun. This will be understood by examining the annexed diagram.

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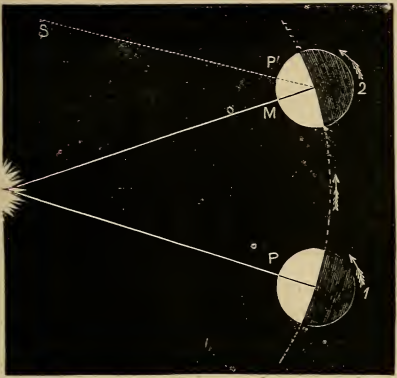
274. What afford standards for measuring time? What is a sidereal day? 275. What is a solar day? Why longer than a sidereal day? Explain from the diagram.

Let 1 represent the earth in one position of its orbit, and 2 the position to which it advances during one day; P, the place at



which the sun is on the meridian at 1; P′, the same place after one complete rotation, as shown by the parallel P′ S. It will be evident that, in order to bring P′ under the meridian, so that the sun may appear to cross it, the earth will have to turn a space represented by the arc P′ M, which will make the solar day so much longer than the sidereal day.

276. The solar day exceeds the sidereal day by an average difference of four minutes; but, owing to the variable motion of the earth in its orbit and the obliquity of the ecliptic, this difference is not the same throughout the year; and, consequently, the solar days are of unequal length.

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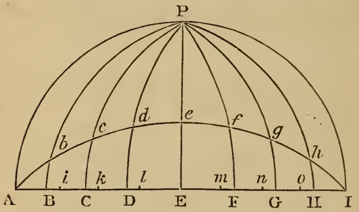
276. How much longer are the solar days than the sidereal days? Why are the solar days unequal?

Why the Solar Days are Unequal.—That the variable motion of the earth in its orbit should produce this effect will be obvious from an inspection of the preceding diagram; since it will be at once apparent that the length of the arc P′ M must depend upon the length of the interval between 1 and 2. If these intervals vary, the arcs which represent the excess over a rotation turned by the earth in order to bring the sun on the meridian, must also vary, and in the same proportion. Hence, they must be longest when the earth is in perihelion, and shortest when it is in aphelion.



The second cause, namely, the obliquity of the ecliptic, may be explained by the annexed diagram:—Let A P I represent the northern hemisphere, A E I the equinoctial, and A *e* I the ecliptic. Let the ecliptic be divided into equal portions, A *b*, *b c*, *c d*, etc., and draw meridians through the points of division, intersecting the equinoctial in B, C, D, etc. The divisions of the ecliptic will be equal arcs of longitude, and the divisions of the equinoctial will be the corresponding arcs of right ascension, and hence passed over by the sun in equal periods of time. These arcs of right ascension, it will be apparent, are not equal; for A *b*, which is oblique to A B, must subtend a smaller arc, A B, than *d e* which is nearly parallel to its arc D E. Thus the arcs of right ascension are shortest at the equinoxes, and longest at the solstices; while the divisions coincide at all these four points.

277. A Mean Solar Day is the average of all the solar days throughout the year. It is divided into twenty-four hours, and commences when the sun is on

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277. What is a mean solar day? A civil day?

the lower meridian, that is, at midnight. Because used for the general purposes of civil and social life, it is also called the *civil day.* Clocks are regulated to show its beginning and end, and the equal division of it into hours, minutes, and seconds. As already stated, it is four minutes longer than a sidereal day.

278. The Equation of Time is the difference between apparent and mean time; that is, the difference between time as shown by the sun, and that shown by a well-regulated clock.

If the solar days were equal in length, the sun would always be on the meridian at 12 o'clock; that is, *apparent noon* would coincide with *mean noon*—the noon of the clock. But this is not the case, and therefore to make the observed noon, as indicated by the sun, correspond with the noon of the clock, a correction has generally to be made, either by adding or subtracting a certain amount of time. This is what is meant by the equation of time.

The unequal motion of the earth in its orbit causes the sun to be in advance of the clock from aphelion to perihelion, that is, from July 1st to January 1st; and behind it from January 1st to July 1st; while they both coincide at those points. The obliquity of the ecliptic causes the sun to be in advance of the clock from Aries to Cancer, behind it from Cancer to Libra, in advance again from Libra to Capricorn, and behind again from Capricorn to Aries; and makes them both agree at those four points. When these two causes act together, as is the case in the first three months and the last three months of the year, the equation of time is the greatest.

279. The equation of time is greatest in the beginning of November, the sun being then about $16\frac{1}{4}$ minutes in advance of the clock. Mean and apparent time coincide

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278. What is the equation of time? How caused? 279. When is it greatest? When nothing?

four times a year, namely: April 15th, June 15th, September 1st, and December 24th. The equation of time then becomes nothing.

280. A Sidereal Year is the period of time that elapses from the sun's leaving any star until it returns to the same again.

This is the true period of the annual revolution of the earth, and is equal to 365 days, 6 hours, 9 minutes, 9 seconds. Owing, however, to the precession of the equinoxes, the sun advances through all the signs, from either equinox to the same again, in a shorter period.

281. A Tropical Year is the period that elapses from the sun's leaving the vernal equinox until it arrives at it again. It is 20 min. 20 sec. shorter than the sidereal year.

Its length is, therefore, 365d. 5h. 48m. 49s. which is the civil year, or the year of the calendar, deducting the 5h. 48m. 49s.; and as this is very nearly one-fourth of a day, one day is added every fourth year, which makes what is called leap year, or bissextile. The tropical year is sometimes called an *equinoctial* or *solar year.*

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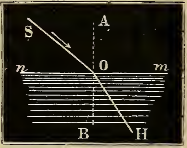
280. What is a sidereal year? 281. A tropical year? Its length?

SECTION XII.

REFRACTION.

282. The observed places of the heavenly bodies are not always the true places; for the rays of light when passing obliquely through the earth's atmosphere undergo a change of direction, called *Refraction.*

283. It is a general fact that the rays of light when passing *obliquely* from one medium into another of a different density, are turned from their course and made to pass more obliquely if the medium which they enter is rarer, and less obliquely if it is denser than that which they leave. Thus, in passing from air into water, or from water into glass, the direction would be less oblique; but in passing from water into air, more oblique.

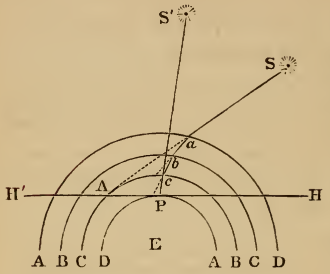


Suppose *n m* to represent the surface of water, and S O a ray of light, entering the water at O. Instead of keeping on in the direction S O, it is bent toward the perpendicular A B, and thus passes less obliquely.

284. As the earth's atmosphere is not of uniform density, but grows more and more dense toward the sur-

282. Why are not the observed places of the heavenly bodies always the true places? What is refraction? 283. What is the general fact? 284. How are the rays of light bent in passing through the atmosphere? Explain from the diagram.

face of the earth, the rays of light which proceed from any body are constantly bent more and more toward a perpendicular direction; and since we see an object in the direction in which the ray of light strikes the eye, the apparent altitude of the body will be increased.



Suppose E to represent the earth, and A B C D, portions or strata of the atmosphere of different densities, P the place of observation. Suppose a ray of light from the star S strike the atmosphere at *a*; on account of refraction, instead of proceeding in the direction S A, it describes *a b*, *b c*, and *c* P, reaching the spectator at P, and in the direction of *c* P; so that the star appears in that direction at S′, and is thus elevated above its true position at S. As the atmosphere does not consist of distinct strata, as represented, but diminishes uniformly in density from the surface of the earth, the broken line *a b c* P is in reality a curve, and the line S′ P a tangent to it at the point P.

285. The effect of refraction is greatest upon a body when it is in the horizon, and diminishes toward the zenith, where it is nothing. At the horizon, it amounts to about 33 minutes.

286. There is no refraction at the zenith, because at that point every ray of light strikes the atmosphere per-

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285. When is the refraction greatest? When is it nothing? What is its amount at the horizon? 286. Why is there no refraction at the zenith?

pendicularly, and refraction only takes place when the direction of the rays is oblique; at the horizon, they are more oblique than they can be at any point above it; hence the refraction is greatest there.

287. At the horizon, the amount of refraction is somewhat greater than the apparent diameter of the sun or moon; and hence these bodies appear to be above the horizon when they are actually below it.

288. The times of the rising of all the heavenly bodies are, therefore, accelerated, and those of their setting retarded, by refraction; each one appears to be above the horizon before it has actually risen, and is seen above the horizon after it has actually set.

Refraction very rapidly diminishes from the horizon towards the zenith. At the horizon its mean value is 33′; at 10° of altitude, $15\frac{1}{4}'$; at 30°, $1\frac{1}{2}'$; at 45°, 57″; at 80°, 10″; at 90°, 0.

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288. What is the effect of refraction upon the sun and moon at rising and setting? 289. Upon the rising and setting of other bodies?

SECTION XIII.

PARALLAX.

289. The apparent position of a heavenly body is also affected by a change of place of the observer. Thus, the moon if viewed from one point of the earth's surface appears in a somewhat different position than it would if seen from another point at a considerable distance from the first; its true position being that at which it would appear if viewed from the centre of the earth. This gives rise to what is called *Parallax.*

290. Parallax may be defined as the difference between the observed place of a heavenly body and its position if viewed from the centre of the earth or the centre of its orbit. Hence parallax is either *Diurnal* or *Annual.*

291. The Diurnal Parallax of a body is the difference between its altitude as seen at the surface of the earth and that which it would have if viewed from the centre.

In the diagram, let the small circle represent the earth, having its centre at E; A, B, and C, a body as seen at different altitudes from the place P; E H, the plane of the rational horizon; P h, the plane of the sensible horizon, and E Z, the direction of the

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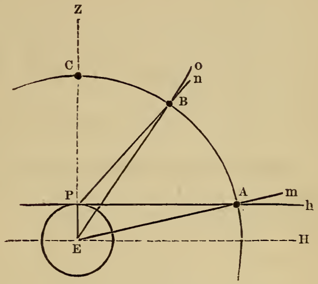
289. What else affects the apparent place of the heavenly bodies? What is the change called? 290. How may parallax be defined? Of how may kinds is it? 291. What is diurnal parallax?

zenith. At A, the body being in the sensible horizon, its apparent altitude will be nothing; but if viewed from E, it would appear to be above the horizon a distance equal to the angle m E H, or its equal m A h, since the difference in direction between the lines E H or P h, and E m, is the difference between the apparent and true altitude. At B, there is evidently a less difference of direction between the lines P n and E o, and when the body is at C, the centre of the earth, the place of the observer, and the position of the body being all on the same straight line, the true is the same as the apparent altitude.



292. It is evident that the apparent altitude is always less than the true altitude, except when the body is seen in the zenith; and that there is the greatest difference when the body is in the horizon. The effect of parallax is, therefore, to diminish the altitude of a body.

293. The parallax of a body is greatest when it is in the horizon, and diminishes towards the zenith, where it is nothing. The parallax of a body when in the horizon is called its *Horizontal Parallax.*

In the preceding diagram, the angle m A h, or its equal P A E, is called the *angle of parallax;* o B n, or P B E, is the angle of

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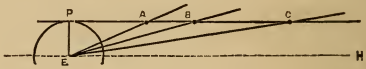
292. How does it affect the altitude? 293. When is the parallax greatest? When nothing?

parallax for the position B. The *angular* distance of the sensible and rational horizons is, of course, the horizontal parallax.

294. The greater the distance of a body from the earth, the smaller is the angle of parallax. Thus, the horizontal parallax of the moon is nearly 1°, while that of the sun is less than 9″. When the parallax of a body is known, its distance from the earth can be determined.

That the parallax diminishes as the distance of a body from the earth increases will be understood by examining the accompanying diagram. The horizontal parallax of a body at A is A E H or



P A E; but at B, it is the smaller angle B E H, or P B E. The horizontal parallax of any body is really the angle subtended by the semi-diameter of the earth at the distance of the body; and, of course, the greater the distance, the smaller the angle.

295. Annual Parallax is the change which would take place in the position of a star, if it could be viewed from the centre of the orbit instead of the orbit itself.

The usual method of finding the parallax of a body by viewing it at different parts of the earth's surface is entirely useless in the case of the stars, as the displacement thus occasioned in the positions of any of them is utterly inappreciable; the radius of the earth at a distance so immense being practically but a mathematical point. If, however, we view the same star at intervals of six months, our stations of observation will be about 180 millions of

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294. How does it depend upon the distance of a body? What is the parallax of the moon? Of the sun? What can be determined by means of the parallax? 295. What is annual parallax? Why applied to the stars?

miles apart; and the amount of displacement thus occasioned, when reduced to the centre of the orbit, is what is meant by the *annual parallax.*

296. The greatest parallax yet discovered in the case of any star is somewhat less than 1″, so that the earth's orbit is but little more than a mere point at the nearest star. The parallaxes of twelve stars have been determined with considerable precision, the smallest being less than $\frac{1}{20}$ of a single second.

The following list contains all the stars whose parallax has been found:

NAME.	PARALLAX.	NAME.	PARALLAX.
	″		″
α Centauri,	0.9187	α Lyræ,	0.155
61 Cygni,	0.5638	Sirius,	0.150
21258 Lalande,	0.2709	ι Ursæ Majoris,	0.133
17415 Oeltzen,	.247	Arcturus,	0.127
1830 Groombridge,	.226	Polaris,	0.067
70 Ophiuchi,	.16	Capella,	0.046

296. What is the greatest parallax of a star? The least discovered? Of how many stars has the parallax been discovered?

INDEX OF ASTRONOMICAL TERMS.

[This index will be useful for *Review*, as well as *Reference*. The definitions, which are very brief, may also be committed to memory in connection with the Text.]

A'erolite.—(Greek, *aer*, the air, and *lithos*, a stone.) A meteoric stone.

Almacan'tars.—(Arabic.) Parallels of altitude.

Altitude.—(Latin, *altitudo*, height.) The distance of a body above the horizon.

Amplitude.—(Latin, *amplitudo*, largeness.) The distance of the sun at its rising or setting from the east or west point of the horizon.

An'nular.—(Latin, *annulus*, a ring.) A term applied to an eclipse in which the sun's disk looks like a ring.

Antarc'tic.—(Greek, *anti*, against, and *arctos*, a bear.) The circle on the other side of the heavens from the Constellation of the Bear.

Antip'odes.—(Greek, *anti*, against, and *podes*, feet.) Those inhabitants of the earth who live on exactly opposite sides of the earth, or feet to feet.

Antœci.—(*an-te'si*,) (Greek, *anti*, against, and *oikos*, a house.) Those who live under the same meridian, but on opposite sides of the equator and at equal distances from it.

Aphe'lion.—(Greek, *apo* or *aph*, from or away, and *hēlios*, the sun.) The point of the planet's orbit farthest from the sun.

Ap'ogee.—(Greek, *apo* and *ge*, the earth.) The point of the moon's orbit farthest from the earth.

Ap'si-des.—Plural of *Apsis*.

Apsis.—(Greek, *apsis*, a joining.) The apsis line is the line which joins the aphelion and perihelion of a planet's orbit.

Arc'tic.—(Greek, *arktos*, a bear.) Near the Constellation of the Bear.

As'teroid.—(Greek, *aster*, a star, and *oid*, like.) A small planet which resembles in appearance a faint star.

Astronomy.—(Greek, *aster*, a star, and *nomos*, a law.) The science of the heavenly bodies.

Atmosphere.—(Greek, *atmos*, vapor, and *sphæra*, a sphere.) The body of air, vapor, etc., which encompasses the earth and some of the other planets.

Axis, plural *Axes.*—(Latin, *axis*, an axle.) The imaginary line on which the earth turns.

Az'imuth.—(Arabic.) The distance of a body from the north or south point of the horizon.

Bi'nary.—(Latin, *bini*, two by two.) A term applied to systems of double stars.

Card'inal.—(Latin, *cardo*, a hinge.) The term applied to the four principal points of the horizon.

Centrif'ugal.—(Latin, *centrum*, the centre, and *fugio*, to flee.) The centrifugal force is that by which a body recedes from the centre of motion.

Centrip'etal.—(Latin, *centrum*, and *peto*, to seek.) The centripetal force is that by which a body is drawn toward the centre of motion.

Comet.—(Latin, *coma*, hair.) A comet is so called because it is surrounded by a nebulous appearance resembling hair.

Concentric.—(Latin, *con*, together, and *centrum*.) Applied to circles drawn around the same centre.

Conjunction.—(Latin, *con*, together, and *jungo*, to join.) The apparent meeting of a planet with the sun.

Constellation.—(Latin, *con*, and *stella*, a star.) A group of stars.

Cra'ter.—(Latin, *crater*, a cup.) A term applied to some of the mountains in the moon.

Crepus'culum.—(Latin.) Twilight.

Culminate.—(Latin, *culmen*, the top.) To pass the meridian, because then a body arrives at its greatest altitude.

Diameter.—(Greek, *dia*, through, and *metron*, a measure.) The line which measures through a circle or sphere.

Digit.—(Latin, *digitus*, a finger.) One of the twelve equal divisions of the diameter of the sun's or moon's disk.

Disk.—(Latin, *discus*, a quoit.) The circular illuminated surface presented by a heavenly body.

Eccentricity.—(Greek, *ec*, from, and *centron*, a centre.) Distance or departure from the centre.

Eclipse.—(Greek, *ecleipsis*, a fainting away.) The obscuration of the disk of the sun or moon.

Ecliptic.—(From *eclipse.*) The great circle in which the sun appears to move ; so called, because eclipses only take place when the moon is in or near its plane.

Elongation.—(Latin, *e*, out, and *longus*, long.) The apparent departure of a planet from the sun.

Equator.—(Latin, *equo*, to divide equally.) The great circle which divides the earth into northern and southern hemispheres.

Equinoctial.—(Latin, *equus*, equal, and *noctes*, nights.) A great circle in the heavens ; so called, because, when the sun is in it, every place on the earth's surface has equal days and nights.

Focus, plural *Foci.*—(Latin, *focus*, a fire-place.) Applied to the two points round which an ellipse is drawn. The sun is situated at the lower focus of every planetary orbit.

Gal'axy.—(Greek, *galaxias*, the milky-way.) The cloudy zone which encompasses the heavens, consisting of vast numbers of stars. (Latin, *Via Lactea.*)

Geocen'tric.—(Greek, *ge*, the earth, and *centron*, a centre.) Seen from the earth as a centre.

Gib'bous.—(Latin, *gibbus*, convex.) Applied to the partial disk of the moon when more than half is visible.

Heliocen'tric.—(Greek, *helios*, the sun, and *centron*, the centre.) Seen from the sun as a centre.

Hori'zon.—(Greek, *horizo*, to bound.) The circle in the heavens which bounds our view.

Libration.—(Latin, *libratio*, a balancing.) An apparent vibratory motion of the moon from side to side, or pole to pole, by which we are enabled to see glimpses of the hemisphere turned from us.

Lunar.—(Latin, *luna*, the moon.) Pertaining to the moon.

Meridian.—(Latin, *meridies*, mid-day.) The circle at which the sun arrives at noon each day.

Me'teor.—(Greek, *meteora*, things in the air.) A small luminous body which shoots like a star from the sky.

Na'dir.—(Arabic, *nazeer*, opposite.) The point opposite the zenith.

Neb'ula.—(Latin, *nebula*, a little cloud.) A faintly luminous appearance in the heavens resembling a speck of cloud or mist. (Plural *nebulæ.*)

Node.—(Latin, *nodus*, a knot.) The nodes are the points at which a planet's orbit crosses the plane of the ecliptic.

Nu'cleus.—(Latin, *nucleus*, a kernel.) The bright and seemingly solid part of a comet.

Nutation.—(Latin, *nutatio*, a nodding.) A vibratory motion of the earth's axis.

Occultation.—(Latin, *occultatio*, a hiding.) The concealment of a star or planet by the interposition of the moon. Applied also to Jupiter's satellites when concealed by their primary.

Octant.—(Latin, *octo*, eight.) The eighth part of a circle.

Orbit.—(Latin, *orbis*, a circle.) The path of a heavenly body.

Par'allax.—(Greek, *parallaxis*, change.) The difference in the apparent position of a heavenly body, occasioned by a change of place in the observer.

Penum'bra.—(Latin, *pene*, almost, and *umbra*, a shadow.) The partial interception of the sun's rays on each side of the *umbra*, or total shadow of the earth or moon.

Per'igee.—(Greek, *peri*, near, and *ge*, the earth.) The point of the moon's orbit nearest the earth.

Perihe'lion.—(Greek, *peri*, near, and *helios*, the sun.) The point of a planet's orbit nearest the sun.

Periœ'ci.—(Greek, *peri*, around, and *oikeo*, to dwell.) Those who dwell under the same parallel of latitude, but under opposite meridians; so that when it is day to one, it is night to the other.

Phase.—(Greek, *phasis*, an appearance.) The portion of a heavenly body's disk visible at any time.

Planet.—(Greek, *planetes*, a wanderer.) The planets are so called because they constantly change their places among the stars.

Precession.—(Latin, *pre*, before, and *cessio*, a going.) Applied to the shifting of the equinoxes because they go, as it were, to meet the sun.

Quadrant.—(Latin, *quadrans*, the fourth part.) The fourth part of a circle.

Quadrature.—(Latin, *quadra*, a square.) The position of a planet when it is 90° from the sun.

Quar'tile.—(Latin, *quartus*, fourth.) The aspect of two planets 90° from each other.

Radius.—(Latin, *radius*, a ray.) Plural, *radii*. Lines drawn from the centre of a circle to the circumference, as *rays* proceed from the sun.

Radius-vec'tor.—(Latin, *radius*, and *vector*, that which carries.) The line which connects the sun and a planet, and which may be conceived as carrying the latter, as it sweeps over the plane of the orbit.

Refraction.—(Latin, *refractio*, a breaking.) The deviation of a ray of light from a straight line.

Retrograde.—(Latin, *retro*, backward, and *gradior*, to go.) An apparent backward motion of the planets; that is, a motion from east to west.

Sat'ellite.—(Latin, *satelles*, a guard.) An attendant body of a primary planet.

Secondary.—(Latin, *secundus*, second.) Applied to planets revolving around other planets; also, to great circles perpendicular to other great circles.

Sextant.—(Latin, *sextus*, sixth.) The sixth part of a circle.

Sextile.—(Latin, *sextilis*, the sixth.) The aspect of two planets 60 degrees, or the sixth of a circle, from each other.

Side'real.—(Latin, *sidus*, a star.) Pertaining to the stars.

Solar.—(Latin, *sol*, the sun.) Pertaining to the sun.

Solstice.—(Latin, *sol*, and *sto*, to stand.) The point of the ecliptic at which the sun appears to stand in respect to declination and meridian altitude.

Spheroid.—(Greek, *sphaira*, a sphere, and *oid*, like.) A solid that resembles a sphere.

Stellar.—(Latin, *stella*, a star.) Pertaining to the stars.

APPENDIX.

TABLE I.—ELEMENTS OF THE SOLAR SYSTEM.

NAME.	Sign.	Mean Diameter.	Oblateness.	Mass, ⊕ being 1.	Density compared with water.	Mean Distance in Millions.	Eccentricity of Orbit.	Inclination of Orbit.	Sidereal Period.		Synodic Period.	Time of Rotation.	Inclination of Axis.
									yrs.	dys.	dys.		
SUN	☉	852,900		315,000	1.42							25d. 8h.	7° 20′
MERCURY...	☿	2,962	?	.065	6.35	35.4	.205	7°		88	116	24h. 5m.	?
VENUS	♀	7,510	?	.885	5.84	66.15	.0039	$3\frac{1}{2}$°		$224\frac{2}{3}$	$584\frac{1}{2}$	23h. 21m.	75°
EARTH......	⊕	7,912	$\frac{1}{299}$	1.	5.67	91.5	.017			$365\frac{1}{4}$		24h.	23° 28′
MARS	♂	4,300	$\frac{1}{50}$	.118	3.97	139.3	.093	1° 51′	1	322	780	24h. 37m.	28° 42′
JUPITER....	♃	85,000	$\frac{1}{17}$	301.	1.37	475.75	.048	1° 19′	11	315	399	9h. $55\frac{1}{2}$m.	3° 6′
SATURN	♄	70,100	$\frac{1}{10}$	90.	.74	872.	.056	2° 30′	29	167	378	10h. 29m.	26° 49′
URANUS.....	♅	33,247	$\frac{1}{10}$	12.65	.97	1,754.	.047	$46\frac{1}{2}$′	81	6	$369\frac{1}{2}$	?	?
NEPTUNE...	♆	36,806	?	16.8	.91	2,746,	.0087	1° 47′	164	226	$367\frac{1}{2}$	?	?
MOON.......	●	2,162		$\frac{1}{80}$	3.4	.2388	.055	$5\frac{1}{7}$°		$27\frac{1}{3}$	$29\frac{1}{2}$	$27\frac{1}{3}$d.	6° 39′

TABLE II.—ASTEROIDS, OR MINOR PLANETS.

NAME.	DATE OF DISCOVERY.	NAME.	DATE OF DISCOVERY.
1 Ceres	1801	42 Isis	1856
2 Pallas	1802	43 Ariadne	1857
3 Juno	1804	44 Nysa	1857
4 Vesta	1807	45 Eugenia	1857
5 Astræa	1845	46 Hestia	1857
6 Hebe	1847	47 Melete	1857
7 Iris	1847	48 Aglaia	1857
8 Flora	1847	49 Doris	1857
9 Metis	1848	50 Pales	1857
10 Hygeia	1849	51 Virginia	1857
11 Parthenope	1850	52 Nemausa	1858
12 Victoria	1850	53 Europa	1858
13 Egeria	1850	54 Calypso	1858
14 Irene	1851	55 Alexandra	1858
15 Eunomia	1851	56 Pandora	1858
16 Psyche	1852	57 Mnemosyne	1859
17 Thetis	1852	58 Concordia	1860
18 Melpomene	1852	59 Danaë	1860
19 Fortuna	1852	60 Olympia	1860
20 Massilia	1852	61 Erato	1860
21 Lutetia	1852	62 Echo	1860
22 Calliope	1852	63 Ausonia	1861
23 Thalia	1852	64 Angelina	1861
24 Themis	1853	65 Cybele	1861
25 Phocea	1853	66 Maia	1861
26 Proserpine	1853	67 Asia	1861
27 Euterpe	1853	68 Hesperia	1861
28 Bellona	1854	69 Leto	1861
29 Amphitrite	1854	70 Panopea	1861
30 Urania	1854	71 Feronia	1861
31 Euphrosyne	1854	72 Niobe	1861
32 Pomona	1854	73 Clytie	1862
33 Polyhymnia	1854	74 Galatea	1862
34 Circe	1855	75 Eurydice	1862
35 Leucothea	1855	76 Freia	1862
36 Atalanta	1855	77 Frigga	1862
37 Fides	1855	78 Diana	1863
38 Leda	1856	79 Eurynome	1863
39 Lætitia	1856	80 Sappho	1864
40 Harmonia	1856	81 Terpsichore	1864
41 Daphne	1856	82 Alcmene	1864

TABLE II.—*Continued.*

NAME.	DATE OF DISCOVERY.	NAME.	DATE OF DISCOVERY.
83 Beatrix	1865	98 Ianthe	1868
84 Clio	1865	99 Dike	1868
85 Io	1865	100 Hecate	1868
86 Semele	1866	101 Helena	1868
87 Sylvia	1866	102 Miriam	1868
88 Thisbe	1866	103 Hera	1868
89 Julia	1866	104 Clymene	1868
90 Antiope	1866	105 Artemis	1868
91 Ægina	1866	106 Dione	1868
92 Undina	1867	107 Camilla	1869
93 Minerva	1867	108 Hecuba	1869
94 Aurora	1867	109 Felicitas	1869
95 Arethusa	1867	110 Lydia	1869
96 Ægle	1868	111 Iphigenia	1870
97 Clotho	1868	112	1870