AN

ELEMENTARY CLASS BOOK

ON

ASTRONOMY:

IN WHICH

MATHEMATICAL DEMONSTRATIONS ARE OMITTED.

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PREFACE.

Every one strives to adapt means to ends, and when the author prepared his large work on Astronomy, he had no other end in view than to teach Astronomy to such as may be competent to the task and fully prepared to learn it. His first aim was to produce a book of the right tone and character, without any regard to the number of persons who might be prepared to use it. That effort was entirely successful, but the book is not adapted to the great mass of pupils, because it requires of the learner considerable mathematical knowledge, and a corresponding discipline of mind, therefore but few persons, comparatively speaking, feel qualified to study that book. At the same time a book of like tone, character, and spirit, is demanded by teachers for the use of their more humble pupils, except that it must be on a lower mathematical plane, and this book is designed to supply that demand.

In this work we have omitted mathematical investigations almost altogether. Yet we have endeavored to retain the spirit of the University edition, and much of the plain matter of fact in that book is the same in this. Some of the more abstruse parts of the science are omitted, and some of the more simple and elementary parts are more enlarged upon in this book, than in that.

Because we have avoided mathematical investigations, and attempted to adapt our work to the common qualifications of pupils, it must not be inferred that we have therefore made an easy text book, one which requires no particular attention on the part of the reader to comprehend. Astronomy is no study for children — the subject admits of no careless reading, and however good the book, and however well qualified the teacher, the student must take vigorous hold of the study for himself, and, in a measure, take his own way to meet with success.

Although this professes to be but a primary and elementary work, it contains more than a mere statement of astronomical facts, it deduces hidden truths from primary observations, and endeavors to draw out the logical powers of the reader and make him feel the true spirit of the science.

Science properly learned is never forgotten, but science committed to memory soon evaporates, and science cannot be obtained from books and teachers alone, — in addition to the materials, the original perceptions and reasoning powers of the learner, must come in with decided earnestness and force, — and these remarks are particularly applicable to the science of Astronomy.

We make these remarks to impress on the mind of the teacher the necessity of giving perfectly sound instruction, and not be contented with *memoritor* recitations, or the mere accumulation of facts.

For instance, the sun is nearer to the earth in January than in July, but this fact alone is not science, scarcely knowledge — and it would be only a dead weight to the mind to crowd it into the memory: but when it is ascertained *how we know* this fact, from what observation it was deduced, and what logical induction was applied, then it becomes another matter, then it is science, and thus learned, could never be lost.

Some elementary works on Astronomy put great stress on pictorial illustrations, — but at best such illustrations are little better than caricatures, and some of them give incorrect impressions; for instance, in attempting to show the relative motions of the sun and moon in space, by a figure, the moon's motion is generally represented as describing loops, when the true motion is progressively onward, and at all times concave towards the sun.

The difficulty of giving true representations on paper, in Astronomy, is so great that the teacher should be careful so to guide the perceptions of the learner, that they be more truthful and refined than the figure can possibly be, or the learner will draw distorted if not erroneous impressions from them. For instance, if we wished to make a correct representation of the sun, earth, and moon, and made the earth but *one-eighth of an inch* in diameter, the diameter of the moon's orbit must be 7½ inches, the diameter of the moon the 32d part of an inch, the diameter of the earth's orbit 3000 inches, or 250 feet, and the diameter of the sun must cover 14 inches. These considerations show the utter impossibility of making correct astronomical representations on paper, for who would have the earth drawn out less than one-eighth of an inch in diameter, and even that small magnitude would require a sheet two hundred and fifty feet wide, on which none of the exterior planets could be drawn. For these reasons we do not place as much value on pictorial representations and astronomical maps as many do, and whenever we make use of such things, as we sometimes do, we take much care that the impressions drawn from them, are not as gross as the representations themselves.

In conclusion, we would remind the reader that the subject of Astronomy is so vast and magnificent, that it is almost as impossible to do justice to it in composition as it is in geometrical diagrams. We have made no pretensions to delineate the high mental satisfaction that a knowledge of this science imparts ; we have only attempted to guide others in attaining that knowledge, and in this particular we do not claim to have made a perfect book, — far from it, — perfection is impossible, decidedly so, when applied to a book ; and if all books were perfect, there would be little need of schools and teachers.

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ASTRONOMY.

CHAPTER I.

INTRODUCTION.

Astronomy is the science which treats of the heavenly bodies, describes their appearances, determines their magnitudes, and discovers the laws that govern their motions.

Astronomy is divided into *Descriptive, Physical,* and *Practical.*

Descriptive Astronomy merely states facts and describes appearances.

Physical Astronomy explains the causes which bring about the known results. It investigates the laws which govern the celestial motions.

Practical Astronomy includes observations, and all kinds of astronomical computations, such as the distances and magnitudes of the planets, the times of their rising, setting, and coming in conjunction, opposition, &c. &c.

By astronomical observations men can determine the position of a ship on sea, and this branch of astronomy is called *Nautical Astronomy*, and thus geography and astronomy are combined, and no one can fully understand geography without some aid from astronomy.

Astronomy is the most ancient of all sciences, for the people could not avoid observing the successive returns of day and

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Define Astronomy. How is Astronomy divided? What is Descriptive Astronomy? What is Physical? What is Practical? Are Geography and Astronomy connected? How? Is Astronomy a modern science? Why is it allowed to be the most ancient science?

night, and of summer and winter. They could not fail to perceive that short days corresponded to winter, and long days to summer; and thus the operations of agriculture, were in a measure connected with astronomy.

DEFINITION OF TERMS.

Every science has its technicalities and conventional terms; and astronomy is by no means an exception to the general rule; and as it will prepare the way for a clearer understanding of our subject, we now give a short list of some of the technical terms, which must be used in our composition.

Horizon.—Every person, wherever he may be, conceives himself to be in the center of a circle; and the circumference of that circle is where the earth and sky apparently meet. That circle is called the *horizon;* it is completely visible, however, only on a smooth sea; on land it is more or less broken and obscured by mountains and hills.

The mathematical and astronomical *horizon* is a plane passing through the center of the earth, and a plumb line from the observer is perpendicular to it.

No two places have the same horizon.

Sphere.—A sphere, as all well know, is a perfect ball, and the surface of the heavens appears to all as a perfect concave sphere. Around every sphere in any direction is *three hundred and sixty degrees*, written thus 360°.

Poles.—The center of any circle round a sphere, which is also on the sphere, is called the *pole* of that circle; and every circle round a sphere has its *poles* 90° distant from the circle.

Zenith.—The *zenith* of any place is the point directly over head; and the *nadir* is directly opposite to the *zenith*, or under our feet. The *zenith* and *nadir* are the *poles* to the horizon.

Meridian.—When the sun (or other celestial object) in its diurnal course attains its highest possible elevation above the

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What is meant by the horizon? Is the horizon every where visible? Why? What is the true astronomical horizon? Explain what is meant by a Sphere? Poles? Degrees? Zenith? Meridian?

horizon, it is said to be on the *meridian*, and the *direction* to that object just at that moment, is said to be *south* or *north*, according to the locality of the observer: hence, a *meridian* is an imaginary line, north and south from any point or place, whether it is conceived to run along the earth or through the heavens. If the meridian is conceived to divide both the earth and the heavens, it is then considered as a plane, and is spoken of as *the plane of the meridian.*

Altitude.—The altitude of any celestial object is its perpendicular distance from the horizon, measured in degrees, there being 90° from the horizon to the zenith.

The altitude and zenith distance of a body always make 90°.

Verticals.—All lines passing from the zenith, perpendicular to the horizon, are called *Verticals*, or *Vertical Circles.* The one passing at right angles to the meridian, and striking the horizon at the east and west points, is called the *Prime Vertical.*

Azimuth.—The angular position of a body from the meridian, measured on the circle of the horizon, is called its *Azimuth.*

The angular position, measured from its prime vertical, is called its *Amplitude.*

The sum of the *azimuth* and *amplitude* must always make 90 degrees.

When the days and nights are equal all over the earth, which is observed to be the fact about the 20th of March and the 23d of September of each year; — then the sun in its diurnal motion appears to describe a great circle about the earth, which is called the equator.

Then the sun (loosely speaking) appears to rise directly in the east and set directly in the west, as seen from all places.

The Earth's Equator.—The *Earth's Equator* is a great circle, east and west, and equi-distant from the poles, dividing the earth into two hemispheres, a northern and a southern.

What is the altitude of any celestial object? How is altitude measured? What are vertical circles? Through what point do all vertical circles pass? What is meant by Azimuth? What by Amplitude? What do you under stand by the Earth's Equator?

The *Celestial Equator* is the plane of the earth's equator conceived to extend into the heavens.

When the sun, or any other heavenly body, meets the celestial equator, it is said to be in the *Equinox*, and the equatorial line in the heavens is called the *Equinoctial*.

Latitude.—The latitude of any place on the earth, is its distance from the equator, measured in degrees on the meridian, either north or south.

If the measure is toward the north, it is north latitude ; if toward the south, south latitude.

The distance from the equator to the poles is 90 degrees — one-fourth of a circle ; and we shall know the circumference of the whole earth whenever we can find *the absolute length of one degree on its surface.*

Co-Latitude.—Co-latitude is the distance, in degrees, of any place from the nearest pole.

The latitude and co-latitude (complement of the latitude) must, of course, always make 90 degrees.

Parallels of latitude are small circles on the surface of the earth, parallel to the equator.

Every point, in such a circle, has the same latitude.

Longitude.—The *longitude* of a place, on the surface of the earth, is the inclination of its meridian to some other meridian which may be chosen to reckon from. English astronomers and geographers take the meridian which runs through Greenwich Observatory, as the zero meridian.

Other nations generally take the meridian of their principal observatories, or that of the capital of their country, as the first meridian ; but this is national vanity, and creates only trouble and confusion : it is important that the whole world

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What do you understand by the Celestial Equator ? What is latitude on the earth ? How is it measured ? How many degrees are there from the equator to the pole ? If the earth were larger, would there be more degrees from the equator to the pole ? What is longitude ? What meridian is it reckoned from ? Why that meridian ? Could it have been from any other ?

should agree *on some one meridian*, from which to reckon longitude; but as nature has designated no particular one, it is not wonderful that different nations have chosen different lines.

In this work, we shall adopt the meridian of Greenwich as the zero line of longitude, because most of the globes and maps, and all the important astronomical tables, are adapted to that meridian, and we see nothing to be gained by changing it.

Declination.—Declination refers only to the celestial equator, and is a leaning or *declining*, north or south of that line, and it is similar to latitude on the earth.

Solsticial points.—The points, in the heavens, north and south, where the sun has its greatest *declination*, are the *solsticial points*.

The northern point we call the *Summer Solstice*, and the southern point the *Winter Solstice;* the first is in longitude 90°, the second in longitude 270°.

As latitude is reckoned north and south, so longitude is reckoned east and west; but it would add greatly to systematic regularity, and tend much to avoid confusion and ambiguity in computations, were this mode of expression abandoned, and longitude invariably reckoned *westward*, from 0 to 360 degrees.

Declination in the heavens is similar to latitude on the earth. If a person were in 20° north latitude when the sun's declination was 20° north, the sun at noon would then be in his zenith, or pass directly over his head.

Ecliptic.—The ecliptic is a great circle in the heavens, along which the sun appears to pass in a year, extending from about 23½ degrees of south declination to about 23½ degrees of north declination in the opposite longitude of the heavens. This circle is called the ecliptic, because all eclipses, both of the sun and moon, take place when the moon is either in or near it.

What is declination? What is the declination of the north pole? What are the solsticial points? In what latitude are they? What circle is the sun always in? Why is that circle called the ecliptic?

Equator and Ecliptic.—The celestial equator and the ecliptic are two great circles, in the heavens, which intersect each other (at the present day) by an angle of about 23° 27′ 32″.

The sun, in its apparent annual motion, runs round the heavens, crosses the equator from the south to the north on the 20th of March of each year, and re-crosses from the north to the south on the 23d of September.

The point on the ecliptic where the sun meets the celestial equator in the spring, is taken as the *zero point* from which to reckon longitude, in astronomy, eastward along the ecliptic. *This point is called the Vernal Equinox.*

From the same point eastward along the equator is reckoned *right ascension,* and it is counted from 0 degrees to 360 degrees, or from 0 hours to 24 hours; 15 degrees of arc corresponding to one hour in time.

Zodiac.—Ancient astronomers defined the zodiac to be a space in the heavens sixteen degrees wide, eight degrees on each side of the ecliptic, and quite round the sphere: the ecliptic was therefore the center of the zodiac. The ecliptic, or zodiac, was divided into twelve signs, called signs of the zodiac, each sign was therefore 30° in extent.

The first sign, commencing at the *vernal equinox,* is called *Aries,* and the character denoting it is written thus ♈.

The sun enters the 12 signs as follows:

Aries (♈) on the 20th of March; *Taurus* (♉) on the 19th of April; *Gemini* (♊) on the 20th of May; *Cancer* (♋) on the 21st of June; *Leo* (♌) on the 22d of July; and *Virgo*(♍) on the 22d of August.

The foregoing are called northern signs, because the sun must have north declination while the sun is in them.

The following are designated as the southern signs of the

Does the ecliptic intersect the equator? At what angle? What point in the heavens is called the Vernal Equinox? What is the Zodiac? What is meant by the signs of the Zodiac? When does the sun enter the first sign of the Zodiac?

zodiac, because the sun must have south declination while he is in them:

The sun enters *Libra* (♎) on the 23d of September; *Scorpio* (♏) on the 22d of October; *Sagittarius* (♐) on the 22d of November; *Capricornus* (♑) on the 21st of December; *Aquarius* (♒) on the 20th of January; and *Pisces* (♓) on the 19th of February. Passing through this last sign the sun again enters (♈) on the 20th of March, to perform the revolution over again, and thus it goes on year by year.

The zodiac and signs of the zodiac being but the offspring of astrology and heathen mythology, they are entirely discarded by modern astronomers; yet they still linger in country almanacs and in many school books, and it is with reluctance that we even mention them. They are of no use, even as points of reference, and they embrace no scientific principle whatever.

Conjunction.—When two celestial bodies have the same longitude, they are said to be in *conjunction.*

When two celestial bodies have the same *right ascension,* that is, *come to the meridian at the same time,* they are said to be in *conjunction in right ascension.*

Opposition.—When two celestial bodies have a difference of longitude of 180 degrees, they are said to be in *opposition.*

Direct.—Direct, in astronomy, is a motion to the eastward among the stars.

Retrograde.—Retrograde is a motion to the westward among the stars. *Stationary* means apparently so in respect to the stars. Other terms not here mentioned will be explained as we use them.

Why are some of the signs called northern, and others southern signs? Is the distinction of signs necessary? What is meant by conjunction? By opposition? What by direct? Retrograde?

CHAPTER II.

PRELIMINARY OBSERVATIONS.

To commence the study of astronomy, we must observe and call to mind the real appearance of the heavens.

Take such a station, any clear night, as will command an extensive view of that apparent, concave hemisphere above us, which we call the sky, and fix well in the mind the directions of *north*, *south*, *east*, and *west*.

At first, let us suppose the observer to be somewhere in the United States, or somewhere in the northern hemisphere, about 40 degrees from the equator.

Soon he will perceive a variation in the position of the stars: those at the east of him will apparently rise; those at the west will appear to sink lower, or fall below the horizon; those at the south, and near his zenith, will apparently move westward; and those at the north of him, which he may see about half way between the horizon and the zenith, will *appear stationary*.

Let such observations be continued during all the hours of the night, and for several nights, and the observer cannot fail to be convinced that not only all the stars, but the sun, moon, and planets, appear to perform revolutions, in about twenty-four hours, round a *fixed point;* and that fixed point, *as appears to us* (in the middle and northern part of the United States), is about midway between the northern horizon and the zenith.

It should always be borne in mind that these motions are

How can a person convince himself that some of the stars have an apparent motion from east to west, like the sun in the day time? Do all the stars have such an apparent motion, as seen from this place? What stars do not?

but apparent, the stars keeping the same positions with respect to each other, whether they are rising or falling, or north or south of the observer, and the general aspect of the heavens is the same now, as it was in the very earliest ages of astronomy, and will be the same in ages to come.

All the heavenly bodies, whether sun, moon, planets, or stars, appear to have a diurnal motion round a *fixed point*, and all those stars which are 90 degrees from that point, apparently describe a great circle. Those stars which are nearer to the fixed point than 90 degrees, describe smaller circles; and the circles are smaller and smaller as the objects are nearer and nearer the *fixed point.*

There is *one star* so near this fixed point, that the small circle it describes, in about 24 hours, is not apparent from mere inspection. To detect the apparent motion of this star, we must resort to nice observations, aided by mathematical instruments.

This *fixed point*, that we have several times mentioned, is the *North Pole of the heavens*, and this *one star* that we have just mentioned, is commonly called the *North Star*, or the *Pole Star.*

As the North Star appears stationary, to the common observer, it has always been taken as the infallible guide to *direction;* and every sailor of the ocean, and every wanderer of the African and Arabian deserts, has held familiar acquaintance with it.

If our observer now goes more to the southward, and makes the same observations on the apparent motions of the stars, he will find the same general results; each individual star will describe the same circle; but the pole, the *fixed point,* will be lower down, and nearer to the northern horizon; and it will be

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Those stars that do not rise and set, what motion, real or apparent, do they have? Is any star apparently stationory? Is there a star just at the north pole? What use has been made of the north star? If a person should go south from this place, what apparent effect would that have on the north star, as viewed by him?

lower and lower in proportion to the distance the observer goes to the south. After the observer has gone sufficiently far, the fixed point, the pole, will no longer be up in the heavens, but down in the northern horizon ; and when the pole does appear in the horizon, the observer is at the equator, and from that line all the stars at or near the equator appear to rise up directly from the east, and go down directly to the west; and all other stars, situated out of the equator, describe their small circles parallel to this perpendicular equatorial circle.

If the observer goes south of the equator, the *north pole* will sink below his horizon, and the south polar point will appear to rise up above his horizon, and it will rise more and more as he goes farther and farther south ; and if he could possibly get to the south pole on the earth, the south pole of the apparent revolving heavens would be right over his head, and the equator of the heavens would bound his horizon.

In a similar manner if an observer goes north, the north pole to him would appear to rise in the heavens; and should he continue to go north, he would finally find the pole in his zenith, and all the stars would apparently make circles round the zenith, as a center, and parallel to the horizon; and the horizon itself would be the celestial equator.

When the north pole of the heavens appears at the zenith, the observer must then be at the north pole, on the earth, or at the latitude of 90 degrees.

Any celestial body, which is north of the equator, is always visible from the north pole of the earth ; hence, the sun, which is north of the equator from the 20th of March to the 23d of September, must be constantly visible during that period, in a clear sky.

Just as the sun comes north of the equator, its diurnal progress, or rather, the progress of 24 hours, is around the horizon. When the sun's declination is 10 degrees north of the equator,

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What is the apparent diurnal motion of the stars, as seen from the equator ? What from the south pole ? What part of the heavens bounds the horizon as seen from the south pole ? What from the north pole ?

the progress of the sun, in 24 hours, as seen from the north pole, is around the horizon at an altitude of about 10 degrees; and so on for any other degree.

From the north pole, all directions on the surface of the earth are south. North, strictly speaking, would be in a vertical direction, which would make the absolute south *directly down towards the center of the earth.*

We have observed that the pole of the heavens rises as we go north, and sinks toward the horizon as we go south; and when we observe that the pole has changed its position one degree, in relation to the horizon, we know that we must have changed place one degree on the surface of the earth.

Now we know by observation, that if we go north about 69¼ English miles on the earth, the north pole will be *one degree* higher above the horizon. Therefore 69¼ miles corresponds to one degree, on the earth; and hence, the whole circumference of the earth must be 69¼ multiplied by 360: for there are 360 degrees to every circle. This gives 24,930 miles for the circumference of the earth, and 7,930 miles for its diameter, which is not far from the truth.

Here, in the United States, or anywhere either in Europe, Asia, or America, north of the equator, say in latitude 40 degrees, the north pole of the heavens must appear at an altitude of 40 degrees above the horizon; and as all the stars and heavenly bodies apparently circulate round this point as a center, it follows that all those stars which are within 40 degrees of the pole, can never go below the horizon, but circulate round and round the pole. All those stars which never go below the horizon, are called *circumpolar* stars.

At the north, and very near the north pole, the sun is a *circompolar body* while it is north of the equator, and it is a

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Describe the apparent diurnal motion of the sun from the north pole when its declination is 15 degrees north? How far must we go north or south on the earth to change the apparent altitude of the pole one degree? What does that show? What is meant by circumpolar stars? Would the term circumpolar apply if the observer were at the equator?

circumpolar body as seen from the south pole, while it is south of the equator; this gives six months day and six months night, at the poles.

North of latitude 66 degrees, and when the sun's declination is more than 23 degrees north (as it is on and about the 20th of June in each year), then the sun comes at, or very near, the northern horizon, at midnight; it is nearly east, at 6 o'clock in the morning; it is south, at noon, and about 23 degrees in altitude; and is nearly west at 6 in the afternoon.

In all latitudes and from all places on the earth, the sun is observed to circulate round the nearest pole, as a center; and when the sun is on the same side of the equator as the observer, more than half of the sun's diurnal circle is above the horizon, and the observer will have more than 12 hours sunlight.

When the sun is on the equator, the horizon, of every latitude, cuts the sun's diurnal circle into two equal parts, and gives 12 hours day and 12 hours night, the world over. When the sun is on the opposite side of the equator from the observer, the smaller segment of the sun's diurnal circle is above the horizon, and, of course, gives shorter days than nights.

We have, thus far, made but rude and very imperfect observations on the apparent motion of the heavenly bodies, and have satisfied ourselves only of two facts:

1st. That all the stars, sun, moon, and planets, included, apparently circulate round the pole, and round the earth, in a day, or in *about* 24 hours.

2d. That the sun comes to the meridian, at different altitudes above the horizon, at different seasons of the year, giving long days in June, and short days in December, in all northern latitudes.

Describe the appearance of the sun, during 24 hours, as seen from latitude 66 degrees north, when the sun's declination is 23 degrees north. Describe the diurnal appearance of the sun, as seen from the north pole, when the sun is on the equator, when its declination is 12 degrees north. What two facts are thus far established?

Let us now pay attention to some other particulars. Let us look at the different groups of stars, and individual stars, so that we can recognize them night after night.

By a little systematic observation, which we shall describe a little further on, or even without any particular system of observation, almost any one is able to recognize certain stars, or groups of stars, such as the *Seven Stars*, the *Belt of Orion*, *Aldebaran*, *Sirius*, and the like, and having likewise the use of a clock, he can observe *when any particular star comes to any definite position.*

Let a person place himself at any particular point, to the north of any perpendicular line, as the edge of a wall or building, and let him observe the stars as they pass behind the building, in their diurnal motions from the east to the west. For example, let us suppose that the observer is watching the star *Aldebaran*, and that, when the eye is placed in a particular definite position, the star passes behind the building at exactly 8 o'clock.

The next evening, the same star will come to the same point about 4 minutes before 8 o'clock; and it will not come to the same point again, at 8 o'clock in the evening, until after the expiration of *one* year.

But in any year, on the same day of the month, and at the same hour of the day, the same star will be at, or very near, the same position, as seen from the same point.

For instance, if certain stars come on the meridian at a particular time in the evening, on the first day of December, the same stars will not come on the meridian again, at the same time of the night, until the first day of the next December.

On the first of January, certain stars come to the meridian at midnight; and (speaking loosely) every first of January the same stars come to the meridian at the same time; and there

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Does the same fixed star come to the meridian at the same hour every night? Does it come to the meridian earlier or later? If a star come to the meridian at 10 o'clock in the evening any particular night, when will it come to the meridian again at the same time in the evening?

will be no other day during the whole year, when the same stars will come to the meridian at midnight.

Thus, the same day of every year is observed to have the same position of the stars at the same hour of the night; *and this is the most definite index for the expiration of a year.*

The year is also indicated by the change of the sun's declination, which the most careless observer cannot fail to notice. On the 21st of June, the sun declines about 23½ degrees from the equator towards the north; and, of course, to us in the northern hemisphere, its meridian altitude is so much greater, and the horizontal shadows it casts from the same fixed objects will be shorter; and the same meridian altitude and short shadow will not occur again until the following June, or after the expiration of one year.

Thus, we see, that the time of the stars coming on to the meridian, and the declination of the sun, have a close correspondence, *in relation to time.*

In all our observations on the stars, we notice that their apparent relative situations are not changed by their diurnal motions. In whatever parts of their circles they are observed, or at whatever hour of the night they are seen, the same configuration is recognized, although the same group, in the different parts of its course, will stand differently, in respect to the horizon. For instance, a configuration of stars resembling the letter A, when east of the meridian, will resemble the letter V, when west of the meridian.

As the stars, in general, do not change their positions in respect to each other, they are called *fixed stars;* but there are a few important stars that do change, in respect to other stars; and for that reason they become especial objects of attention, and form the most interesting portion of astronomy.

In the earliest ages, those stars that changed their places,

What is the most definite index of the expiration of a year? What other index is there of the expiration of a year? Do the stars change their configuration really or apparently while performing their diurnal circles? Explain.

were called *wandering stars;* and they were subsequently found to be the planetary bodies of the solar system, like the earth on which we live ; or rather, the earth on which we live, after strict investigation, was found to be a planet belonging to that class of wandering stars ; and this striking fact gives to astronomy much of its sublimity and importance. In a subsequent part of this work we hope to be able to explain to the general reader how science developed this and other facts, but at present they must all be taken on authority.

The fixed stars come to the meridian at intervals of 23h. 3m. 56.555s. of mean solar time, and if any star should be observed coming to the meridian at a greater interval of time, then that star could not be a fixed star, but a planet, or comet, whose motion was then eastward. But if the interval be less than 23h. 3m. 56s., the star is then *wandering* towards the west, and is said to be *retrograding.*

The planets of our system, sometimes wander eastward — sometimes westward — and sometimes they appear stationary ; but the eastward motion prevails, and all the planets appear to make revolutions round the earth from west to east.

The apparent irregularities of their motions, are perfectly natural results, arising from the motion of the earth round the sun; and these facts are brought in to show that the earth does revolve round the sun, and is, in fact, a planet.

To study astronomy properly, it is not sufficient to read it off the pages of a book ; we must read it off of the face of the sky ; and before we can do that, we must be better acquainted with the face of the sky than we are at present, and that will be the object of the following chapter.

What stars became objects of special attention to the ancients ? Is the earth one of a class of stars ? Was this known in an early day ?

CHAPTER III.

THE FIXED STARS—AS CELESTIAL LOCALITIES.

The fixed stars are the only *landmarks* in astronomy, in respect to both time and space. They seem to have been thrown about in irregular and ill-defined groups and clusters, called *constellations*. The individuals of these groups and clusters differ greatly as to brightness, hue, and color; but they all agree in one attribute — a high degree of permanence, as to their relative positions in the group; and the groups are as permanent in respect to each other. This has procured them the title of *fixed stars;* an expression which must be understood in a comparative, and not in an absolute, sense; for, after long investigation, it is ascertained that some of them, if not all, are in motion; although too slow to be perceptible, except by very delicate observations, continued through a long series of years.

The stars are also divided into different classes, according to their degree of brilliancy, called *magnitudes*. There are *six* magnitudes, visible to the naked eye; and *ten* telescopic magnitudes — in all, *sixteen*.

The brightest are said to be of the first magnitude; those less bright, of the second magnitude, etc.; the sixth magnitude is just visible to the naked eye.

The stars are very unequally distributed among these classes; nor do all astronomers agree as to the number belonging to each; for it is impossible to tell where one class ends and another begins; nor is it important, for all this is but a matter of fancy, involving no principle. In the first magnitude there

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What are constellations? In what sense should we apply the term fixed stars? What is meant by the magnitude of a star? How many classes of magnitudes are there? Can we define where one class of magnitudes begins or ends?

is really but one star (*Sirius*); for this is manifestly brighter than any other; but most astronomers put fifteen or twenty into this class.

The second magnitude includes from fifty to sixty; the third about two hundred, the numbers increasing very rapidly, as we descend in the scale of brightness.

From some experiments on the intensity of light, it has been determined, that if we put the light of a star, of the *average* 1st magnitude, 100, we shall have:

1st magnitude	=	100	4th magnitude	=	6
2d "	=	25	5th "	=	2
3d "	=	12	6th "	=	1

On this scale, Sir William Herschel placed the brightness of Sirius at 320.

Ancient astronomy has come down to us much tarnished with superstition and heathen *mythology*. Every constellation bears the name of some pagan deity, and is associated with some absurd and ridiculous fable; yet, strange as it may appear, these masses of rubbish and ignorance — these clouds and fogs, intercepting the true light of knowledge, are still not only retained, but cherished, in many modern works, and dignified with the name of astronomy.*

* As a specimen of what was once called astronomy, and is even now studied for astronomy in some female boarding schools, we give the following extracts, taken from Keith on the globes. To say nothing of other branches of knowledge, we congratulate the learner that ancient fables no longer obscure astronomy.

"Coma Berenices is composed of the unformed stars, between the Lion's tail and Bootes. Berenice was the wife of Evergetes, a surname signifying benefactor: when he went on a dangerous expedition, she vowed to dedicate her hair to the goddess Venus, if he returned in safety. Sometime after the victorious return of Evergetes, the locks which were in the temple of Venus, disappeared; and Conon, an astronomer, publicly reported that Jupiter had carried them away, and made them a constellation.

"Cor Caroli, or Charles's heart, in the neck of Chara, the southernmost of the two dogs held in a string by Bootes, was so denominated by Sir Charles Scarborough, physician to king Charles II, in honor of King Charles I."

How many stars are there in the first magnitude? What is said of ancient superstition, and mythology?

Merely as names, either to constellations or to individual stars, we shall make no objections; and it would be useless, if we did; for names long known, will be retained, however improper or objectionable; hence, when we speak of *Orion*, the *Little Dog*, or the *Great Bear*, it must not be understood that we have any *great respect* for mythology.

It is not our object now to give any very minute or scientific description of the starry heavens — such as pointing out the *variable, double,* and *multiple* stars — the *Milky Way,* and *nebulæ;* these will receive special attention in some future chapter: at present, our only aim is to point out the method of obtaining a knowledge of the mere appearance of the sky, to the common observer, which may be called *the geography of the heavens.*

To give a person an idea of locality, on the earth, we refer to points and places supposed to be known. Thus, when we say that a certain town is 15 miles northwest of Boston, or that a ship is 100 miles east of the Cape of Good Hope, or that a certain mountain is 10 miles north of Calcutta, we have a pretty definite idea of the locality of the town, the ship, and the mountain, on the face of the earth, provided we have a clear idea of the face of the earth, and know the position of Boston, the Cape of Good Hope, and Calcutta.

So it is with the geography of the heavens; the apparent surface of the whole heavens must be in the mind, and then the localities of certain bright stars must be known, as *landmarks,* like Boston, the Cape of Good Hope, and Calcutta.

We shall now make some effort to point out these *landmarks.* The *North Star* is the first, and most important to be recognized; and it can always be known to an observer, in any northern latitude, from its stationary appearance and altitude; which is never more than *one and a half* degrees from the latitude of the observer. Thus, a person in 10° north latitude,

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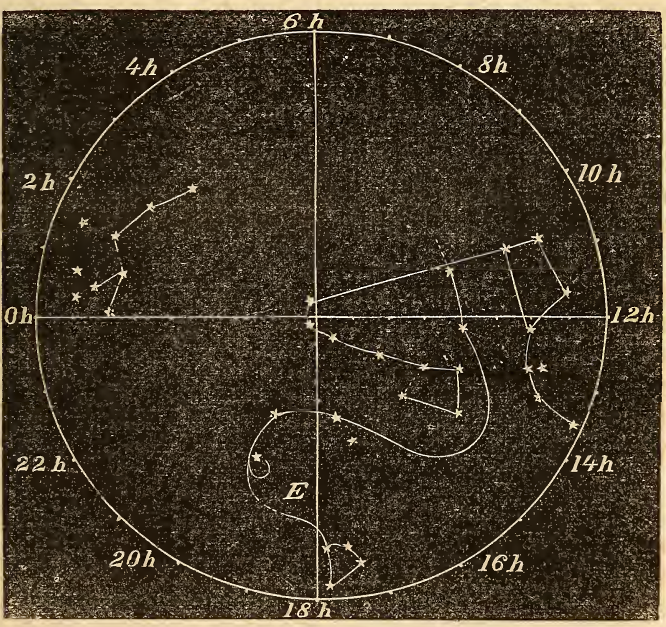
How does the author regard mythology? What is meant by the geography of the heavens? What star is the most important to be recognized? How can it be known?

will find the north star very nearly in a northern direction, between 8° and 12° above the northern horizon. An observer in 25° north latitude, will find the north star nearly north in direction, and between 24° and 26° of altitude, and so on for any other northern latitude. It is by such observations on the north star, that latitude can be found.

When the influence of refraction is allowed for, the latitude of a place is midway between the greatest and least altitudes of the north star.



We have here attempted to make a faint representation of the region about the north pole to the distance of 40°. The hours are hours of right ascension in the heavens. The pole star is nearly (not exactly) in the center of this circle. Directly

What star is always very nearly north? What is the latitude of any place in the northern hemisphere equal to?

opposite the cup or Great Bear, is the constellation *Cassiopea.* *E* is the position of the pole of the ecliptic, and a little south of *E*, in right ascension, about 18 hours, is the constellation called the *Dragon* or *Draco.* At the distance of about 32 degrees from the pole, are seven bright stars, between the 1st and 2d magnitudes, forming a figure resembling a *dipper*, four of them forming the cup, and three the handle. They occupy a space between the right ascension of 10h. 45m. and 13h. 40m. The two stars forming the sides of the cup, opposite to the handle, are always in a line with the North Star, and are therefore called *pointers : they always point to the North Star.* The line joining the equinoxes, or the first meridian of right ascension, runs from the pole, between the other two stars forming the cup. The first star in the handle, nearest the cup, is called *Alioth*, the next *Mizar*, near which is a small star, of the 4th magnitude; the last one is *Benetnasch.* The stars in the handle are said to be in the *tail of the Great Bear.*

About four degrees from the pole star, is a star of the 3d magnitude, ε *Ursæ Minoris.* A line drawn through the pole (not pole star) and this star, will pass through, or very near, the poles of the *ecliptic* and the *tropics.* A small constellation, near the pole, is called *Ursa Minor*, or the Little Bear. An irregular semicircle of bright stars, between the dipper and the pole, is called the *Serpent.*

If a line be drawn from ε *Ursæ Minoris*, through the pole star, and continued about 45 degrees, it will strike a very beautiful star, of the 1st magnitude, called *Capella.* Within five degrees of Capella are three stars, of about the 4th magnitude, forming a very exact isosceles triangle, the vertical angle about 28 degrees. A line drawn from *Alioth*, through the pole star, and continued about the same distance on the other side, passes through a cluster of stars called *Cassiopea in her chair.* The

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Why are two certain stars called pointers? What small constellation is near the north pole? What stars are in the handle of the cup, or in the tail of the Great Bear?

principal star in *Cassiopea,* with the pole star and Capella, form an isosceles triangle, Capella at the vertex.

More attention has been paid to the constellations along the equator and ecliptic, than to others in remoter regions of the heavens, because the *sun, moon,* and *planets,* apparently traverse through them.

There are nine bright stars near the ecliptic, which are used by seamen, in connection with the position of the moon, to find longitude from, — and for this reason these stars are called *lunar* stars. Their proper names are *Arietis, Aldebaran, Pollux, Regulus, Spica, Antares, Aquilœ, Fomalhaut,* and *Pegasi.*

Beginning with the first point of *Aries* as it now stands, no prominent stars are near it; and, going along the ecliptic to the eastward, there is nothing to arrest special attention, until we come to the *Pleiades,* or *Seven Stars,* though only six are visible to the naked eye. This little cluster is so well known, and so remarkable, that it needs no description. Southeast of the *Seven Stars,* at the distance of about 18 degrees, is a remarkable cluster of stars, said to be in the *Bull's Head;* the largest star in this cluster is of the 1st magnitude, of a red color, called *Aldebaran.* It is one of the nine stars selected as points from which to compute the moon's distance, for the assistance of navigators.

This cluster resembles an A when east of the meridian, and a V when west of it. The *Seven Stars, Aldebaran,* and *Capella,* form a triangle very nearly isosceles — Capella at the vertex. A line drawn from the *Seven Stars,* a little to the west of *Aldebaran,* will strike the most remarkable constellation in the heavens, *Orion,* (it is out of the zodiac however); some call it the Ell and Yard. The figure is mainly distinguished by three stars in one direction, within two degrees of each other; and two other stars, forming, with one of the three first mentioned, another line at right angles with the first line.

Why are certain stars called lunar stars? Is there any star near the first point of Aries? What is meant by the first point of Aries? What bright star is about 18° southeast of the Seven Stars? How would you find Orion on seeing the Seven Stars and Aldebaran?

The five stars thus in lines, are of the 1st or 2d magnitude. A line from the *Seven Stars*, passing near *Aldebaran* and through *Orion*, will pass very near to *Sirius*, the most brilliant star in the heavens. The ecliptic passes about midway between the Seven Stars and Aldebaran, in nearly an eastern direction. Nearly due east from the northernmost and brightest star in *Orion*, and at the distance of about 25 degrees, is the star *Procyon;* a bright, lone star.

The northernmost star in *Orion*, with *Sirius* and *Procyon*, form an equilateral triangle.

Directly north of *Procyon*, at the distances of 25 or 30 degrees, are two bright stars, *Castor* and *Pollux*. Castor is the most northern. *Pollux* is one of the nine *lunar stars*. Thus we might run over that portion of the heavens which is ever visible to us, and by this method every student of astronomy can render himself familiar with the aspect of the sky; but it is not sufficiently *definite* and *scientific* to satisfy a mathematical mind.

The only scientific method of defining the position of a place on the earth, is to mention its *latitude* and *longitude;* and this method fully defines any and every place, however unimportant and unfrequented it may be: so in astronomy, the only scientific method of *defining the position* of a star, is to mention its *latitude* and *longitude*, or, more conveniently, its *right ascension* and *declination*.

It is not sufficient to tell the navigator that a coast makes off in such a direction from a certain point, and that it is so far to a certain cape; and, from one cape to another, it is *about* 40 miles south-west—he would place very little reliance on any such directions. To secure his respect, and command his confidence, the *latitude* and *longitude* of every point, promontory, river, and harbor, along the coast, must be given; and then he can shape his course to any point, or strike in upon it

What three bright stars form an equilateral triangle? Where is Castor and Pollux? What is the scientific method of defining a place on the earth? What of locating a star in the heavens?

from the indefinite expanse of a pathless sea. So with an astronomer; while he understands and appreciates the *rough aud general descriptions*, such as we have just given, he requires the *certain description*, comprised in *right ascension* and *declination.*.

Accordingly, astronomers have given the *right ascensions* and *declinations* of every visible star in the heavens (and of very many that are invisible), and arranged them in tables, in the order of right ascension.

There are far too many stars, for each to have a proper name; and, for the sake of reference, Mr. John Bayer, of Augsburg, in Suabia, about the year 1603, proposed to denote the stars by the letters of the Greek and Roman alphabets; by placing the first Greek letter α to the principal star in the constellation, β to the second in magnitude, γ to the third, and so on; and if the Greek alphabet shall become exhausted, then begin with the Roman, *a*, *b*, *c*, etc.

"*Catalogues* of particular stars, in sections of the heavens, have been published by different astronomers, each author numbering the individual stars embraced in his list, according to the places they respectively occupy in the catalogue." These references to particular catalogues are sometimes marked on celestial globes, thus: 79 H, meaning that the star is the 79th in Herschel's catalogue; 37 M, signifies the 37th number in the catalogue of Mayer, etc.

Among our tables will be found a catalogue of a *hundred* of the principal stars, *inserted for the purpose of teaching a definite and scientific method of making a learner acquainted with the geography of the heavens*, which will be given in another chapter.

What did John Bayer propose? How are stars, in sectional catalogues, referred to?

CHAPTER IV.

TIME—AND THE MEASURE OF TIME.

Time is but a measured portion of unlimited duration — and it is measured off, directly or indirectly, by astronomical events.

The most obvious astronomical event is that of a natural day, from sunrise to sunset, or from sunrise to sunrise again, — but as these intervals are variable in length, they are not proper standards for time.

The interval embracing the four seasons of the year, is another astronomical period which serves to measure time on a large and indefinite scale.

The interval from full moon to full moon again, is also an astronomical period, — but after careful observation, it has been found to be a period of variable duration ; and, moreover, it is impossible for the unlearned to define the moment when such an interval begins or ends, — therefore this period is useless, as a measure of time — and none but savages pretend to use it as such.

For a standard of measure, we must find, if possible, some *invariable period* that can be distinctly defined. In the early ages of astronomy, the interval from noon, to noon again, was considered a constant interval, and taken for the measure of time, — and for the common business of the world, this will be the standard for time, because it is the most obvious, natural, and convenient. But after close investigation and careful observations, this interval was found to be slightly variable, and another interval, *the passage of a fixed star* from the meridian to the meridian again, was found to be a *constant* interval, therefore this interval is taken *as the standard measure of time.*

What is time? What is an astronomical event? Is from noon to noon, by the sun, an invariable interval of time? What astronomical events mark equal intervals of time?

The interval from one passage of a star across the meridian, to the next, is a *sidereal day*, and measured by the common solar clock, the interval is 23h. 56m. 4.09s. No matter what star is observed, the interval is the same, and as this has been the universal experience of astronomers in all ages, it completely establishes the fact, that all the fixed stars come to the meridian in exactly equal intervals of time; and this gives us a *standard measure* for time, and the only standard measure, for all other motions are variable and unequal.

Again, this interval must be the time that the earth employs in turning on its axis; for if the star is *fixed*, it is a mark for the time, that the meridian is in exactly the same position in relation to *absolute space*.

Soon after the fact was established that the fixed stars came to the meridian in *equal times*, and that interval less than 24 hours, astronomers conceived the idea of *graduating a clock* to that interval, and dividing it into 24 hours. Thus graduating a clock to the *stars*, and not to the sun, it is therefore called a *sidereal*, and not a solar, or common clock; and as it was suggested by astronomers, and used only for the purposes of astronomy, it is also very appropriately called an astronomical clock; but save its graduation, and the nicety of its construction, it does not differ from a common clock.

With a perfect astronomical clock, the same star will pass the meridian at exactly the same time, from one year's end to another. If the time is not the same, the clock does not run to sidereal time; and the variation of time, or the difference between the time when the star passes the meridian, and the time which ought to be shown by the clock, will determine the rate of the clock. And with the *rate* of the clock, and its *error*, we can readily deduce the true time from the time shown by the face of the clock. We have several times mentioned the fact, that the same star returns to the same meridian again and

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What is a sidereal day? What is an astronomical clock? How does it differ from a common clock? How can we determine whether the astronomical clock moves perfectly or not?

again, after every interval of 24 sidereal hours. So, two different stars come to the meridian at constant and invariable intervals of time from each other; and by *such intervals* we decide how far, or how many degrees, one star is east or west of another. For instance, if a certain fixed star was observed to pass the meridian when the sidereal clock marked 8 hours, and another star was observed to pass at 9, just one sidereal hour after, then we know that the latter star is on a celestial meridian, just 15 degrees eastward of the meridian of the first mentioned star.

With a perfect astronomical clock, or one which shows true sidereal time, we can find the right ascension of any heavenly body, by simply observing the time it passes the meridian. For *right ascension* is but another term for the *sidereal time* the body passes the meridian.

That meridian in the heavens which passes through the point where the ecliptic and equator intersect, at the *first point of Aries*, the point where the sun crosses the equator in the spring, is taken as the first meridian of *right ascension*, and from thence we reckon eastward, from 0 hours to 24 hours, to the same meridian again.

This being the case, the sidereal clock should show 0h. 0m. 0s. when the equinox is on the meridian; and, if a star or a planet were observed to pass the meridian at 4h. 20m. 30s., then the right ascension of that star or planet, at that time, was 4h. 20m. 30s.

This, however, is on the supposition that the clock is perfect, and runs perfectly uniform, which is never the case; unfortunately, there is no such thing as a perfect clock, and the difficulties thus arising, must be surmounted by artifice and multiplied observations.

Just as the sun crosses the equator in the spring, its right

How can we find the rate of the clock? What difference is there between true sidereal time and right ascension? Define the first astronomical meridian? What time should the clock show when the equinox is on the meridian?

ascension is 0h., and from this, its right ascension increases about four minutes each day; this shows that the sun has an apparent motion eastward, among the stars.

The right ascensions of all the fixed stars increase at a very slow rate, in consequence of the *precession of the equinoxes*, that is, a slow motion of the first meridian to the westward, among the stars, of about 50″1 per year; this gives the stars the appearance of moving eastward and increasing their right ascensions. The entire increase since the first reliable observations on record, is about 30°, or 2 hours.

The great multitude of stars retain the same relative right ascensions, and the same relative declinations, for very long periods of time,—that is, they retain the same positions with respect to each other. But occasionally, stars may be observed that change their right ascension from day to day, and these stars, in early times, were called wandering stars—mentioned in the preceding chapter,—they are the planets of our system, the earth itself being one of them.

When it is discovered that a star does not pass the meridian at equal intervals of time, as shown by a good astronomical clock, we then decide that that star must have a motion of its own—and of course must be a planet or a comet.

The reason why astronomers commence the day at noon rather than at midnight, is because noon, the time that the sun passes the meridian, is a distinct and *visible moment*, which, with proper care and proper instruments, can be exactly defined by observation; not so with midnight, or any other moment, during the 24 hours.

Suppose the right ascension of a star is 8h. 32m. 16s., what time should be shown by the astronomical clock, when that star passes the meridian? How are planets and comets distinguished from the fixed stars? By what observations? Why do astronomers commence the day at noon?

CHAPTER V.

LATITUDE—DECLINATION—ASTRONOMICAL INSTRUMENTS.

In the last chapter we have given a general idea of finding the right ascensions of the heavenly bodies — but to give a true view or map of the heavens, we must give the declinations also.

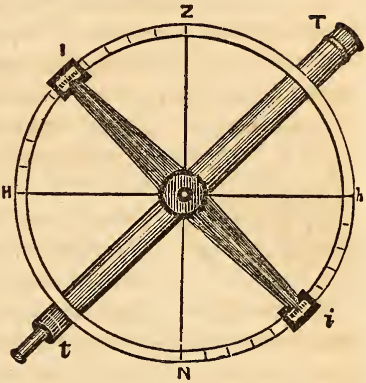
To observe declination, we must have an instrument to measure angles, and with it, determine the latitude of the place from whence the observations are made.

The true altitude of the celestial pole is the latitude of the place of observation, and primarily, the observation to find this altitude is the only method of finding the latitude, — but after the positions of the heavenly bodies have been established, then there are many other methods of finding the latitude.

As the north *pole* is but an imaginary point, *no star being there,* we cannot directly observe its altitude. But there is a bright star near the pole, called the *Polar Star,* which, like all other stars in the same region, apparently revolves round the pole, and comes to the meridian twice in 24 sidereal hours; once above the pole, and once below it; and it is evident that the altitude of the pole itself must be midway between the greatest and least altitudes of the same star, *provided the apparent motion of the star round the pole is really in a circle;* but before we examine this fact, we will show how altitudes can be taken by the *mural circle.*

The *mural,* or *wall circle,* is a large metalic circle, firmly fastened to a wall, so that its plane shall coincide with the plane of the meridian.

Define the latitude of a place. In the early stages of Astronomy, were there many ways of finding latitude? When can we find many methods of finding latitude? Is the celestial pole a visible point? How then can we define it?



A perpendicular line through the center, *ZN*, represents the zenith and nadir points; and at right angles to this, through the center, is the horizontal line, *Hh*.

A telescope, *Tt*, and an index bar, *Ii*, at right angles to the telescope, are firmly fixed together, and made to revolve on the center of the mural circle.

The circle is graduated from the zenith and nadir points, each way, to the horizon, from 0 to 90 degrees.

When the telescope is directed to the horizon, the index points, *I* and *i*, will be at *Z* and *N*, and, of course, show 0° of altitude. When the telescope is turned perpendicular to *Z*, the index bar will be horizontal, and indicate 90 degrees of altitude.

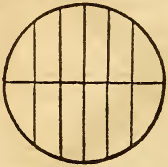
When the telescope is pointed toward any star, as in the figure, the index points, *I* and *i*, will show the position of the telescope, or its angle from the horizon, *which is the altitude of the star*.

As the telescope, and index of this instrument, can revolve freely round the whole circle, we can measure altitudes with it equally well from the north or the south; but as it turns only in the plane of the meridian, we can observe *only* meridian altitudes with it.

This instrument has been called a *transit circle*, and, says Sir John Herschel, "The mural circle is, in fact, at the same time, a transit instrument; and, if furnished with a proper system of vertical wires in the focus of its telescope, may be used as such."

When the telescope points to a star, how will the instrument show the altitude of the star? Can the telescope move out of the meridian?

For a transit instrument, the focus of the eye-piece must be furnished with a system of wires, as here represented, "one horizontal and five equi-distant threads or wires, " which always appear in the *field of view*, when properly illuminated, by day



Meridian Wires.

by the light of the sky, by night by that of a lamp, introduced by a contrivance not necessary here to explain. The place of this system of wires may be altered by adjusting screws, giving it a lateral (horizontal) motion; and it is by this means brought to such a position, that the middle one of the vertical wires shall intersect *the line of collimation* of the telescope, where it is arrested and permanently fastened. In this situation it is evident that the middle thread will be a visible representation of that portion of the celestial meridian to which the telescope is pointed; and when a star is seen to cross this wire in the telescope, it is in the act of culminating, or passing the celestial meridian. The instant of this event is noted by the clock or chronometer, which forms an indispensable accompaniment of the transit instrument. For greater precision, the moment of its crossing each of the vertical threads is noted, and a mean taken, which (since the threads are equi-distant) would give exactly the same result, were all the observations perfect, and will, of course, tend to subdivide and destroy their errors in an average of the whole."

To measure altitudes in all directions, we must have another instrument, or *a modification of this.*

Conceive this instrument to turn on a perpendicular axis parallel to ZN, in place of being fixed against a wall; and conceive, also, that the perpendicular axis rests on the center of a horizontal circle, and on that circle carries a horizontal index, to measure *azimuth angles.*

This instrument, so modified, is called an altitude and

How is the meridian made visible? What is the use of more than one vertical wire? What instrument must always accompany the transit instrument? What is meant by azimuth angles?

azimuth instrument, because it can measure altitudes and azimuths at the same time.

We have before said, that the altitude of the celestial pole must be midway between the greatest and least altitude of the *polar star*, provided *that star apparently circulates round the pole in a circle.* To decide that question, all we have to do is to measure the direction of the star, east and west of the meridian, and compare the amount with the difference between its greatest and least altitudes, and if the amount is the same, the apparent motion is unquestionably circular; but observation shows that the horizontal diameter of the circle is greater than the perpendicular diameter.

Hence, we cannot say that the midway altitude of the polar star is the measure of the latitude of the place. But if it is, the same kind of observation on other circumpolar stars, must give the same latitude. Such observations have been taken, and stars at the same distance from the pole gave the *same* latitude, and stars at different distances from the pole gave *different* latitudes; and the greater the distance of any star from the pole, the greater the latitude deduced from it. A star 30 or 35 degrees from the pole, observed from about the latitude of 40 degrees, will give the latitude 12 or 15 minutes of a degree greater than the pole star.

Astronomers investigated this subject thoroughly, and examined the apparent paths of the stars round the pole, by means of the *altitude and azimuth instrument,* and they were found to be not *exact circles;* but departed more and more from a circle, as the star was a greater and greater distance from the pole.

These curves were found to be somewhat like *ovals* — the longer diameter passing horizontally through the pole — the

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What is the latitude of a place measured by, or what does it correspond to? Do the stars apparently circulate round the pole in perfect circles? What kind of a figure does the motion of a star round the pole appear to describe? What is the position of the longest diameter of these ovals? What half of these ovals more nearly correspond to semicircles, the upper or lower?

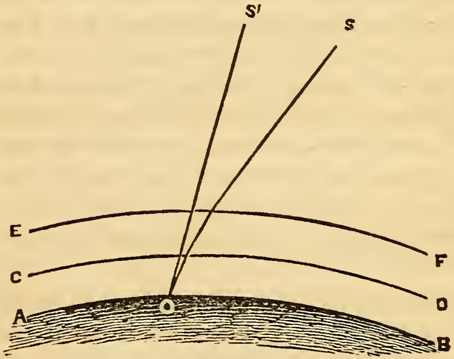
upper segments *very nearly semicircles*, and the lower segments *flattened* on their under sides.

With such evidences before the mind, men were not long in deciding that these discrepancies were owing to

ATMOSPHERICAL REFRACTION.

It is shown, in every treatise on natural philosophy, that light, passing obliquely from a rarer medium into a denser, is bent towards a perpendicular to the new medium.

Now, when rays of light pass, or are conceived to pass, from any celestial objects, through the earth's atmosphere to an observer, the rays must be *bent downward*, unless they pass perpendicularly through the atmosphere; that is, come from the zenith.



Let *AB*, *CD*, *EF*, &c. represent different strata of the earth's atmosphere. Let *s* be a star, and conceive a line of light to pass from the star through the various strata of air, to the observer, at O. When the ray of light meets the first strata, as *EF*, it is slightly bent downward; and as the air becomes more and more dense, its refracting power becomes greater and greater, which more and more bends the ray. But the direction of the ray, at the point where it meets the eye of the observer, will determine the position of the star as seen by him. Hence, the observer at *O* will see the star at *s'*, when its real position is at *s*.

As a ray of light, from any celestial object, is bent down-

Do lines of light pass through the atmosphere in straight lines? In what direction are the rays bent?

ward, therefore, as we may see by inspecting the figure, *the altitude of all the heavenly bodies is increased by refraction.*

This shows that all altitudes, as they come from the instrument, must be *apparent* altitudes and not *true* altitudes, and the apparent altitude is always greater than the corresponding true altitude, because the body is elevated by refraction.

If it were not for refraction, the curves round the pole would be *perfect circles*, and the mathematician, by means of the altitude and azimuth, which can be taken at any and every point of a curve, can determine how much it deviates from a circle, and from thence the amount of refraction, at the several points.

By using the refraction thus imperfectly obtained, he can correct his altitudes, and obtain his latitude, to considerable accuracy. Then, by repeating his observations, he can further approximate to the refraction.

In this way, by a multitude of observations and computations, the table of refraction (which appears among the tables of every astronomical work) was established and drawn out.

The effect of refraction, as we have already seen, is to increase the altitude of all the heavenly bodies. Therefore, by the aid of refraction, the sun rises before it otherwise would, and does not set as soon as it would if it were not for refraction; and thus the apparent length of every day is increased by refraction, and *more than half of the earth's surface is constantly illuminated.* The extra illumination is equal to a zone, entirely round the earth, of about 40 miles in breadth.

As the refraction in the horizon is about 33′ of a degree, the length of a day, at the equator, is *more than four minutes* longer than it otherwise would be, and the *nights four minutes shorter.*

At all other places, where the diurnal circles are oblique to

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What is apparent altitude? What is true altitude? Which is greatest, the apparent or the true altitude of a heavenly body? What effect does refraction have on the time of the sun's rising? What on the length of a day?

the horizon, the difference is still greater, especially if we take the average of the whole year.

In high northern latitudes, the long days of summer are very materially increased, in length, by the effects of refraction; and near the pole, the sun rises, and is kept above the horizon, even for days, longer than it otherwise would be, owing to the same cause.

Refraction varies very rapidly, in its amount, near the horizon; and this causes a visible distortion of both sun and moon, just as they rise or set.

For instance, when the lower limb of the sun is just in the horizon, it is elevated, by refraction, 33′.

But the altitude of the upper limb is then 32′, and the refraction, at this altitude, is 27′ 50″, elevating the upper limb by this quantity. Hence, we perceive, that the lower limb is elevated more than the upper; and the perpendicular diameter of the sun is apparently shortened by 5′ 10″, and the sun is distinctly seen of an oval form, which deviates more from a circle below than above.

The apparently dilated size of the sun and moon, when near the horizon, has nothing to do with refraction: *it is a mere illusion*, and has no reality, as may be known by applying the following means of measurement.

Roll up a tube of paper, of such a size and dimensions as just to take in the rising moon, at one end of the tube, when the eye is at the other. After the moon rises some distance in the sky, observe again with this tube, and it will be found that the apparent size of the moon will even more than fill it.

When small stars are near the horizon, they become invisible; either the refraction enfeebles and dissipates their light,

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What effect does refraction have on the length of a day in high northern latitudes? How much more than half of the earth is enlightened by the sun at any one time? What effect does refraction have on the apparent shape of the sun at rising and setting? Why should refraction give that appearance? Is the moon apparently larger when near the horizon, than when near the zenith?

or the vapors, which are always floating in the atmosphere, serve as a cloud to obscure them.

Having shown the possibility of making a table of refraction corresponding to all apparent altitudes, we can now, by applying its effects to the observed altitudes of the circumpolar stars, obtain the true latitude of the place of observation.

A table of refraction is to be found in the latter part of this volume, and we give a few examples to explain its use.

1. *The apparent altitude of a star was* 31° 20′, *what was its true altitude?*

By inspecting the table we find 1′ 35″ corresponds to the apparent altitude 31° 20′.

Therefore, from - -	31° 20′ 00″
Subtract, - - -	1′ 35″
True altitude required, -	31° 18′ 25″

2. *The apparent altitude of the sun's center, was observed to be* 22° 12′ 12″, *what was its true altitude?*

Apparent altitude, -	22° 12′ 12″
From the table, (Sub.)	2′ 22″
True altitude, - -	22° 9′ 50″

3. *The altitude of a star was observed to be* 8° 32′, *what was its true altitude?*

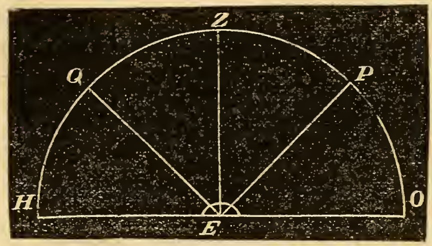
From, - - -	8° 32′ 00″
Subtract 6′ 9″ from the table,	6′ 9″
True altitude, at that time,	8° 25′ 51″

Thus we might add examples without end.

Let it be borne in mind, that the latitude of any place on the earth, *is the inclination of its zenith to the plane of the equator;* which inclination *is equal to the altitude of the pole above the horizon.*

What is the inclination of the zenith and the celestial equator equal to?

We demonstrate this as follows. Let E represent the earth.



Now as an observer always conceives himself to be on the topmost part of the earth, the vertical point, Z, truly and naturally represents his zenith. Through E, draw $HE\ O$, at right angles to EZ; then $HE\ O$ will represent the horizon (for the horizon is always at right angles to the zenith).

Let EQ represent the plane of the equator, and at right angles to it, from the center of the earth, *must be the earth's axis;* therefore, EP, at right angles to EQ, is the direction of the pole.

$$\begin{array}{ll} \text{Now the arcs,} \quad - \quad - & ZP+PO=90^\circ, \\ \text{Also,} \quad - \quad - \quad - \quad - & ZP+ZQ=90^\circ, \\ \hline \text{By subtraction,} \quad - \quad - & PO-ZQ=0; \end{array}$$

Or, by transposition, the arc $PO=ZQ$; that is, the altitude of the pole is equal to the latitude of the place; which was to be demonstrated.

In the same manner, we may demonstrate that the arc HQ is equal to the arc ZP; that is, *the polar distance of the zenith is equal to the meridian altitude of the celestial equator.* Now, we perceive, that by knowing the latitude, we know the several divisions of the celestial meridian, from the northern to the southern horizon, namely, OP, PZ, ZQ, and QH.

By observing the extreme altitudes of the circumpolar stars, and correcting such altitudes for refraction, the half sum of the true extreme altitudes of any one star, will be the latitude of the place of observation.

What place is the earth's axis perpendicular to? What is the altitude of the pole equal to? What is the polar distance of the zenith equal to?

We give an example.

The greatest observed altitude of the polar star,	41° 37′
Refraction, - - - - - -	1′ 5″
True altitude, - - - -	41° 35′ 55″
The least observed altitude of the same star,	38° 39′ 15″
Refraction, - - - - -	1′ 12″
Least true altitude - - - -	38° 38′ 3″
Greatest true altitude, - - -	41° 35′ 55″
Sum, - - - - - - -	80° 13′ 58″
Half sum latitude - - - -	40° 6′ 59″

We might take any other circumpolar star, as well as the pole star—but the pole star is the least liable to error, because of the smaller circle it describes.

We are now prepared to observe and record the declination of the stars, or any heavenly body.

The declination of a star, or any celestial object, is its meridian distance from the celestial equator.

To determine the declination of a star, we must observe its meridian altitude (by some instrument, say the mural circle,) and correct the altitude for refraction, the difference will be the star's *true altitude.*

If the true meridian altitude of the star is less than the meridian altitude of the celestial equator, then the declination of the star is south. If the meridian altitude of the star is greater than the meridian altitude of the equator, then the declination of the star is north.

These truths will be apparent by merely inspecting the last figure.

How is the latitude of a place originally determined? What is understood by the declination of a star? When the declination of a star is 0, how far is it from the pole?

EXAMPLES.

1. *Suppose an observer in the latitude of* 40° 12′ 18″ *north, observes the meridian altitude of a star, from the southern horizon, to be* 31° 36′ 37″; *what is the declination of that star?*

From - - - - -				90°	0′	00″
Take the latitude, - - -				40°	12′	18″
Diff. is the meridian alt. of the equator,				49°	47′	42″
Alt. of star,	31°	36′	37″			
Refraction,		1′	32″			
True altitude,	31°	35′	5″ - -	31°	35′	5″
Declination of the star, south, - -				18°	12′	37″

2. *The same observer finds the meridian altitude of another star, from the southern horizon, to be* 79° 31′ 42″; *what is the declination of that star?*

Observed altitude, - - -	79°	31′	42″
Refraction, - - - -			11
True altitude, - - - -	79	31	31
Altitude of equator, - - - -	49	47	42
Star's declination, north, - -	29°	43′	49″

3. *The same observer, and from the same place, finds the meridian altitude of a star, from the northern horizon, to be* 51° 29′ 53″; *what is the declination of that star?*

Observed altitude, - - -	51°	29′	53″
Refraction, - - - - -			46
True altitude of star, - - -	51	29	7
Altitude of pole (or latitude), -	40	12	18
Star from the pole (or polar dist.),	11	16	49
Polar dist., from 90°, gives decl. north,	78°	43′	11″

How do you find the meridian altitude of the equator? When a star comes to the zenith, how can we find its declination?

In this way the *declination* of every star in the visible heavens can be determined.

In Chapter IV, we explained how to obtain the difference of the right ascension of the stars, and this, with the declination, *will enable us to mark down the position of the stars, on a globe, and thus give a true representation of the appearance of the heavens.*

Quite a region of stars exists around the south pole, which are never seen from these northern latitudes; and to observe them, and define their positions, Dr. Halley, Sir John Herschel, and several other English and French astronomers, have, at different periods, visited the southern hemisphere. Thus, by the accumulated labors of many astronomers, we at length have correct catalogues of all the stars in both hemispheres, even down to many that are never seen by the naked eye.

There are several constellations in the southern regions, worthy of notice—the *Southern Cross* and the *Magellan Clouds*. The Southern Cross very much resembles a cross; so much so, that any person would give the constellation that appellation. Its principal star is, in the right ascension, 12 h. 20 m., and south declination 33°.

The Magellan Clouds were at first supposed to be clouds, by the navigator Magellan, who first observed them. They are four in number; two are white, like the Milky Way, and have just the appearance of little white clouds. They are *nebulæ*. The other two are black—extremely so—and are supposed to be places entirely devoid of all stars; yet they are in a very bright part of the Milky Way—right ascension 10 h. 40 m., declination 62° south.

Can we see all the stars in the heavens from the northern latitudes? What is said of the stars in the southern hemisphere? What are the Magellan Clouds? Have they all a similar appearance?

CHAPTER VI.

SCIENTIFIC METHODS OF FINDING PARTICULAR STARS.

Among our tables will be found a catalogue of one hundred of the principal stars, *inserted for the purpose of teaching the learner the scientific method of defining the stars.*

To have a clear understanding of the method we are about to explain, we must again consider that right ascension is reckoned from the equinox, eastward along the equator, from 0h. to 24 hours. When the sun comes to the equator, in March, its right ascension is 0; and from that time its right ascension increases about four minutes in a day, through the year, to 24 hours; and then it is again at the eqninox, *and the 24 hours are dropped.*

But whatever be the right ascension of the sun, it is apparent noon when it comes to the meridian; and the more eastward a body is, the later it is in coming to the meridian. Thus: *If a star comes to the meridian at two o'clock in the afternoon (apparent time),* * *it is because its right ascension* IS TWO HOURS GREATER *than the right ascension of the sun.*

Therefore, if from the right ascension of a star we subtract the right ascension of the sun, the remainder will be the apparent time for that star to come to the meridian.

If we put ($R\ast$) to represent the star's right ascension, and ($R\odot$) to represent that of the sun, and T to represent the *apparent time* that the star passes the meridian, then we shall have the following equation:

$$R\ast - R\odot = T;$$

By transposition $$R\ast = R\odot + T;$$

*We will explain the difference between apparent time, and common clock time, in a future chapter. The difference is never 17 minutes, commonly much less.

How do you find the right ascension of a star, or any heavenly body?

That is, to find the right ascension of a star, (or any heavenly body), *Add the right ascension of the sun to the apparent time the body is observed to pass the meridian.*

The right ascension of the sun is given, in the Nautical Almanac (and in many other almanacs), for every day in each year, when the sun is on the meridian of Greenwich; but many of the readers of this work may not have such an almanac at hand, and for their benefit, we give the right ascension for every fifth day of the year 1846, in the following table, which will show the right ascension for the same day in any other year within *three* minutes of time during the present century, and this will be sufficiently accurate to illustrate the principle.

SUN'S RIGHT ASCENSION FOR 1846.

Day of Mo.	January.	February.	March.	April.	May.	June.
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
1	18 46 52	20 59 11	22 48 17	0 41 52	2 23 6	4 35 48
5	19 4 30	21 15 22	23 3 12	0 56 26	2 48 25	4 52 12
10	19 26 21	21 35 18	23 21 40	1 14 43	3 7 47	5 12 50
15	19 47 57	21 54 54	23 40 0	1 33 6	3 27 24	5 33 34
20	20 9 17	22 14 12	23 58 14	1 51 38	3 47 15	5 54 22
25	20 30 19	22 33 14	0 16 25	2 10 22	4 7 20	6 15 10
30	20 51 0		0 34 36	2 29 17	4 27 18	6 35 55

Day of Mo.	July.	August.	September.	October.	November.	December.
	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.
1	6 40 4	8 44 55	10 41 0	12 29 4	14 25 16	16 29 1
5	6 56 34	9 0 23	10 55 29	12 43 36	14 41 2	16 46 23
10	7 17 5	9 19 29	11 13 30	13 1 54	15 1 5	17 8 17
15	7 37 25	9 38 21	11 31 28	13 20 24	15 21 28	17 30 22
20	7 57 33	9 56 60	11 49 25	13 39 8	15 42 14	17 52 33
25	8 17 28	10 15 27	12 7 24	13 58 9	16 3 19	18 14 46
30	8 37 7	10 33 44	12 25 27	14 17 27	16 24 43	18 36 57

To obtain sufficient data to apply the preceding rule, the observer should adjust his watch to apparent time, that is, apply the equation of time, or in other words, see that his watch shows 12 o'clock when the sun is on the meridian, and he must know the direction of the meridian from which he takes the observations. In short, by the range of definite objects, he

When is it apparent noon?

must be able to decide, within *two or three minutes*, when a celestial body is on the meridian.

Thus being all prepared, we give a few

EXAMPLES.

1. *Being in latitude about* 40° *north, and on the 20th of May, at 9h. 27m. in the evening, apparent time, I observed a lone bright star, of about the 2d magnitude, on the meridian. I had no instrument to measure its altitude, but I simply judged the altitude to be about* 42° *from the southern horizon. What star was this?*

We determine it thus:

On the 20th of May, at 9 in the evening, the right ascension of the sun cannot be far from, - - - -	3h 49m
To this add the apparent time of passing the merid.	9h 27m
The sum is the right ascension of the star. -	13h 16m

By inspecting the catalogue of stars, we find the right ascension of Spica is registered at 13h 17m 8s., therefore it is *more than probable* that the star observed was Spica.

To make it sure, we find that the declination of Spica in the catalogue, is 10° 21′ 35″ south; but in latitude 40° north, the meridian altitude of the celestial equator must be 50°; and any stars south of that must have a less altitude. Therefore, the meridian altitude of *Spica* must be 50°, less 10° 21′, or 39° 39′; but the star I observed, I simply judged to have had an altitude of 42°. It is very possible that I should err, in altitude, two or three degrees;* *but, it is not possible that the star I*

*Ten or twenty degrees, near the horizon, is apparently a much larger space than the same number of degrees near the zenith. Two stars, when near the horizon, appear to be at a greater distance asunder than when their altitudes are greater. The variation is a mere optical illusion; for, by applying instruments to measure the angle in the different situations, we find it the same. Unless this fact is taken into consideration, an observer will always conceive the altitude of any object to be greater than it really is, especially if the altitude is less than 45 degrees.

If a star was observed to pass the meridian at 10h 12m in the evening, when the sun's right ascension was 2h 5m., what must have been the right ascension of that star?

observed should be any other star than Spica; for there is no other bright star near it. This is one of the lunar stars.

Being now certain that this star is Spica, I can observe it in relation to its appearance—the small stars that are near it, and the clusters of stars that are about it—or the fact, that no remarkable constellation is near it. In short, I can so make its acquaintance as to know it ever after; but I am unable to convey such acquaintance to others by language; true knowledge, in this particular, demands personal observation.

2. *On the 3d of July, at 9h 30m. apparent time, in the evening, in latitude 39° north, and longitude about 75° west, a star of the first magnitude was observed to pass the meridian. The star was of a deep red color, and, as near as my judgment could decide, its altitude was between 25° and 30°. Two small stars were near it, and a remarkable cluster of smaller stars were west and northwest of it, at the distances of 5°, 6°, or 7°. What star was this?*

Sun's right ascension at the time, - -	6h 50m
Apparent time the star passed meridian, -	9h 30m
Right ascension of the star, - - -	16h 20m

By inspecting the catalogue of stars, I find *Antares* to have a right ascension of 16h. 20m. 2s. and a declination of 26° 4′, south.

In the latitude mentioned, the meridian altitude of the celestial equator must be - - - - -	51° 0′
Objects *south of that plane must be less, hence* (sub.)	26° 54′
Meridian altitude of Antares, in lat. 39° north,	24° 56′

As the observation corresponds to the right ascension of *Antares* (as nearly as possible, considering errors in observations, and probably in the watch), and as the altitudes do not differ many degrees (within the limits of guess work), it is certain

Can any one recognize particular stars in the heavens without personal observation? In the 2d example, how do we know that the star observed was Antares? What is the right ascension of Antares?

that the star observed was ANTARES. By its peculiar *red color*, and the remarkable clusters of stars surrounding it, I shall be able to recognize this star again, without the trouble of direct observation.

3. *On the night of the* 20*th of June, in latitude* 40° *north and longitude* 75° *west, at* 1*h* 47*m. past midnight, apparent time, a star of the first magnitude was observed to pass the meridian : two other stars of about the third magnitude were within* 3° *of it ; the three stars forming nearly a right line north and south ; the altitude of the principal stars from the south was about* 60°. *What star was it?*

In these examples, the time must be reckoned from noon to noon again, 24 hours, and if the sum of any addition exceeds 24 hours, the excess only must be taken.

In this example, 1h 47m after midnight must be written 13h 47m.

The longitude of 75° west, also adds 5 hours to the Greenwich time, hence the time that this star passed the meridian, was June 20th, the 18th hour of that day, within 6 hours of the 21st of June. To this time we compute the sun's right ascension.

Sun's right ascension at the time the star was on the meridian could not be far from, - - - -	5h 58m
To this add, - - - - - -	13 47
Sum, is the right ascension of the star, -	19h 45m.

By inspecting the catalogue of stars, we find the right ascension of *Altair* 19 h. 43 m. 15 s., and its declination 8° 27′ *N.* In latitude 40° *N.*, the declination of 8° 27′ *N.* will give a meridian altitude of 55° 27′; and, in short, I know the star observed must be *Altair*, and the two other stars, near it, I recognize in the catalogue.

What is the color of Antares? Is there a cluster of stars near Antares, and in what direction? Suppose the time is after midnight, how do you reckon it? If the sum found by adding the right ascension of the sun to the time a body passed the meridian, should exceed 24 hours, what would you do?

By taking these observations, any person may become acquainted with all the principal stars, and the general aspect of the heavens; but no efforts, confined merely to the study of books, will accomplish this object.

The rule here used is not solely confined to the stars, it is applicable to any heavenly body, *moon*, *comet*, or *planets*, and if the foregoing examples are understood, the reader will have a good general idea how the right ascension of the moon, and planets, are from time to time, determined by *observation.*

The time of passing the meridian is *relatively* but another term for right ascension, and if observations are made on any bright star, and no corresponding star is to be found in the catalogue, such a star would probably be found to be a planet, and if a planet, its right asension will change.

WE MAY NOW REVERSE THE PROBLEM.

Suppose that we wish to find any particular star, for example, *Aldebaran.*

It is a clear star light night, January 19th, the sun's right ascension by the Nautical Almanac, I find approximately to be about 20h. 5m., and in the catalogue of stars I find the right ascension of Aldebaran to be 4h. 27m. disregarding the seconds.

The equation, $R\ast - R\odot = T$ is general, and shows us that we must subtract the right ascension of the sun from the right ascension of the star, and the remainder is the apparent time that the star comes to the meridian. To render the subtraction possible, we must in some cases increase the right ascension of the star by 24 hours.

	h.	*m.*
From $R\ast + 24$ hours - - -	28	27
Subtract $R\odot$ - - - - -	20	5
Aldebaran on the meridian (Jan. 19th), -	8	22

How can we find the right ascension of the moon, or a planet, by observation? How do we find the time when any particular star will pass the meridian?

This shows, that if the stars are visible on the 19th of January, of any year, and we look along the meridian at about 20 minutes after 8 in the evening, we shall certainly see Aldebaran.

Suppose it the 10th of March, of any year, and a learner wishes to be sure of finding the star *Sirius.*

He must inspect the catalogue of stars, and he will find its right ascension to be 6h. 38m.; and by the table on page 51, or better, by a Nautical Almanac, he will find the right ascension of the sun, on the 10th of March, to be not far from 23h. 22m., therefore

		h.	*m.*	
From *R*✳ 6h. 38m.+24h.	-	30	38	
Subtract - - -		23	22	
Sirius on the meridian, March 10th,		7	16	apparent time.

Now, if on that day of the year, at about 16 minutes past 7, apparent time in the evening, we observe the heavens, we shall certainly see Sirius in a southern direction, and by taking into consideration our latitude and the declination of the star, we can form a very correct estimate of its altitude, and we could as readily find the star as we could find the moon.

In this manner we may find when any particular star will come to the meridian, and take that time to observe it. Speaking loosely, the same star comes to the meridian at the same hour and minute, *sidereal time,* througout the year, but at different times, on different days, by the *solar clock.* On account of the sun changing its right ascension from day to day, *sidereal time is in fact right ascension.*

Do the stars come to the meridian at the same time throughout the year, by the sidereal clock? Why then do they vary by the solar or common clock?

CHAPTER VII.

PLANETS — FIGURE AND MAGNITUDE OF THE EARTH.

In the preceding chapter, we have been careful to impress the fact, that the great mass of the stars pass the meridian at regular intervals of time, and that the same star will pass the meridian at intervals of 24 sidereal hours, which corresponds to 23h. 56m. 4.09s. of mean solar time.

If sidereal time of 24h. between the passage of the same star over the meridian is taken for the standard measure of time, then the *mean* intervals between two consecutive passages of the sun across the meridian is 24h. 3m. 56.5554s.

We say *mean* interval, because this interval is not always the same, and not being the same, gives rise to the equation of time. The cause of this inequality, and consequently the cause of the equation of time, will be examined hereafter; the fact was first observed by noting the passage of the sun across the meridian, in comparison with a well regulated sidereal clock.

All those stars that pass the meridian at equal intervals ot time, and always at the same altitude, if observed from the same station, are called and must be in fact, *fixed stars*, but the sun coming to the meridian at unequal intervals of time, and at different altitudes from the horizon, shows that it is not a *fixed* body.

When we compare the times of the moon passing the meridian, with the astronomical clock, we are very forcibly struck with the *irregularity* of the interval.

The least interval between two successive transits of the moon (which may be called a *lunar day*), is observed to be

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What has the author been careful to impress, in the previous chapter? What astronomical interval is always the same? Does the sun come to the meridian at equal intervals of time? To what does this give rise?

about 24h. 42m.; the greatest, 25h. 2m,; and the mean, or average, 24h. 54m., of mean *solar time.*

These facts show, conclusively, that the moon is not a fixed body, like a fixed star, for then the interval would be 24 hours of sidereal time.

But as the interval is always more than 24 hours, it shows that the general motion of the moon is eastward, among the stars, with a daily motion varying from 10½ to 16 degrees, traveling, or appearing to travel, through the whole circle of the heavens (360°) in a little more than 27 days.

Thus these observations, however imperfectly and rudely taken, at once disclose the important fact, that the sun and moon are in constant change of position, in relation to the stars, and to each other; and we may add, that the chief object and study of astronomy, is, to discover the reality, the causes, the nature, and extent of such motions.

Besides the sun and moon, several other bodies were noticed as coming to the meridian at very unequal intervals of time, intervals not differing so much from 24 sidereal hours as the moon, but, unlike the sun and moon, the intervals were sometimes less, sometimes greater, and sometimes equal to 24 sidereal hours.

These facts show that these bodies have a real, or apparent motion, *among the stars*, which is sometimes westward, sometimes eastward, and sometimes stationary; but, on the whole, the eastward motion predominates; and, like the sun and moon, they finally perform revolutions through the heavens from west to east.

Only *four* such bodies (stars) were known to the ancients, namely, *Venus*, *Mars*, *Jupiter*, and *Saturn.*

These stars are a portion of the *planets* belonging to our solar system, and, by subsequent research, it was found that the Earth was also one of the number. As we come down to more modern times, several other planets have been discovered,

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What direction does the moon move in respect to the fixed stars? How many degrees does it move in a day? In how many days will it make a revolution? What other wandering bodies were observed by the ancients?

namely *Mercury, Uranus, Vesta, Juno, Ceres, Pallas,* and very recently, *Neptune, Iris, Hebe, Flora, Astrea,* and one or two others of no moment to record in a work like this.

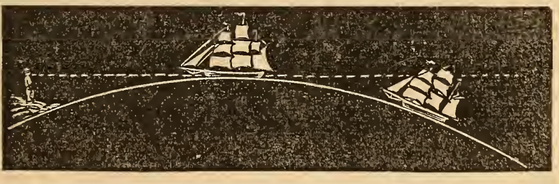
We here mention the names of these planets in the order of their discovery, and not in the order in which they revolve in the system, for as yet we have no definite idea of a planet or a planetary system. In the tables, they will be found in their proper order in reference to the center of the system.

It is unreasonable and unnatural to suppose that the apparent motions of these *wandering stars* are their real motions, as viewed from a *stationary point;* such irregularities in apparent motions can only be accounted for, on the supposition that the observer, on the earth, that is, the earth itself, is in motion as well as the planets.

The ancients, taking the first impressions of their senses, supposed the earth to be a plane, and the principal object in the universe, and under this idea the planetary motions were inexplicable; but we shall not pretend to explain the slow process of knowledge which gradually melted away this erroneous impression, we shall simply bring forth science, as it is now known to exist, and therefore we must now consider the

FIGURE AND MAGNITUDE OF THE EARTH.

The greater portion of the surface of the earth is water, and the surface of water is *every where convex,* as any observer may convince himself who takes the opportunity to do so. In coming in from sea, the high land, back in the country, is seen before the shore, which is nearer to the observer; the tops of trees, and the tops of towers, are seen before their bases. If



Is it probable that very irregular motions, such as we observe in the planets, are real motions? Did the ancients suppose the earth to be a plane? How do we know that it is not a plane?

the observer is on shore, viewing an approaching vessel, he sees the topmast first; and from the top, downward, the vessel gradually comes in view. These facts are sufficiently illustrated by the adjoining figure.

One of the most striking observations of this kind, is made in the Mediterranean sea. On the island of Minorca, near its center, stands Mount Toro, and on the very vertex of the mountain stands a Monastery, three stories high.

On approaching the island from any direction, in moderate and clear weather, the first object that comes to view is the top of the Monastery, and approaching nearer, the upper story with its windows, becomes distinctly visible — continuing to approach, the whole building gradually becomes visible, standing apparently alone on the surface of the sea. Then the mountain itself appears to rise, and finally, the island and shores around. Similar observations are made every day, on every sea, and on every portion of the earth, which shows to a demonstration that the earth is *convex* on every part, hence it must be a globe or sphere, or nearly so.

In addition to this, the earth has been *circumnavigated* many times, and navigators make their computations on the supposition that the earth is a sphere, and this supposition, at all times corresponding to fact, settles the question.

To this, we will simply call to mind the fact, that the shadow of the earth, on the moon, in eclipses of the moon, is always circular, which could not *always* be the case if the earth had any other shape than that of a sphere.

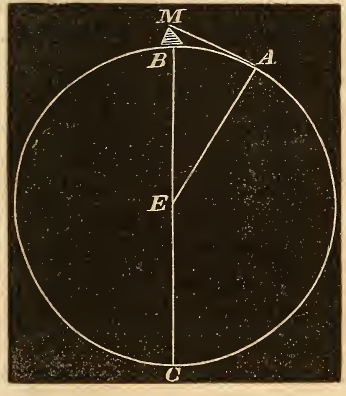
On the supposition that the earth is a sphere, there are several methods of measuring it, without the labor of applying the measure to every part of it. The first, and most natural method (which we have already mentioned), is that of measuring any definite portion of the meridian, and from thence computing the value of the whole circumference.

What is said of the Monastery on the island of Minorca? What is said of the shadow of the earth? If the earth is spherical, how can we measure it, without measuring entirely round?

Thus, if we can know the number of degrees, and parts of a degree, in the *arc AB*, and then measure the distance in miles, we in fact virtually know the whole circumference; for whatever part the arc *AB* is of 360 degrees, the same part, the number of miles in *AB*, is of the miles in the whole circumference.

That is, *as the arc AB is to the whole circumference* 360°, *so is the number of miles in AB to the number of miles in the circumference.*

To find the arc *AB*, the latitude of the two points, *A* and *B*, must be very accurately taken, and their difference will give the *arc* in *degrees, minutes,* and *seconds.* Now *AB* must be measured simply in distance, as *miles, yards,* or *feet;* but this is a laborious operation, requiring great care and perseverance. To measure, *directly,* any considerable portion of a meridian, is indeed impossible, for local obstructions would soon compel a deviation from any definite line; but still the measure can be continued, by keeping an account of the deviations, and *reducing* the measure to a meridian line.



When we know the hight of a mountain, as represented in this figure, and at the same time know the distance of its visibility over the surface of the earth; that is, know the line *MA;* then we can compute the line *MC*, by a simple theorem in geometry; thus,

$$CM \times MB = (AM)^2;$$

Or, $CM = \frac{(AM)^2}{MB}$

Now as the right hand mem-

How do we find the arc *AB*? How do we find the length of the arc in miles or feet? What rule have we to find the diameter of the earth, when we know the hight of a mountain, and the distance of the visible horizon therefrom?

ber of this equation is known, CM is known; and as part of it (MB) is already known, the other part, BC, the diameter of the earth, thus becomes known.

This method would be a very practical one, if it were not for the uncertainty and variable nature of refraction near the horizon;* and for this reason, this method is never relied upon, although it often well agrees with other methods. As an example under this method, we give the following:

A mountain, two miles in perpendicular hight, was seen from sea at a distance of 126 miles. If these data are correct, what then is the diameter of the earth?

$$\text{Solution: } MC=\frac{(126)^2}{2}=63\times126=7938. \quad BC=7936.$$

This same geometrical theorem serves to compute the *dip of the horizon.* The true horizon is at right angles from the zenith; but the navigator, in consequence of the elevation of his vessel, can never use the true horizon; he must use the sea offing, making allowance for its dip. If the navigator's eye were on a level with the sea, and the sea perfectly stable, the true and apparent horizon would be the same. But the observer's eye must always be above the sea; and the higher it is, the greater the dip; and the amount of dip will depend on the hight of the eye, and the diameter of the earth. The difference between the angle AMC, and a right angle (which is equal to the angle AEM), is the measure of the dip corresponding to the hight BM.

For the benefit of navigators, a table has been formed, showing the dip for all common elevations.

No one should object to considering the earth a sphere, because its surface is diversified with mountains and valleys, for the highest mountain on the earth is not so large, compared

*Sometimes a distant object over sea appears distinctly visible, and at other times appears depressed below the horizon.

What objection is there to the last mentioned method of measuring the earth? What is the dip of the horizon? If the observer's eye were down on the level of the sea, would there be any dip?

to the earth itself, as a fine grain of sand is compared to a globe of 18 inches in diameter. No one objects to calling an orange round, because of the roughness of its external surface.

After correct views were entertained, as to the magnitude of the earth, and its revolution on an axis, philosophers concluded that its equatorial diameter might be greater than its polar diameter; and investigations have been made to decide that fact.

If the earth were exactly spherical, it is plain that the curvature over its surface would be the same in every latitude; but if not of that figure, a degree would be longer on one part of the earth than on another. "But," says Herschel, "when we come to compare the measures of meridianal arcs made in various parts of the globe, the results obtained, although they agree sufficiently to show that the supposition of a spherical figure is not *very* remote from the truth, yet exhibit discordances far greater than what we have shown to be attributable to errors of observation; and which render it evident that the hypothesis, in strictness of its wording, is untenable. Without troubling the reader with the details of actual measurement, which have been made from time to time with all care and precision, it is sufficient to state that the *measured length of a degree increases with the latitude*, being greatest near the poles and least near the equator, giving the following magnitude of the earth:

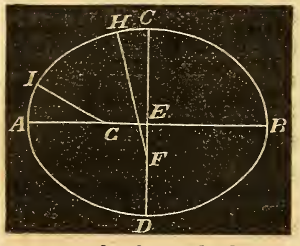
Greatest, or equatorial diameter,	7924.65	miles.
Least, or polar diameter, -	7899.17	
Diff. or polar compression, -	26.48	

The proportion of the diameters is very nearly that of 298 to 299, and their diff. $\frac{1}{299}$ of the greater, or a very little over $\frac{1}{300}$. The shape of the earth, thus ascertained by actual measurement, is just what theory would give to a body of water equal to our globe, and revolving on an axis in 24 hours; and

Is the earth exactly spherical, aside from the roughness of its surface? How was the shape of the earth determined? What is the length of the equatorial diameter? What of the polar?

this has caused many philosophers to suppose that the earth was formerly in a fluid state.

If the earth were a sphere, a plumb line at any point on its surface would tend directly towards the center of gravity of the body; but the earth being an ellipsoid, or an *oblate spheroid*, and the plumb lines, being perpendicular to the surface at any point, do not tend to the center of gravity of the figure, but to different points, as represented in the figure.



The plumb line at *H* tends to *F*, yet the mathematical center, and center of gravity of the figure, is at *E*. So at *I*, the plumb line tends to the point *G;* and as the length of a degree at *A*, is to the length of a degree at *H*, so is *AG* to *HF*. If, however, a passage were made through the earth, and a body let drop through it, the body would not pass from *I* to *G:* its *first tendency* at *I* would be toward the point *G;* but after it passed below the surface at *I*, its tendency would be *more and more* toward the point *E*, the center of gravity; but it would not pass exactly through that point, *unless dropped* from the point *A*, or the point *C*.

If the earth were a perfect and stationary sphere, the force of gravity, on its surface, would be everywhere the same; but, it being neither stationary, nor a perfect sphere, the force of gravity, on the different parts of its surface, must be different. The points on its surface, nearest its center of gravity, must have more attraction than other points more remote from the center of gravity; and if those points which are more remote from the center of gravity have also a rotary motion, there will be a diminution of gravity on that account.

What caused philosophers to suppose that the earth's equatorial diameter was greater than its polar diameter? Does the plumb line always tend towards the mathematical center of the earth? Does it always tend perpendicularly to the surface of still water?

Let AB in the figure, represent the equatorial diameter of the earth, and CD the polar diameter; and it is obvious that E will be the center of gravity, of the whole figure, and that the force of gravity at C and D will be greater than at any other points on the surface, because EC, or ED, are less than any other lines from the point E to the surface. The force of gravity will be greatest on the points C and D, also, because they are stationary: all other points are in a circular motion; and circular motion has a tendency to depart from the center of motion, and, of course, to diminish gravity. The diminution of the earth's gravity by the rotation on its axis, amounts to its $\frac{1}{289}$th part* at the equator. By this fraction, then, is the weight of the sea about the equator *lightened*, and thereby rendered susceptible of being supported at a higher level than at the poles, where no such *counteracting* force exists.

It is this centrifugal force itself that changed the shape of the earth, and made the equatorial diameter greater than the polar. Here, then, we have the same cause, exercising at once a direct and an indirect influence. Owing to the elliptic form of the earth, and independently of the centrifugal force, its attraction ought to increase the weight of a body, in going from the equator to the pole, by nearly its $\frac{1}{590}$th part; which, together with the $\frac{1}{289}$th part, due from centrifugal force, make the whole quantity $\frac{1}{194}$th part; that is, 194 pounds pressure at the equator, will press with a force of 195 pounds when carried to the poles, which corresponds with the result of observations deduced from the vibrations of pendulums.

The form of the earth is so nearly a sphere, that it is considered such, in geography, navigation, and in the general problems of astronomy.

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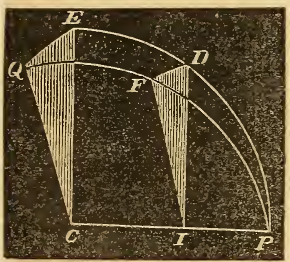
*For the computation which brings this result, see the university edition of Astronomy.

Give two distinct reasons why the force of attraction is greater at the poles than at the equator? In what proportion do bodies increase in weight on being carried from the equator to the poles?

The average length of a degree is $69\frac{1}{4}$ English miles; and, as this number is fractional, and inconvenient, navigators have tacitly agreed to retain the ancient, rough estimate of sixty miles to a degree; calling the mile a *geographical* mile. Therefore, the geographical mile is longer than the English mile.

As all meridians come together at the pole, it follows that a degree, between the meridians, will become less and less as we approach the pole; and it is an interesting problem to trace the *law* of decrease.

This law will become apparent, by inspecting the figure in the margin.



Let EQ represent a degree, on the equator, and EQC a sector on the plane of the equator, and of course EC is at right angles to the axis CP. Let DFI be any plane parallel to EQC; then we shall have the following proportion;

$$EC : DI :: EQ : DF.$$

In trigonometry, EC is known as the radius of the sphere; DI as the cosine of the latitude of the point D (the numerical values of sines and cosines, of all arcs, are given in trigonometrical tables): therefore we have the following rule, to compute the length of a degree between two meridians, on any parallel of latitude:

RULE.—*As radius is to the cosine of the latitude, so is the length of a degree on the equator, to the length of a parallel degree in that latitude.*

We give the following as an example, although pupils will not, and cannot fully comprehend it, unless they are acquainted with trigonometry.

What is the average length of a degree on the earth? What is the difference between an English and a geographical mile? By what rule do two meridians approach each other between the equator and the poles?

Calling a degree, on the equator, 60 miles, what is the length of a degree of longitude, in latitude 42°?

SOLUTION BY LOGARITHMS.

As radius (see tables), - - - -	10.000000
Is to cosine 42° (see tables), - - -	9.871073
So is 60 miles (log.), - - - -	1.778151
To $44\frac{582}{1000}$ miles, - *Ans.* - -	1.649224

At the latitude of 60°, the degree of longitude is 30 miles; the diminution is very slow near the equator, and very rapid near the poles.

In navigation, the *DF*'s are the known quantities obtained by the estimations from the log line, etc.; and the navigator wishes to convert them into longitude, or, what is the same thing, he wishes to find their values projected on the equator, and he states the proportion thus:

$$DI : EC :: DF : EQ;$$

That is, *as cosine of latitude, is to radius, so is departure, to difference of longitude.*

If we take *one mile,* (either the English or the Nautical mile), for the distance between two meridians on the equator; the distance between the same two meridians in any latitude will be expressed by the cosine of that latitude in any table of natural cosines.*

Thus, Inspecting a table of natural cosines we find that in lat. 25° the cosine is 0.906. That is, the distance of one mile on the equator, corresponds to the parallel distance of .906, 25 degrees distant from the equator. Or 10 miles on the equator corrresponds, to $9.\frac{6}{100}$ miles in lat. 25°. In Navigation, the distance on the equator is called difference of longitude, and the corresponding distance is called departure.

We might have taken any other latitude for an example as well as 25°. *Thus, the decimal cosine of any latitude corresponds to one mile on the equator.*

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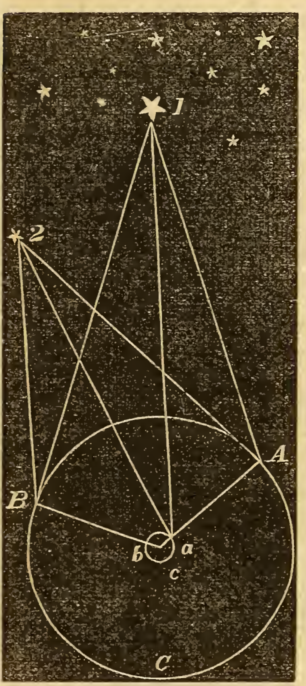
*Such a table is to be found, between pages 21 and 65, of our tables, and bound in each of the three volumes, of Robinson's Mathematics, viz. In the Geometry, the Surveying and Navigation, and in the Mathematical Operations.

SECTION II.

DESCRIPTIVE ASTRONOMY.

CHAPTER I.

FIRST CONSIDERATIONS AS TO THE DISTANCES OF THE HEAVENLY BODIES.—LUNAR PARALLAX AND DISTANCE TO THE MOON.



HITHERTO we have considered only appearances, and have not made the least inquiry as to the nature, magnitude, or distances of the celestial objects.

Abstractly, there is no such thing as great and small, near and remote; *relatively* speaking, however, we may apply the terms, great, and very great, as regards both magnitude and distance. Thus, an error of *ten* feet in the measure of the length of a building, is very great—when an error of ten rods, in the measure of one hundred miles, would be too trifling to mention.

Now if we consider the distance to the stars, it must be relative to some measure taken as a standard, or our inquiries will not be definite, or even intelligible. We now

Abstractly, is there any such thing as great and small? When we use the term great or small, does it imply a standard of measure? Can the same amount of error be both small and great at the same time.

make this general inquiry: *Are the heavenly bodies near to, or remote from, the earth?* Here, the earth itself seems to be the natural standard for measure; and if any body were but two, three, or even ten times the diameter of the earth, in distance, we should call it *near;* if 100, 200, or 2000 times the diameter of the earth, we should call it remote. To answer the inquiry, *Are the heavenly bodies near or remote?* we must put them to all possible mathematical tests; a mere opinion is of no value, without the foundation of some positive knowledge. Let 1, 2, represent the absolute position of two stars; and then, if $A\ B\ C$ represents the circumference of the earth, these stars may be said to be *near;* but if $a\ b\ c$ represents the circumference of the earth, the stars are many times the diameter of the earth, in distance, and therefore may be said to be remote. If ABC is the circumference of the earth, in *relation* to these stars, the apparent distance of the two stars asunder, as seen from A, is measured by the angle $1\ A\ 2$; and their apparent distance asunder, as seen from the point B, is measured by the angle $1\ B\ 2$; and when the circumference ABC is very large, as represented in our figure, the angle A, between the two stars, is manifestly greater than B. But if $a\ b\ c$ is the circumference of the earth, the points a and b are relatively the same as A and B. And, it is *an occular demonstration* that the angle under which the two stars would appear at a is the same, or nearly the same, as that under which they would appear at b; or, at least, we can conceive the earth so small, in relation to the distance to the stars, that the angle under which two stars would appear, would be the same, seen from any point on the earth.

Conversely, then, if the angle under which two stars appear is the same, as seen from all parts of the earth's surface, it is certain that the diameter of the earth is very small, compared with the distance to the stars; or, which is the same thing,

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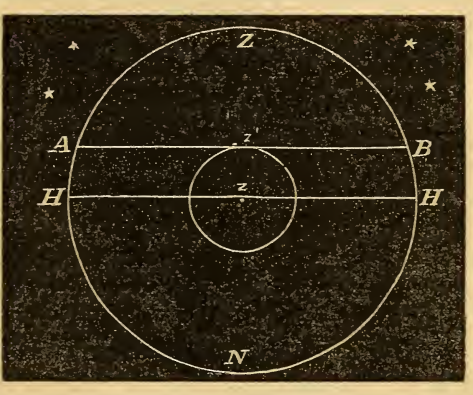
To measure the distances to the heavenly bodies — what seems to be the natural standard of measure? If the stars appeared at different distances asunder, as seen from different parts of the earth, what would that show?

the distance to the stars is many times the diameter of the earth. Therefore, observation has long since decided this important point. Sir John Herschel says: "The nicest measurements of the apparent angular distance of any two stars, *inter se*, taken in any parts of their diurnal course (after allowing for the unequal effects of refraction, or when taken at such times that this cause of distortion shall act equally on both), manifest *not the slightest* perceptible variation. Not only this, but at whatever point of the earth's surface the measurement is performed, the results are *absolutely identical.* No instruments ever yet invented by man are delicate enough to indicate, by an increase or diminution of the angle subtended, that one point of the earth is nearer to or farther from the stars than another."

Perhaps the following view of this subject will be more intelligible to the general reader.



Let *Z H N H* represent the celestial equator, as seen from the equator on the earth; and if the earth be large, in *relation* to the distance to the stars, the observer will be at *z'*; and the part of the celestial arc above his horizon would be represented by *AZB*, and the part below his horizon by *ANB*, and these arcs are obviously *unequal;* and their relation would be measured by the time a star or heavenly body remains above the horizon, as seen from the equator,

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What is the testimony of Sir J. Herschel? What do we infer from this fact? What other illustration is given?

compared with the time below it; but by observation, (refraction being allowed for) not the least difference is to be discovered, and the stars are above the horizon as long as they are below; which shows that the observer is not at z', but at z, and even more near the center; so that the arc AZB, is imperceptibly unequal to the arc HNH; that is, they are equal to each other; and the earth is comparatively but a point, in relation to the distance to the stars.

This fact is well established, as applied to the fixed *stars, sun* and *planets; but with the moon it is different:* that body is longer below the horizon than above it, which shows that its distance from the earth is at least measurable.

We view the moon from the earth, and it appears to cover a certain portion of the celestial circle, which we called the *moon's apparent diameter*; the half of this *arc* is called the semi-diameter. Now if we were at the moon to look down upon the earth, the *semi-diameter of the earth* would apparently cover a certain *arc* in the heavens, and this certain arc viewed from the moon is called the moon's

HORIZONTAL PARALLAX.

We place these two words into one line to make them conspicuous, on account of their importance in astronomy.

When we can find the horizontal parallax of any heavenly body, we can determine the distance of that body from the earth, as we shall soon explain.

Parallax is the difference in position, of any body, as seen from the center of the earth, and seen from its surface.

When a body is in the zenith of any observer, *to him* it has no parallax; for he sees it in the same place in the heavens, as though he viewed it from the center of the earth. The greatest possible parallax that a body can have, takes place when

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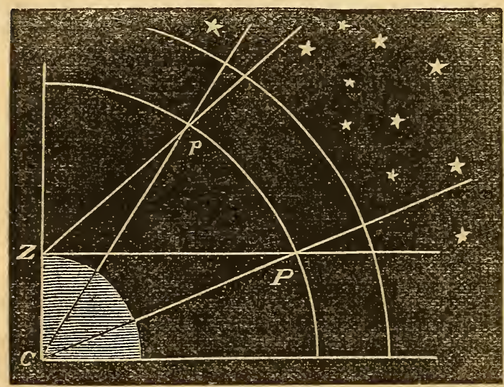
As seen from the equator, do the stars remain as long above the horizon as below it? What does that show? Is the moon observed to be as long above the horizon, (after refraction is allowed for) as below it? What does this fact show? What is parallax? When a body is in the zenith, has it any parallax? Why?

the body is in the horizon of the observer; and this parallax is called *horizontal parallax.* Hereafter, when we speak of the parallax of a body, *horizontal parallax* is to be understood, unless otherwise expressed.

A clear and summary illustration of parallax in general, is given by the following figure:



Let C be the center of the earth, Z the observer, and P, or p, the position of a body. From the center of the earth, the body is seen in the direction of the line CP, or Cp; from the observer at Z, it is seen in the direction of ZP, or Zp; and the *difference in direction*, of these two lines, is parallax. When P is in the zenith, there is no parallax; when P is in the horizon, the angle ZPC is then greatest, and it is the *horizontal parallax.*

We now perceive that the horizontal parallax of any body is equal to the *apparent semi-diameter of the earth,* as seen from the body. The greater the distance to the body, the less is its horizontal parallax; and when the distance is so great that the semi-diameter of the earth would appear only as a point, then the body has no parallax. Conversely, if we can detect no sensible parallax, we know that the body must be at a vast distance from the earth, and the earth itself must appear as a point from such a body, if, in fact, it were even visible.

What is the position of a heavenly body when its parallax is greatest? Why is parallax then called horizontal parallax? When the distance of a body from the earth increases, does its horizontal parallax increase or decrease?

Trigonometry gives the relation between the angles and sides of every conceivable triangle; therefore, we know all about the horizontal triangle *ZCP*, when we know *CZ* and the angles.* It is obvious that the less the angle *ZPC* the greater must be the distance *CP*; that is, the less the horizontal parallax, the greater is the distance, and the difficulty, and the *only difficulty*, is to obtain the horizontal parallax, or the angle *ZPC*.

The horizontal parallax cannot be directly observed, by reason of the great amount, and irregularity of horizontal refraction; but if we can obtain a parallax at any considerable altitude, we can compute the horizontal parallax therefrom.

The fixed stars have no sensible horizontal parallax, as we have frequently mentioned; and the parallax of the sun is so small, that it cannot be directly observed; the moon is the only celestial body that comes forward and presents its parallax; and from thence we know that the moon is the only body that is within a moderate distance of the earth.

That the moon had a sensible parallax, was known to the earliest observers, even before mathematical instruments were at all refined; but to decide upon its exact amount, and detect

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*Calling the horizontal parallax of any body p, and the radius of the earth r, and the distance of the body from the center of the earth x, (the radius of the table always R, or *unity*), then, by trigonometry, we have,

$$R : x :: \sin. p : r.$$

Therefore, - - - $x = \left(\frac{R}{\sin. p}\right) r.$

From this equation we have the following general rule, to find the distance to any celestial body:

Rule.—*Divide the radius of the tables by the sine of the horizontal parallax. Multiply that quotient by the semi-diameter of the earth, and the product will be the result.*

This result will, of course, be in the same terms of *linear* measure as the semi-diameter of the earth: that is, if r is in feet, the result will be in feet; if r is in miles, the result will be in miles, etc.:

Can horizontal parallax be directly observed? Have the fixed stars any sensible parallax? Why have they none? Was the moon's parallax sensible to early observers?

its variations, required the combined knowledge and observations of modern astronomers.

The lunar parallax was first recognized in Europe, and in northern countries, by *that luminary appearing to describe more than a semicircle south of the equator, and less than a simicircle north of that line,* during its revolutions among the stars, and, on an average, it was observed to be a longer time south, than north of the equator; *but no such inequality could be observed from the region of the equator.*

Observers at the south of the equator, observing the position of the moon, see it for a longer time north of the equator than south of it; *and, to them, it appears to describe more than a semicircle north of the equator.*

Here then, we have observation against observation, unless we can reconcile them. But the only reconciliation that can be made, is to conclude that the moon is really as long in one hemisphere as in the other, and the observed discrepancy must arise from the *positions* of the observers; and when we reflect that parallax must always depress the object, and throw it farther from the observer, it is therefore perfectly clear that a northern observer should see the moon farther to the south than it really is, and a southern observer see the same body farther north than its true position.

To find the amount of the lunar parallax requires the concurrence of two observers. They should be near the same meridian, and as far apart, in respect to latitude, as possible; and every circumstance that could affect the result, must be known.

The two most favorable stations are Greenwich (England) and the Cape of Good Hope. They would be more favorable if they were on the same meridian; but the small change in

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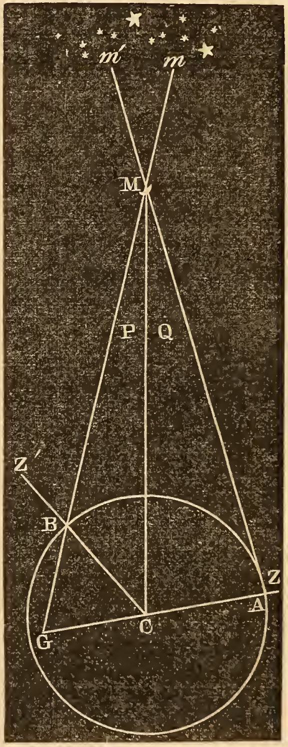
By what observation was the moon's parallax shown? Does the moon, on an average, appear to cross the equator to us, just at the time it really does cross the equator? Does parallax elevate or depress the object? How many observers are necessary to determine lunar parallax? What two stations are most favorable, and why?

declination, while the moon is passing from one meridian to the other, can be allowed for; and thus the two observations are reduced to the same meridian, and are equivalent to being made at the same time.

The most favorable times for such observations, are when the moon is near her greatest declinations, for then the change of declination is *extremely slow.*



Let A represent the place of the Greenwich observatory, and B the station at the Cape of Good Hope. C is the center of the earth, and Z and Z' are the zenith points of the observers. Let M be the position of the moon, and the observer at A will see it projected on the sky at m', and the observer at B will see it projected on the sky at m.

Now the figure $ACBM$ is a quadrilateral; the angle ACB is known by the latitudes of the two observers; the angles MAC and MBC are the respective zenith distances, taken from 180°.

But the sum of all the angles of any quadrilateral is equal to four right angles; and hence the angles at A, C, and B, being known, the parallactic angle at M is known.

In this quadrilateral, then, we have two sides, AC and CB, and all the angles; and this is sufficient for the most ordinary mathematician to decide every particular in connection with it; that is, we can find AM, MB,

What are most favorable times for observations? Why? In the figure before us, how is the angle M, determined?

and finally MC. Now MC being known, the horizontal parallax can be computed, for it is but a *function** of the distance.

The result of such observations, taken at different times, show all values to MC, between $55\frac{92}{100}$, and $63\frac{84}{100}$; taking the semi-diameter of the earth as unity.

These variations are regular and systematic, both as to time and place, in the heavens ; and they show, without further investigation, that the moon does not go round the earth in a circle, or, if it does, the earth is not in the center of that circle.

The parallax corresponding to these extreme distances, are 61′ 29″ and 53′ 50″.

When the moon moves round to that part of her orbit which is most remote from the earth, it is said to be in *apogee;* and, when nearest to the earth, it is said to be in *perigee.* The points apogee and perigee, mainly opposite to each other, do not keep the same place in the heavens, but gradually move forward in the same direction as the motion of the moon, and perform a revolution in a little less than nine years.

Many times, when the moon comes round to its perigee, we find its parallax less than 61′ 29″, and, at the opposite apogee, greater than 53′ 50″. It is only when the sun is in, or near a line with the lunar perigee and apogee, that these greatest extremes are observed to happen; and when the sun is near a right angle to the perigee and apogee, then the moon moves round the earth in an orbit near a circle ; and thus, by observing with care the variation of the moon's parallax, we find that its orbit is a *revolving* ellipse, of *variable eccentricity.*

Because the moon's distance from the earth is variable,

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*Function of the distance, that is, horizontal parallax and distances are mathematically and invariably connected, as expressed in the following equation in which p is the parallax and x the distance MC. $x \sin. p = r$.

How is it known that the moon's distance from the earth is visible? What are the extreme distances? What is understood by apogee and by perigee? What is the figure of the lunar orbit? Is the orbit equally eccentric at all times? When is the orbit nearest a circle?

therefore there must be a *mean* distance: we shall show, hereafter, that her motion is variable; therefore there is a *mean* motion; and as the eccentricity is variable, there is a *mean eccentricity.*

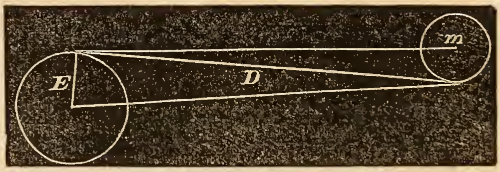
The mean distance is 60.26, the semi-diameter of the earth, corresponding to the parallax of 57′ 3″.

The variations in the moon's real distance must correspond to apparent variations in the moon's diameter; and if the moon, or any other body, should have no variation in apparent diameter, we should then conclude that the body was always at the same distance from us.

The change, in apparent diameter, of any heavenly body, is numerically *proportional to its real change in distance.*

Now if the moon has a real change in distance, as observations show, such change *must be* accompanied with apparent changes in the moon's diameter; and, by directing observations to this particular, we find a perfect correspondence; showing the harmony of truth, and the beauties of real science.

We have several times mentioned that the moon's horizontal parallax is the semi-diameter of the earth, as seen from the moon; which will be obvious by inspecting the following figure, in which E represents the semi-diameter of the earth, m the semi-diameter of the moon, and D the distance between them. The angle at the extremity E, takes in the moon's semi-diameter, and the like angle at the extremity m is the moon's *horizontal parallax,* or the earth's semi-diameter, as seen from the moon.



The variations of these two angles depend on the *same circumstance*—the variation of the distance between the earth and

What is the mean distance between the earth and the moon? How is the change in the moon's distance indicated? Does the moon's semi-diameter and horizontal parallax correspond, in all their variations?

moon; and, depending on one and the same cause, they must vary in just the same proportion.

When the moon's horizontal parallax is greatest, the moon's semi-diameter is greatest; and, when least, the semi-diameter is the least; and if we divide the tangent of the semi-diameter by the tangent of its horizontal parallax, we shall always find the *same quotient* (the decimal 0.27293); and that quotient is the ratio between the real diameter of the earth and the diameter of the moon. Having this ratio, and the diameter of the earth, 7912 miles, we can compute the diameter of the moon thus:

$$7912 \times 0.27293 = 2169.4 \text{ miles.}$$

As spheres are to each other in proportion to the *cubes* of their diameters, therefore the bulk (not mass) of the earth, is to that of the moon, as 1 to $\frac{1}{49}$, nearly.

It may be remarked, by every one, that we always see the same face of the moon; which shows that she must roll on an axis, in the same time as her mean revolution about the earth; for, if she kept her surface towards the same part of the heavens, it could not be constantly presented to the earth, because, to her view, the earth revolves round the moon, the same as to us the moon revolves round the earth; and the earth presents *phases* to the moon, as the moon does to us, except opposite in time, because the two bodies are opposite in position. When we have new moon, the lunarians have full earth; and when we have first quarter, they have last quarter, etc. The moon appears, to us, about half a degree in diameter; the earth appears, to them, a moon, about two degrees in diameter, *invariably fixed in their sky.*

The moon is an opake body, and shines only by reflecting the light of the sun, but its phases, its peculiar and variable path about the earth, and its periods of revolution, will be the subject of a future chapter.

What is the ratio between the diameter of the earth and the diameter of the moon? What is the ratio between their masses, and how is it determined? What is the appearance of the earth as seen from the moon?

CHAPTER II.

SOLAR PARALLAX—DISTANCE TO THE SUN—CHANGES OF THE SEASONS—CLIMATE, &c.

We have seen in the preceding chapter, that the horizontal parallax, and semi-diameter of any body, have a constant relation to each other, and as we can distinctly observe the diameter of the sun, if we could observe his horizontal parallax we could then obtain the diameter of the sun, by the following proportion:

$\odot$'s hor. par. : $\odot$ semidia. : : diam. of earth : diam. of $\odot$.

But the sun's horizontal parallax is too small to be detected by any common means of observation; hence it remained unknown, for a long series of years, although many ingenious methods were proposed to discover it. The only decision that ancient astronomers could make, concerning it, was, that it must be less than 20″ or 15″ of arc; for, were it as much as that quantity, it could not escape observation.

Now let us suppose that the sun's horizontal parallax is less than 20″; that is, the apparent semi-diameter of the earth, as seen from the sun, must be less than 20″; but the semi-diameter of the sun is 15′ 56″, or 956″; therefore the sun must be vastly larger than the earth—by at least 48 times its diameter; and the bulk of the earth must be, to that of the sun, in as high a ratio as 1 to the cube of 48. But as at present we do not suffer ourselves to know the true horizontal parallax of the sun, all the decision we can make on this subject is, that the sun is *vastly larger* than the earth.

We shall now call to mind the fact, that the solar day is about 4 minutes longer than the sidereal day, which shows that the sun has an apparent motion eastward among the stars,

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By what proportion can we find the diameter of any heavenly body? Why can we not at present determine the diameter of the sun?

and has the appearance of going round the earth once in a year: but the *appearance* would be the same, whether the earth revolves round the sun, or the sun round the earth, or both bodies revolve round a point between them. We are now to consider which is the most probable: *that a large body should circulate round a much smaller one; or, the smaller one round a larger one.* The last suggestion corresponds with our knowledge and experience in mechanical philosophy; the first is opposed to it.

The apparent diameter of a heavenly body can be measured *by the time it occupies in passing the meridian wire of a transit instrument,* but for very small objects, such as the planets, the use of a *micrometer* is better. A *micrometer* is a pair of parallel wires near the focus of a telescope, which open and close by a mathematical contrivance, and the amount of opening is measured by the turns of a screw from the closing point, which amount determines the apparent diameter of the body.

Observations can be made every clear day through the year, to determine the apparent diameter of the sun, and they have been made at many places, and for many years; and the combined results show that the apparent diameter of the sun is the same, on the same day of the year, from whatever station observed.

The least semi-diameter is 15′ 45″.1; which corresponds, in time, to the first or second day of July; and the greatest is 16′ 17″.3, which takes place on the 1st or 2d of January.

Now as we cannot suppose that there is any *real* change in the diameter of the sun, we must impute this apparent change to *real change in the distance of the body.*

Therefore the distance to the sun on the 30th of December,

How do we know that the sun appears to move round the earth in a year? Does the sun really move, or is it the earth that moves? How can we measure the apparent diameter of a body? What is a micrometer, give some general idea of one? Is the apparent diameter of the sun always the same? What must we infer from this fact? When is the apparent semi-diameter least? When greatest? Is the change uniform and gradual?

must be to its distance on the first day of July, as the number $15' 45''.1$ is to the number $16' 17''.3$, or as the number 945.1 to 977.3; and all other days in the year, the *proportional distance* must be represented by intermediate numbers.

From this, we perceive that the sun must go round the earth, or the earth round the sun, in very nearly a circle; for were a representation of the curve drawn, corresponding to the apparent semi-diameter in different parts of the orbit, and placed before us, the eye could scarcely detect its departure from a circle.

It should be observed, that the time elapsed between the greatest and least apparent diameter of the sun, or the reverse, is just half a year; and the change in the sun's longitude is 180°.

If we consider the mean distance between the earth and sun as *unity* (as is customary with astronomers), and then put x to represent the least distance, and y the greatest distance, we shall have

$$x+y=2.$$

And, - - $x : y :: 9451 : 9773.$

A solution gives $x=0.98326$, nearly, and $y=1.01674$, nearly; showing that the *least*, *mean* and *greatest* distance to the sun, must be very nearly as the numbers .98326, 1., and 1.01674.

The fractional part, (.01674,) or the difference between the extremes and mean (*when the mean is unity*), is called the *eccentricity* of the orbit.

In theory, the apparent diameters are sufficient to determine the eccentricity, could we really observe them to rigorous exactness; but all luminous bodies are more or less affected by *irradiation*, which dilates a little their apparent diameters; and the exact quantity of this dilatation is not yet well ascertained.

How great is the elapsed time from one extreme to the other? What is the difference in the sun's longitude? What is meant by the eccentricity of the earth's orbit? What is the amount of the eccentricity?

The *eccentricity*, as just mentioned, must not be regarded as accurate. It is only a first approximation, deduced from the first and most simple view of the subject; when we obtain full command over science, we can find methods which, with less care, will give more accurate results.

The sun's right ascension and declination can be observed from any observatory, any clear day, and from thence we can trace its path along the celestial concave sphere above us, and determine, its change from day to day; and we find it runs along a great circle called the *ecliptic*, which crosses the equator at opposite points in the heavens; and the ecliptic inclines to the equator with an angle of about 23° 27′ 37″.

The plane of the ecliptic passes through the center of the earth, showing it to be a great circle, or what is the same thing, showing that the apparent motion of the sun has its center in the line which joins the earth and sun.

The apparent motion of the sun along the ecliptic is called longitude; and this is, its most regular motion.

When we compare the sun's motion, in longitude, with its semi-diameter, we find a correspondence — at least, an apparent connection.

When the semi-diameter is greatest, the motion in longitude is greatest; and, when the semi-diameter is least, the motion in longitude is least; *but the two variations have not the same ratio.*

When the sun is nearest to the earth, on or about the 30th of December, it changes its longitude, in a mean solar day, 1° 1′ 9″.95. When farthest from the earth, on the 1st of July, its change of longitude, in 24 hours, is only 57′ 11″.48. A uniform motion, for the whole year, is found to be 59′ 8″.33.

The ancient philosophers contended that the sun moved

What is understood by the ecliptic? How can that circle be determined? What is the inclination of the ecliptic to the equator. What connection do we observe between the sun's semi-diameter, and its motion in longitude? Do they both increase and decrease at the same time, and in the same ratio?

about the earth in a *circular orbit,* and its real velocity uniform; but the earth not being in the center of the circle, the same portion of the circle would appear under *different angles;* and hence the variation in the sun's apparent angular motion.

Now if this were a true view of the subject, the variation in the angular motion must be in *exact proportion* to the variation in distance; that is, 945″.1 should be to 977″.3 as 57′ 11″.48 to 61′ 9″.95, if the supposition of the first observers were true. But these numbers have *not* the same ratio; therefore this supposition was not satisfactory; and it was probably abandoned for the want of this mathematical support. The ratio between

945″.1 and 977″.3 - - - - $\frac{9773}{9451}=1.0341$, nearly;

Between 57′ 11″.48 and 61′ 9″.95 $\frac{3669''.95}{3431''.48}=1.0694$, nearly.

If we square (1.0341) the *first* ratio, we shall have 1.06936, a number so near in value to the second ratio, that we conclude it ought to be the same, and would be the same, provided we had perfect accuracy in the observations.

Thus we compare the angular motion of the sun in different parts of its orbit; and we always find, *that the inverse square of its distance is proportional to its angular motion;* and this incontestible *fact* is so exact and so regular, that we lay it down as a *law;* and if solitary observations do not correspond with it, we must condemn the observations, and not the law.

By the aid of a little geometry in connection with this law,*

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* By making use of this law, we can find the eccentricity of the solar orbit, to greater precision than by the apparent diameters, because the same error of observation on longitude would not be as proportionally great as on apparent diameter.

Let E be the eccentricity of the orbit; then $(1-E)$ is the least distance to the sun, and $(1+E)$ the greatest distance. Then, by observation, we have

$$(1-E)^2 : (1+E)^2 :: 57' \, 11''.48 : 61' \, 9''.95;$$

$$\text{Or, } (1-E)^2 : (1+E)^2 :: 343148 : 366995;$$

$$\text{Or, } 1-E : 1+E :: \sqrt{343148} : \sqrt{366995}.$$

Whence $E=.016788+$.

What law exists between the distance of the sun and its angular motion? What other law is derived from this one by the aid of geometry?

it is easily demonstrated that *the solar radius vector describes equal areas in equal times.* This is one of Kepler's laws that applies to all the planets, and it is capable of an abstract geometrical demonstration. (See page 163, Univ. Ed.)

If we draw lines from any point in a plane, reciprocally proportional to the sun's apparent diameter, and at angles differing as the change of the sun's longitude, and then connect the extremities of such lines made all round the point, the connecting lines will form a curve, corresponding with an ellipse, which represents the apparent solar orbit; and, from a review of the whole subject, we give the following summary:

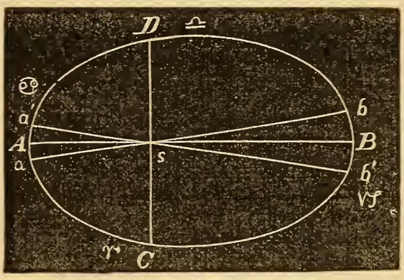
1. *The eccentricity of the solar ellipse, as determined from the apparent diameter of the sun, is* .01674.

2. *The sun's angular velocity varies inversely as the square of its distance from the earth.*

3. *The real velocity is inversely as the distance.*

4. *The areas described by the radius vector are proportional to the times of description.*

We have several times mentioned, that, as far as appearances are concerned, it is immaterial whether we consider the sun moving round the earth, or the earth round the sun; for, if the earth is in one position of the heavens, the sun will appear exactly in the opposite position, and every motion made by the earth must correspond to an apparent motion made by the sun.



But for the purpose of being nearer to fact, we will now suppose that the earth revolves round the sun in an elliptical orbit, as represented in the figure in the margin.

What figure will represent the solar orbit? Would appearances be the same, whether the earth moved round the sun, or the sun round the earth?

We have very much exaggerated the eccentricity of the orbit, for the purpose of bringing principles clearer to view.

The *greatest* and *least* distances, from the sun to the earth, make a *straight line* through the sun, and cut the orbit into *two* equal parts.

When the earth is at *B*, the sun is said to be in *apogee*, or the earth is said to be in its *aphelion;* when the earth is at *A*, the sun is said to be in *perigee*, or the earth is said to be in its *perihelion.*

The line joining these two points is the *major diameter* of the orbit; *and it is the only diameter passing through the sun, that cuts the orbit into two equal parts.*

Now, as *equal areas* are described in *equal times*, it follows that the sun must be just *half a year* in passing from apogee to perigee, and from perigee to apogee; provided that these points are stationary in the heavens, and they are so, very nearly.

If we suppose the earth moves along the orbit from *D* to *A*, and we observe the sun from *D*, and continue observations upon it until the earth comes to *C*, then the longitude of the sun has changed 180°; and if the time is less than half a year, we are sure the perigee is in this part of the orbit. If we continue observations round and round, and find where 180° of longitude correspond with half a year, there will be the position of the longer axis; which is sometimes called the *line of the apsides.*

By this method the position of the longer axis is more accurately ascertained than it could be by observing variations in the sun's apparent diameter, because the variations of apparent diameter are quite imperceptible, for several degrees, at the extremities of the major axis.

The longitude of the aphelion, for the year 1801, was 99° 51′ 9″, and of course, the perihelion was in longitude 279°

What line, passing through the sun, will cut the orbit of the earth into two equal parts? Does the sun describe 180° from any point in just half a year, or must it be from some particular point? How do astronomers find the position of the major axis? What was the position of it in 1801?

51′ 9″. These points move forward, in respect to the stars, about 12″ annually, and, in respect to the equinox, about 62″; more exactly 61″.905, and, of course, this is their annual increase of longitude.

In the year 1250, the perigee of the sun coincided with the winter solstice, and the apogee with the summer solstice; and at that time the sun was 178 days and about 17½ hours on the south side of the equator, and 186 days and about 12½ hours on the north side; being longer in the northern hemisphere than in the southern, by seven days and 19 hours. At present, the excess is seven days and near 17 hours.

As the sun is a longer time in the northern than in the southern hemisphere, the first impression might be, that more solar heat is received in one hemisphere than in the other; but the amount is the same; for whatever is gained in time, is lost in distance; and what is lost in time, is gained by a decrease of distance. The amount of heat depends on the intensity multiplied by the time it is applied; and the product of the time and distance to the sun, is the same in either hemisphere; but the amount of heat received, for a single day, is different in the two hemispheres.

When the earth is at B and at A, the mean and true longitude, of the sun agree; at all other points the mean place of the sun is not the same as its true place. The mean place can be determined by the time from the apogee or perigee points, and the true place can be determined by meridian observations at any observatory. The difference between these two places is noted and put down in a table called the equation of the sun's center. The equation of the center can also be determined by mathematical computation when once the eccentricity of the ellipse is known.

Are there different degrees of heat received in the different hemispheres during the year? What does the amount of heat depend upon? What is meant by the equation of the sun's center?

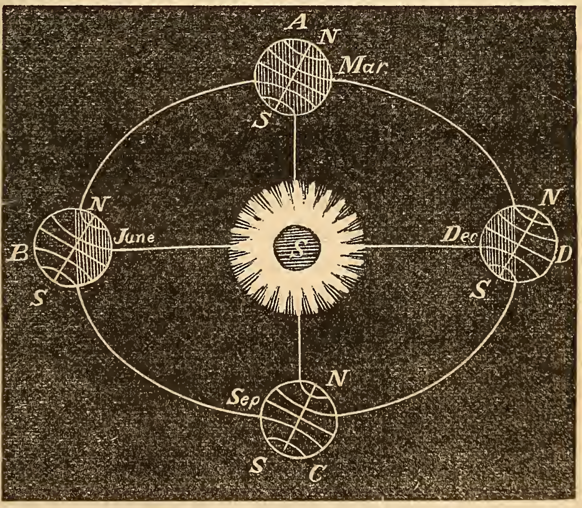
CHAPTER III.

THE CAUSES OF THE CHANGE OF SEASONS.

The annual revolution of the earth in its orbit, combined with the position of the earth's axis to the plane of its orbit, produces the change of the seasons.

If the axis were perpendicular to the plane of its orbit, there would be no change of seasons, and the sun would then be all the while in the celestial equator.

This will be understood by the following figure. Conceive the plane of the paper to be the plane of the earth's orbit, and conceive the several representations of the earth's axis, *NS*, to be inclined to the paper at an angle of 66° 32′.



In all representations of *NS*, one half of it is supposed to be above the paper, the other half below it.

NS is always parallel to itself; that is, it is always in the

What produces the change of seasons?

same position — always at the same inclination to the plane of its orbit — always directed to the same point in the heavens, in whatever part of the orbit the earth may be.

The plane of the equator represented by *Eq*, is inclined to the plane of the orbit by an angle of 23° 28′.

By inspecting the figure, the reader will gather a clearer view of the subject than by whole pages of description : he will perceive the reason why the sun must shine over the north pole, in one part of its orbit, and fall as far short of that point when in the opposite part of its orbit ; and the number of degrees of this variation depends, of course, on the position of the axis to the plane of the orbit.

Now conceive the line *NS* to stand perpendicular to the plane of the paper, and continue so ; then *Eq* would lie on the paper, and the sun would at all times be in the plane of the equator, and there would be no change of seasons. If *NS* were more inclined from the perpendicular than it now is, then we should have a greater change of seasons.

By inspecting the figure, we perceive, also, that when it is summer in the northern hemisphere, it is winter in the southern; and conversely, when it is winter in the northern, it is summer in the southern.

When a line from the sun makes a right angle with the earth's axis, as it must do in two opposite points of its orbit, the sun will shine equally on both poles, and it is then in the plane of the equator; which gives equal days and nights the world over.

Equal days and nights, for all places, happen on the 20th of March of each year, and on the 22d or 23d of September. At these times the sun crosses the celestial equator, and it is said to be in the equinox.

The longitude of the sun at the vernal equinox, is 0° ; and at the autumnal equinox, its longitude is 180°.

What is the inclination of the earth's axis to the plane of its orbit? If the inclination were 90°, would there be any change of seasons? Does the earth's axis always keep the same position? How do we know that?

The time of the greatest north declination is the 20th of June; the sun's longitude is then 90°, and is said to be at the *summer solstice.*

The time of the greatest south declination is the 22d of December; the sun's longitude, at that time, is 270°, and is said to be at the *winter solstice.*

By inspecting the figure, we perceive, that when the earth is at the summer solstice, the north pole, P, and a considerable portion of the earth's surface around, is within the enlightened half of the earth; and as the earth revolves on its axis NS, this portion constantly remains enlightened, giving a constant day — or a day of weeks and months duration, according as any particular point is nearer, or more remote from the pole: the pole itself is enlightened full six months in the year, and the circle of more than 24 hours constant sunlight, extends to 23° 28′ from the pole (not estimating the effects of refraction). On the other hand, the opposite, or south pole, S, is in a long season of darkness, from which it can be relieved only by the earth changing position in its orbit.

"Now, the temperature of any part of the earth's surface depends mainly, if not entirely, on its exposure to the sun's rays. Whenever the sun is above the horizon of any place, that place is receiving heat; when below, parting with it, by the process called radiation; and the whole quantities received and parted with in the year, must balance each other at every station, or the equilibrium of temperature would not be supported. Whenever, then, the sun remains more than 12 hours above the horizon of any place, and less beneath, the general temperature of that place will be above the average; when the reverse, below. As the earth, then, moves from A to B, the days growing longer, and the nights shorter, in the northern hemisphere, the temperature of every part of that hemisphere

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When does the sun attain its greatest northern declination? When its greatest southern declination? Is there any night at the north pole while the sun's declination is north? What is the extent of constant daylight from the pole when the sun's declination is 18 degrees north?

increases, as we pass from spring to summer, while at the same time the reverse is going on in the southern hemisphere. As the earth passes from *B* to *C*, the days and nights again approach to equality — the excess of temperature in the northern hemisphere, above the mean state, grows less, as well as its defect in the southern; and at the autumnal equinox, *C*, the mean state, is once more attained. From thence to *D*, and, finally round again to *A*, all the same phenomena, it is obvious, must again occur, but reversed; it being now winter in the northern, and summer in the southern, hemisphere."

The inquiry is sometimes made, why we do not have the warmest weather about the summer solstice, and the coldest weather about the winter solstice.

This would be the case if the sun immediately ceased to give extra warmth, on arriving at the summer solstice; but if it could radiate extra heat to warm the earth three weeks before it came to the solstice, it would give the same extra heat three weeks after; and the northern portion of the earth must continue to increase in temperature as long as the sun continues to radiate more than its medium degree of heat over the surface, at any particular place. Conversely, the whole region of country continues to grow cold as long as the sun radiates less than its mean annual degree of heat over that region. The medium degree of heat, for the whole year, and for all places, of course, takes place when the sun is on the equator; the average temperature, at the time of the two equinoxes. The medium degree of heat, for our northern summer, considering only two seasons in the year, takes place when the sun's declination is about 12 degrees north; and the medium degree of heat, for winter, takes place when the sun's declination is about 12 degrees south; and if this be true, the heat of summer will begin to decrease about the 20th of August, and the cold of

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Why is not the 20th of June considered as mid-summer in the northern hemisphere, — or, rather, why is July the mid-summer season, and not June? At what time may we expect the severity of winter to be past?

winter must essentially abate, on, or about the 16th of February, in all northern latitudes.

The warmest part of the day, (other circumstances being equal,) is not at 12, but about 2 o'clock in the afternoon. The sun is then west of the meridian, and its rays will strike more perpendicularly on a plane whose downward slope is towards the west, than on one, whose downward slope is towards the east.

This will account for the fact, that climates are more mild west of mountain ranges than on the eastern side of the same mountains, other circumstances being equal. The vicinity of large bodies of water, and the general elevation of the country above the level of the sea, have much to do with climate, but as these causes have no particular connection with astronomy, we omit them.

What time of day is warmest? Why not at noon? Which locality has the warmest climate, on the east or west side of the Alleghany mountains, in the same latitude and at the same elevation above the sea?

CHAPTER IV.

EQUATION OF TIME.

We now come to one of the most important subjects in astronomy — the equation of time.

Without a good knowledge of this subject, there will be constant confusion in the minds of the pupils; and such is the nature of the case, that it is difficult to understand even the *facts*, without investigating their causes.

Sidereal time has no *equation;* it is uniform, and, of itself, perfect and complete.

The time, by a perfect clock, is theoretically perfect and complete, and it is called *mean solar time.*

The time, by the sun, *is not uniform;* and, to make it agree with the *perfect* clock, requires a correction—a quantity to make equality; and this quantity is called the equation of time.*

If the sun were stationary in the heavens, like a star, it would come to the meridian after exact and equal intervals of time; and, in that case, there would be no equation of time.

If the sun's motion, in right ascension, were uniform, then it would also come to the meridian after equal intervals of time, and there would still be no equation of time. But (speaking in relation to appearances) the sun is not stationary in the heavens, nor does it move uniformly; therefore it cannot come to the meridian at equal intervals of time, and, of course, the solar days must be *slightly unequal.*

* In astronomy, the term equation, is applied to all corrections, to convert a mean to its true quantity.

Are all sidereal days alike in length? Are all solar days alike in length? If solar days are unequal in length, what will it produce?

When the sun is on the meridian, it is then apparent noon for that day: it is the *real solar noon*, or, the half elapsed time between sunrise and sunset.

A fixed star comes to the meridian at the expiration of every 23h. 56m. 04.09s. of mean solar time; and if the sun were stationary in the heavens, it would come to the meridian after every expiration of just that same interval. But the sun increases its right ascension every day, by its apparent eastward motion; and this increases the time of its coming to the meridian; and the *mean interval* between its successive transits over the meridian is just 24 hours; but the actual intervals are variable — some less, and some more, than 24 hours.

On and about the 1st of April, the time from one meridian of the sun to another, as measured by a perfect clock, is 23h. 59m. 52.4s.; less than 24 hours by about 8 seconds. Here, then, the sun and clock must be constantly separating. On and about the 20th of December, the time from one meridian of the sun to another is 24h. 0m. 24.2s., more than 24 seconds over 24 hours; and the daily accumulation of a few seconds will soon amount to minutes — and thus the sun and clock will become very sensibly separated — *and this is the equation of time.*

To detect the law which separates the sun and clock, and find the amount of separation for any particular day, we must consider

1st. *The unequal apparent motion of the sun along the ecliptic.*

2d. *The variable inclination of this motion to the equator.*

If the sun's apparent motion along the ecliptic were uniform, still there would be an equation of time; for that motion, in some parts of the orbit, is oblique to the equator, and, in other parts, parallel with it; and its eastward motion, in right ascension, would be greatest when moving parallel with the equator.

When is it apparent noon? When is it mean noon? The difference between these two noon's is always equal to what? If the sun's apparent motion along the ecliptic were uniform, would there still be an equation of time, and why?

From the first cause, separately considered, the sun and clock would agree two days in a year — the 1st of July and the 30th of December.

From the second cause, separately considered, the sun and clock agree *four* days in a year — the days when the sun crosses the equator, and the days he reaches the solsticial points.

When the results of these two causes are combined, the sun and clock will agree four days in the year; but it is on neither of those days marked out by the separate causes; and the intervals between the several periods, and the amount of the equation, appear to want regularity and symmetry.

The four days in the year on which the sun and clock agree, that is, show noon at the same instant, are April 15th, June 16th, September 1st, and December 24th.

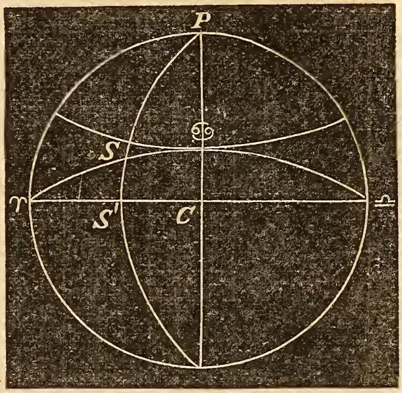
The elliptical form of the earth's orbit gives rise to the unequal motion of the earth in its orbit, and thence to the apparent unequal motion of the sun in the ecliptic; and this same *unequal* motion is what we have denominated the first cause of the equation of time. Indeed, this part of the equation of time is nothing more than the equation of the sun's center, changed into time, at the rate of four minutes to a degree.

The greatest equation for the sun's longitude, is by observation $1° 55' 30''$; and this, proportioned into time, gives 7m. 42s. for the maximum effect in the equation of time arising from the sun's unequal motion. When the sun departs from its perigee, its motion is greater than the mean rate, and, of course, comes to the meridian later than it otherwise would. In such cases, the sun is said to be slow — and it is slow all the way from its perigee to its apogee; and fast in the other half of its orbit.

On what days in the year would the sun and clock agree, if the sun's motion were uniform along the ecliptic? On what days in the year do the sun and clock agree? What is the maximum effect for the sun's unequal motion?

For a more particular explanation of the second cause, we must call attention to the figure in the margin.

Let ♈ ♋ ♎ represent the ecliptic, and ♈ C ♎ the equator.



By the first correction, the apparent motion along the ecliptic is rendered uniform; and the sun is then supposed to pass over equal spaces in equal intervals of time along the arc ♈ S ♋. But equal spaces of arc, on the ecliptic, do not include the same meridians, as equal spaces on the equator. In short, the points on the ecliptic must be reduced to corresponding points on the equator. For instance, the number of degrees represented by ♈ S on the ecliptic, is greater than to the same meridian along the equator. The difference between ♈ S and ♈ S', turned into time, is the equation of time arising from the obliquity of the ecliptic corresponding to the point S.

At the points ♈, ♋, and ♎, and also at the southern tropic, the ecliptic and the equator correspond to the same meridian; but all *other equal distances,* on the ecliptic and equator, are included by different meridians.

It will be observed, by inspecting the figure, that what the sun loses in eastward motion, by *oblique direction* near the equator, is made up, when near the tropics, by the diminished distances between the meridians.

For a more definite understanding of this matter, we give the following table:

When does the sun lose most in eastward motion on the ecliptic? When does it gain most in eastward motion?

Table showing the separate results of the two causes for the equation of time, corresponding to every fifth day of the second years after leap year; but is nearly correct for any year.

		1st cause. Sun slow of Clock.	2d cause. Sun slow of Clock.			1st cause. Sun fast.	2d cause. Sun fast.
		m. s.	m. s.			m. s.	m. s.
January	5	0 41	5 8	July	1	0 0	3 32
	10	1 22	6 35		7	0 40	5 8
	15	2 2	7 48		12	1 19	6 35
	20	2 41	8 45		17	1 57	7 48
	25	3 19	9 26		22	2 35	8 45
	29	3 56	9 49		28	3 12	9 26
February	3	4 30	9 53	August	2	3 47	9 49
	8	5 2	9 40		7	4 21	9 53
	13	5 32	9 9		12	4 52	9 40
	18	5 39	8 23		17	5 22	9 9
	23	6 24	7 22		22	5 50	8 23
	28	6 45	6 9		28	6 14	7 22
March	5	7 3	4 46	Sept.	2	6 36	6 9
	10	7 18	3 15		7	6 56	4 46
	15	7 29	1 39		12	7 12	3 15
	20	7 37	sun fast.		17	7 24	1 39
	25	7 42	1 39		23	7 34	sun fast.
	30	7 42	3 15		28	7 40	1 39
April	4	7 40	4 46	October	3	7 42	3 15
	9	7 34	6 9		8	7 40	4 46
	14	7 24	7 22		13	7 34	6 9
	19	7 12	8 23		18	7 24	7 22
	24	6 56	9 9		23	7 12	8 23
	30	6 36	9 40		28	6 56	9 9
May	5	6 14	9 53	Nov.	2	6 36	9 40
	10	5 50	9 49		7	6 14	9 53
	15	5 22	9 26		12	5 50	9 49
	20	4 52	8 45		17	5 22	9 26
	26	4 21	7 48		22	4 52	8 45
	31	3 47	6 35		27	4 22	7 48
June	5	3 12	5 8	Dec.	2	3 47	6 35
	10	2 35	3 32		7	3 12	5 8
	16	1 57	1 48		12	2 35	3 32
	21	1 19	sun slow		17	1 57	1 48
	26	0 40	1 48		21	1 19	sun slow
					26	0 40	1 48

By this table, the regular and symmetrical result of each cause is visible to the eye; but the actual value of the equation of time, for any particular day, is the combined results

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What is the first cause of the equation of time? What is the second cause?

of these two causes. Thus, to find the equation of time for the 5th day of March, we look in the table and find that

The first cause gives sun slow	- -	7m. 3s.
The second " sun slow	- -	4 46
Their combined result (or algebraic sum) is		11 49 slow.

That is, the sun being *slow,* it does not come to the meridian until 11m. 49s. after the noon shown by a perfect clock; but whenever the sun is on the meridian, it is then noon, apparent time; and, to convert this into mean time, or to set the clock, we must *add* 11m. 49s.

By inspecting the table, we perceive that on the 14th of April the two results nearly counteract each other; and consequently the sun and clock nearly agree, and indicate noon at the same instant. On the 2d of November the two results unite in making the *sun fast;* and the equation of time is then the sum of 6 36 and 9 40, or 16m. 16s.; the *maximum* result.

The sun at this time being *fast,* shows that it comes to the meridian 16m. 16s. before 12 o'clock, true mean time; or, when the sun is on the meridian, the clock ought to show 11h. 43m. 44s.; and thus, generally, *when the sun is fast, we must subtract the equation of time from apparent time, to obtain mean time;* and add, when the sun is *slow.*

As no clock can be relied upon, to run to true mean time, or to any exact definite rate, therefore clocks must be frequently rectified by the *sun.* We can observe the apparent time, and then, by the application of the equation of time, we determine the true *mean time.*

A table for the equation of time, corresponding to each degree of the sun's longitude, is to be found in many astronomical works, and such a table would be perpetual, provided the longer axis of the solar orbit did not change its position in relation to the equinox. But as that change is *very slow,* a

When is the sun said to be slow? When fast? Can any clock be relied upon to run to mean time? How then is mean time discovered? Why can we not have a perpetual table for the equation of time?

table of that kind will serve for many years, with a trifling correction.

We repeat, sidereal time is the interval of time elapsed since the equinoctial point in the heavens passed the meridian.

The solar day is 3m. 56s.55 of sidereal time, longer than a sidereal day.

At the instant of mean noon, Greenwich time, on the 1st of March, 1857, the sidereal time was

	h.	m.	s.
Estimated at - - - -	22	36	56.65
To this add - - - - -		3	56.55
Sidereal time at noon, March 2d,	22	40	53.20

Thus we might compute the sidereal time at mean noon, Greenwich time, for any number of days, (omitting 24h. when we passed that sum.)

At *mean noon*, the right ascension of the sun, plus or minus the equation of time, is always equal to the sidereal time.

Twenty-four hours of mean solar time is equal to 24h. 3m. 56s.55 of sidereal time. Therefore eight hours of solar time is equal to 8h. 1m. 18s.82 of sidereal time; and thus we may correct any hour of solar time to its corresponding value of sidereal time.

On the 1st day of May, 1857, at mean noon,

	h.	m.	s.
The sidereal time was - - - -	2	37	26.46
Add, - - - - - - -	8	1	18.82
Sidereal time at 8, mean time, -	10	38	45.28

Thus we might find the sidereal time corresponding to any other hour, on any other day, having the use of a Nautical Almanac.

It is very important that the *navigator*, *astronomer*, and *clock regulator*, should thoroughly understand the equation of time; and persons thus occupied pay great attention to it; but most people in common life are hardly aware of its existence.

To whom is equation of time important?

CHAPTER V.

THE APPARENT MOTIONS OF THE PLANETS.

We have often reminded the reader of the great regularity of the fixed stars, and of their uniform positions in relation to each other; and by this very regularity and constancy of relative positions, we denominate them fixed; but there are certain other celestial bodies, that manifestly change their positions in space, and, among them, the sun and moon are most prominent.

In previous chapters, we have examined some facts concerning the sun and moon, which we briefly recapitulate, as follows:

1. That the sun's distance from the earth is very great; but at present we cannot determine how great, for the want of one element — its horizontal parallax.

2. Its magnitude is much greater than that of the earth.

3. The distance between the sun and earth is slightly variable; but it is regular in its variations, both in distance and in apparent angular motion.

4. The moon is comparatively very near the earth; its distance is variable, and its mean distance and amount of variations are known. It is smaller than the earth, although, to the mere vision, it appears as large as the sun.

The apparent motions of both sun and moon are always in one direction; and the variations of their motions are never far above or below the mean.

But there are several other bodies that are not fixed stars; and although not as conspicuous as the sun and moon, have been known from time immemorial.

What is repeated in chapter v. concerning the fixed stars? What is mentioned again concerning the sun? What in relation to the moon?

They appear to belong to one family; but, before the true system of the world was discovered, it was impossible to give any rational theory concerning their motions, so irregular and erratic did they appear; and this very irregularity of their apparent motions induced us to delay our investigations concerning them to the present chapter.

In general terms, these bodies are called planets — and there are several of recent discovery — and some of very recent discovery; but as these are not conspicuous, nor well known, all our investigations of principles will refer to the larger planets, Venus, Mars, Jupiter, and Saturn. We now commence giving some *observed facts*, as extracted from the Cambridge astronomy.

"There are few who have not observed a beautiful star in the west, a little after sunset, and called, for this reason, the *evening star*. This star is Venus. If we observe it for several days, we find that it does not remain constantly at the same distance from the sun. It departs to a certain distance, which is about 45°, or $\frac{1}{4}$th of the celestial hemisphere, after which it begins to return; and as we can ordinarily discern it with the naked eye only when the sun is below the horizon, it is visible only for a certain time immediately after sunset. Subsequently it sets with the sun, and then we are entirely prevented from seeing it by the sun's light. But after a few days, we perceive in the morning, near the eastern horizon, a bright star which was not visible before. It is seen at first only a few minutes before sunrise, and is hence called the *morning star*. It departs from the sun from day to day, and precedes its rising more and more; but after departing to about 45°, it begins to return, and rises later each day; at length it rises with the sun, and we cease to distinguish it. In a few days the evening star again appears in the west, very near the sun; from which it departs in the same manner as before; again returns; disap-

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What bodies are planets? In what respects do their motions differ from the fixed stars? Why has the author delayed mentioning these bodies until now? What planet is called the morning and evening star?

pears for a short time; and then, the morning star presents itself.

These alternations, observed without interruption for more than 2000 years, evidently indicate that the evening and morning star are one and the same body. They indicate, also, that this star has a proper motion, in virtue of which it oscillates about the sun, sometimes preceding and sometimes following it.

These are the phenomena exhibited to the naked eye; but the admirable invention of the telescope enables us to carry our observations much farther.''

On observing Venus with a telescope, the *irradiation* is, in a great measure, taken away, and we perceive that it has *phases, like the moon.* At evening, when approaching the sun, it presents a luminous crescent, the points of which are from the sun. The crescent diminishes as the planet draws nearer the sun; but after it has passed the sun, and appears on the other side, the crescent is turned in the other direction; the enlightened part always toward the sun, showing that it receives its light from that great luminary. The crescent now gradually increases to a semicircle, and finally, to a full circle, as the planet again approaches the sun; *but, as the crescent increases, the apparent diameter of the planet diminishes;* and at every alternate approach of the planet to the sun, the phase of the planet is full, and the apparent diameter small; and at the other approaches to the sun, the crescent diminishes down to zero, and the apparent diameter increases to its maximum. When very near the sun, however, the planet is lost in the sunlight; but at some of these intervals, between disappearing in the evening and reappearing in the morning, it appears to run over the sun's disc as a *round, black spot;* giving a fine opportunity to measure its greatest apparent diameter. When Venus appears full, its apparent diameter is not more than 10″, and when a black spot on the sun, it is 59″.8, or very nearly 1′.

How do we know that the morning and evening star must be the same body? What is the appearance of the planet when viewed through a telescope? How does it appear that Venus receives its light from the sun?

Hence, its greatest distance must be, to its least distance, as 59″.8 to 10, or nearly as 6 to 1.

The learner should impress this fact on his mind, that this planet is always in the same part of the heavens as the sun — never departing more than 47° on each side of it — called its greatest *elongation*. In consequence of being always in the neighborhood of the sun, it can never come to the meridian near midnight. Indeed, it always comes to the meridian *within* three hours twenty minutes of the sun, and, of course, in daylight. But this does not prevent meridian observations being taken upon it, through a good telescope;* and, as to this particular planet, it is sometimes so bright as to be seen by the unassisted eye in the daytime.

Even without instruments and meridian observations, the attentive observer can determine that the motion of Venus, in relation to the stars, is very irregular — sometimes its motion is very rapid — sometimes slow — sometimes *direct* — sometimes *stationary*, and sometimes *retrograde;*† but the direct motion prevails, and, as an attendant to the sun, and in its own irregular manner, as just described, it appears to traverse round and round among the stars.

But Venus is not the only planet that exhibits the appearances we have just described. There is one other, and only one — *Mercury;* a very small planet, rarely visible to the naked

* The stars continue visible through telescopes, during the day, as well as the night; and that, in proportion to the power of the instrument, not only the largest and brightest of them, but even those of inferior luster, such as scarcely strike the eye, at night, as at all conspicuous, are readily found and followed, even at noonday, by those who possess the means of pointing a telescope accurately to the proper places — unless the star is in that point of the heavens very near the sun.—Herschel.

† In astronomy, direct motion is eastward among the stars; stationary is no apparent motion; and retrograde is a westward motion.

Is the distance of Venus from the earth very variable, and how great is the variation? How is that fact ascertained? Describe the apparent motion of Venus among the stars. What is understood by stationary, in astronomy? What by direct and retrograde motions? What other planet exhibits like appearances to Venus?

eye, and not known to the very ancient astronomers. Whatever description we have given of Venus applies to Mercury, except in degree. Its variations of apparent diameter are not so great, and it never departs so far from the sun; and the interval of time, between its vibrations from one side to the other of the sun, is much less than that of Venus.

These appearances clearly indicate that the sun must be the center, or near the center, of these motions, and not the earth; and that Mercury must revolve in an orbit within that of Venus.

So clear and so unavoidable were these inferences, that even the ancients (who were the most determined advocates for the immobility of the earth, and for considering it as the principal object in creation — the center of all motion, etc.) were compelled to admit them; but with this admission, they contended, that the sun moved round the earth, carrying these planets as attendants.

By taking observations on the other planets, the ancient astronomers found them variable in their apparent diameters, and angular motions; *so much so, that it was impossible to reconcile appearances with the idea of a stationary point of observation;* unless the appearances were taken for realities, and that was against all true notions of philosophy.

The planet *Mars* is most remarkable for its variations; and the great distinction between this planet and Venus, is, that it does not always accompany the sun; but it sometimes, yea, at regular periods, is in the opposite part of the heavens from the sun — called Opposition — at which time it rises about sunset, and comes to the meridian about midnight.

The greatest apparent diameter of Mars takes place when the planet is in opposition to the sun, and it is then 17″.1; and its least apparent diameter takes place when in the neighbor-

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What do these appearances clearly indicate? What is the planet Mars most remarkable for? What great distinction is there between some appearances of Mars and Venus? When a planet is in opposition to the sun, what time of the day does it pass the meridian? What is shown by the great variation in the apparent diameter of Mars?

hood of the sun, and it is then but about 4″; *showing that the sun, and not the earth, is the center of its motion.*

The general motion of all the planets, in respect to the stars, is *direct;* that is, eastward; but all the planets that attain opposition to the sun, while in opposition, and for some time before and after opposition, have a retrograde motion — and those planets which show the greatest change in apparent diameter, show also, the greatest amount of retrograde motion — and all the observed irregularities are systematic in their irregularities, showing that they are governed, at least, by constant and invariable laws. If the earth is really stationary, we cannot account for this retrograde motion of the planets, unless that motion is real; and if real, why, and how can it change from direct to stationary, and from stationary to retrograde, and the reverse?

But if we conceive the earth in motion, and going the same way with the planet, and moving more rapidly than the planet, then the planet will appear to run back; that is, retrograde.

And as this retrogradation takes place with every planet, when the earth and planet are both on the same side of the sun, and the planet in opposition to the sun; and as these circumstances take place in all positions from the sun, it is a sufficient explanation of these appearances; and conversely, then, these appearances show the motion of the earth in an orbit round the sun.

When a planet appears to be stationary, it must be really so, or be moving directly to or from the observer. And if it be moving to or from the observer, that circumstance will be indicated by the change in apparent diameter; and observations confirm this, and show that no planet is really stationary, although it may appear to be so.

If we suppose the earth to be but one of a family of bodies, called planets — all circulating round the sun at different

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When do planets appear to retrograde? When a planet appears to be stationary, is it really so? What supposition is here made in respect to the earth?

times — in the order of *Mercury, Venus, Earth, Mars,* (omitting the small telescopic planets), Jupiter, Saturn, Herschel, or *Uranus,* we can then give a rational and simple account for every appearance observed, and without discussing the ancient objections to the true theory of the solar system, we shall adopt it at once, and thereby save time and labor, and introduce the reader into simplicity and truth.

This, the true solar system, as now known and acknowledged, is called the Copernican system, from its discoverer, Copernicus, a native of Prussia, who lived some time in the fifteenth century.

But this theory, simple and rational as it now appears, and capable of solving every difficulty, was not immediately adopted; for men had always regarded the earth as the chief object in God's creation; and consequently man, the lord of creation, a most important being. But when the earth was hurled from its imaginary, dignified position, to a more humble place, it was feared that the dignity and vain pride of man must fall with it; and it is probable that this was the root of the opposition to the theory.

So violent was the opposition to this theory, and so odious would any one have been who had dared to adopt it, that it appears to have been abandoned for more than one hundred years, and was revived by Galileo about the year 1620, who, to avoid persecution, presented his views under the garb of a dialogue between three fictitious persons, and the points left undecided. But the caution of Galileo was not sufficient, or his dialogue was too convincing, for it woke up the Inquisition, and he was forced to sign a paper denouncing the theory as heresy, on the pain of perpetual imprisonment.

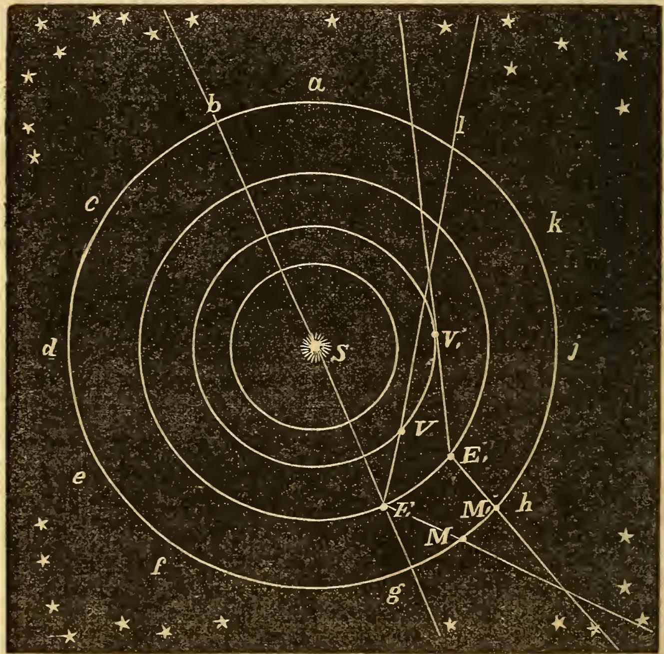
Thus, persecuting error, has always moved in advance of truth, and though powerful, it can never be finally successful.

Who discovered the true solar system? Give a brief outline of the Copernican system? Why did men so violently oppose this system? How long was this system lost, and how can we account for its being neglected and abandoned? Who revived it? What trouble did this bring on that Philosopher?

CHAPTER VI.

THE COPERNICAN SYSTEM ILLUSTRATED.

THE following figure is designed to be a partial representation of the solar system. The center is the locality of the *Sun*, and the innermost circle represents the orbit of *Mercury*, the second circle the orbit of *Venus*, the third circle the orbit of the *Earth*, and the outermost circle represents the orbit of *Mars*.



Whereabouts in the solar system is the sun located? What orbit is nearest to the sun? What orbit does the third circle represent?

There is not space on the page to represent the orbit of the planets, beyond or more remote from the sun than Mars, and, indeed, there is not space to represent these in due proportion, on a scale of sufficient magnitude.

Far, far away beyond the orbits of the planets are the fixed stars — so far, that the whole solar system is but a point in comparison. To help the imagination, we have represented stars about the borders of the figure.

Let *a, b, c, d,* &c. be the *direct* course of the planets in the heavens, and suppose E to be the position of the earth at some particular time; then we know that those stars, a little in advance of g, will come to the meridian at midnight, and the sun is in the direction of the stars, near b, directly opposite. Let M be the position of *Mars,* and V the position of *Venus.* The line from E to M, extended to the stars, will show the position of Mars among the stars; and a line from E to V shows the position of Venus among the stars at l. Now suppose the earth to move from E to E_1, and during the same time Venus must move through a larger arc, as from V to V_1, and Mars move through a lesser arc, as from M to M_1. Now *Mars* appears to have gone backward among the stars, and *Venus* to have moved a little in advance, and S the center of the sun, is the only point in the solar system from which the motion of the planets can appear uniform as to velocity or direction.

When the earth is at E_1, and Mars at M_1, as here represented the apparent diameter of Mars is greatest, and when Mars is in its orbit beyond the sun, its apparent diameter is least, as was noticed in the preceding chapter. Indeed, it was appearances, or rather, observations, that established this theory of the solar system.

Mercury and *Venus,* never coming in opposition to the sun, but revolving around that body in orbits that are within that of the earth, are therefore called *inferior* planets.

Why are Mercury and Venus called inferior planets? Why are all others called superior planets? To the inhabitants of Mars is the Earth an inferior or a superior planet?

Those that come in opposition, and thereby show that their orbits are outside of the earth, are called *superior* planets.

We shall show how to investigate and determine the position of one inferior planet; and the same principles will be sufficient to determine the position of any inferior planet.

It will be sufficient, also, to investigate and determine the orbit of one superior planet; and, if that is understood, it may be considered as substantially determining the orbits of all the superior planets; and after that, it will be sufficient to state results.

For materials to operate with, we give the following table of the planetary irregularities, (so called,) drawn from observation:

Planets.	Greatest Apparent Diameters.	Least Apparent Diameters.	Angular Distance from Sun at the instant of being stationary.	Mean arc of Retrogradation.
	"	"	° ′	° ′
Mercury,	11.3	5.0	18 00	13 30
Venus,	59.6	9.6	28 48	16 12
Earth,				
Mars,	17.1	3.6	136 48	16 12
Jupiter,	44.5	30.1	115 12	9 54
Saturn,	20.1	16.3	108 54	6 18
Uranus,	4.1	3.7	103 30	3 36

On the supposition, however, that the planets revolve in circles (which is not far from the truth), the greatest and least apparent diameters furnish us with sufficient data to compute the distances of the planets from the sun in *relation* to the distance of the earth, taken as *unity.*

In addition to the facts presented in the preceding table, we must not fail to note the important element of the *elongations* of *Mercury* and *Venus.* This term can be applied to no other planets.

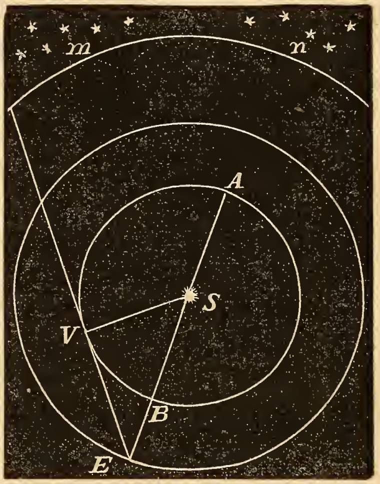
It is very variable in regard to Mercury — showing that the orbit of that planet is quite elliptical. The variation is much

What observations will furnish means to determine the relative distances of the planets from the sun? How is it known that the orbit of Mercury is more elliptical than that of Venus?

less in regard to *Venus*, showing that Venus moves round the sun more nearly in a circle.

	For Mercury.	For Venus.
The least extreme elongation,	17° 37′	44° 58′
The greatest " "	28° 4′	47° 30′
The mean elongation,	22° 46′	46° 20′

Relying on these facts as established by observations, we can easily deduce the relative orbits of Mercury and Venus.



Let S represent the sun, E the earth, V Venus.

Conceive the planet to pass round the sun in the direction of AVB.

The earth moves also in the same direction, but not so rapidly as Venus.

Now it is evident from inspection, that when the planet is passing by the earth, as at B, it will appear to pass along in the heavens in the direction of m to n. But when the planet is passing along in its orbit, at A, and the earth about the position of E, the planet will appear to pass in the direction of n to m. When the planet is at V, as represented in the figure, its absolute motion is nearly toward the earth, and, of course, its appearance is nearly stationary.

It is *absolutely stationary* only at one point, and even then but for a moment; and that point is where its apparent motion changes from direct to retrograde, and from retrograde to di-

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When does the motion of the inferior planets appear most direct? When most retrograde? When stationary? Do the planets appear stationary for any considerable time?

rect; which takes place when the angle SEV is about 29 degrees on each side of the line SE.

When the line EV touches the circumference AVB, the angle SEV, or *angle of elongation*, is then greatest; and the triangle SEV is right angled at V; and if SE is made radius, SV will be the sine of the angle SEV.

But the line SE is assumed equal to *unity*, and then SV will be the natural sine of 46° 20′, and can be taken out of any table of natural sines; or it can be computed by logarithms, and the result is .72336.

For the planet Mercury, the mean of the same angle is 22° 46, and the natural sine of that angle, or the mean radius of the planet's orbit, is .38698.

Thus we have found the relative mean distances of three planets from the sun, to stand as follows:

Mercury, - - - - - - -	0.38698
Venus, - - - - - - - -	0.72336
Earth, - - - - - - - - -	1.00000

If the orbits were perfect circles, then the angle SEV of greatest elongation, would always be the same; but it is an *observed fact* that it is not always the same; therefore the orbits are not circles; and when SV is least, and SE greatest, then the angle of elongation is *least;* and conversely, when SV is greatest and SE least, then the angle of elongation is the greatest possible; and by observing in what parts of the heavens the greatest and least elongations take place, we can approximate to the positions of the longer axis of the orbits.

By means of the apparent diameters, we can also find the approximate relations of their orbits. For instance, when the planet Venus is at B, and appears on the sun's disc, its apparent diameter is 59″.6; and when it is at A, or as near A as can be seen by a telescope, its apparent diameter is 9″.6. Now put

$$SB=x; \quad \text{then} \quad EB=1-x; \quad \text{and} \quad AE=1+x.$$

If the greatest elongation of a planet were always the same, what would that circumstance show?

By Art. 66, $1-x : 1+x :: 96 : 596$;

Hence, $x=0.72254$.

By a like computation, the mean distance of Mercury from the sun is 0.3864.

To obtain the relative distance of Mars from the sun, we proceed as follows:

Let x be the distance sought; then when the planet is nearest to the earth, its distance must be expressed by $(x-1)$, and when at its greatest distance by $(x+1)$; and these quantities must be to each other, inversely, as the observed diameters; that is, we have the following proportion;

$$x-1 : x+1 :: 3.6 : 17.1.$$

Whence $x=1.53333$.

In like manner we may obtain the *relative* distance of any other planet from the sun.

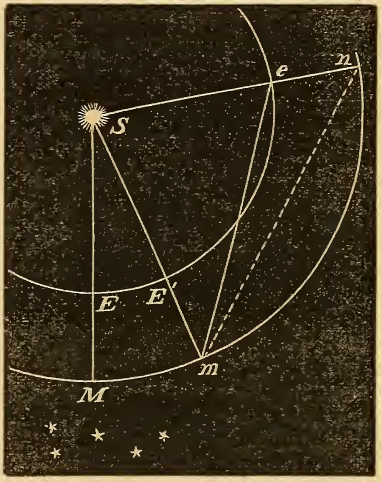
The next step in the path of astronomical knowledge is to determine what observations are necessary to find the periodical revolutions of the planets around the sun. If observers on the earth were at the center of motion, they could determine the times of revolution by simple observation. But as the earth is one of the planets, and all observers on its surface are carried with it, the observations here made must be subjected to mathematical corrections, to obtain true results; and this was an impossible problem to the ancients, as long as they contended for a stationary earth.

If the observer could view the planets from the center of the sun, he would see them in their true places among the stars — and there are only two positions in which an observer on the earth will see a planet in the same place as though he viewed it from the center of the sun, and these positions are *conjunction* and *opposition*.

By what means can astronomers obtain the relative distances of the superior planets from the sun? What is the next step in astronomical knowledge? Why cannot the periodical revolutions of the planets be observed directly?

Thus, when the earth is at E, and the planet at M, the planet is in opposition to the sun; and it is seen projected among the stars at the same point, whether viewed from S or from E.

The time that any planet comes in opposition to the sun, can be very distinctly determined by observation. Its longitude is then 180 degrees from the longitude of the sun, and comes to the meridian nearly or exactly at midnight. If it is a little short of opposition at the time of one observation, and a little past at another, the observer can proportion to the exact time of opposition, and such time can be definitely recorded — and by such observation, we have the true position of the planet, as seen from the sun.



Now suppose the planet at E to pass on and make a revolution, and when it comes round to E again, the planet M is near m, and the planet at E has to pass on to E_1 before the planet is again in opposition to the sun.

During this time, *the earth, or inferior planet, must describe one revolution, and the arc MSm, and the superior planet must describe the excess arc MSm.*

The time from one of these oppositions of the same planet to another, is called the *synodic revolution* of the planet, and observations have furnished us with the facts as stated in the following table:

When can we see a planet in the same position among the stars as though it were seen from the center of the sun? What is understood by the synodical revolution of a planet?

Planets.	Mean Duration of the Retrograde motion.	Mean Duration of the Synodic Revolution, or interval between two successive oppositions.
Mercury,	23 days.	118 days.
Venus,	42 "	584 "
Earth,		
Mars,	75 "	780 "
Jupiter,	121 "	399 "
Saturn,	139 "	378 "
Uranus,	151 "	370 "

In the preceding table, the word *mean* is used at the head of the several columns, because these elements are variable—sometimes more, and sometimes less, than the numbers here given — which indicate that the planets do not revolve in circles round the sun, but most probably in ellipses, like the orbit of the earth.

Let us now take the time of the synodic revolution of Jupiter, from the above table, and from it determine the periodical revolution of that planet. In 365.256 days the earth describes a revolution, or 360°, at an average rate of 59′ 8″ per day. From 399 days subtract 365.256 days, and the difference is 33.744 days. In 33.744 days at 59′ 8″ per day, the earth will describe 33°.256, which is the arc that Jupiter describes in 399 days, as seen from the sun. How many days then will be required by that planet to describe 360°? The proportion stands thus :

$$33°.256 : 360° : : 299 : \text{the time required.}$$

This proportion gives a little over 4319 days for the sidereal revolution of Jupiter. The true time is a little over 4332 days, the cause of the difference will soon be explained.

Let us now determine, approximately, the sidereal revolution of Venus.

Its synodic revolution is put down at 584 days. In this time the earth describes (575.58) degrees, *but because Venus is an inferior planet, it describes one revolution more.* Therefore Venus

Why do astronomers use the word mean, so often? In a synodic revolution, how many degrees does one planet describe more than the other? Which one describes the greatest number of degrees?

must describe 935.58 degrees in 584 days. In what time then will that planet describe 360 degrees?

The proportion is this :

$$935\tfrac{58}{100} : 360 :: 584 : \text{the time sought.}$$

The result of this proportion gives $224\frac{7}{10}$ days for the sidereal revolution of Venus, which is very near the truth.

All these results are, of course, understood as first approximations, and accuracy here is not attempted. We are only showing principles ; and it will be noticed, that the times here taken in these computations, are only to the nearest days, and not fractions of a day, as would be necessary for accurate results. By this method, accuracy is never attained, on account of the eccentricities of the orbits. No two synodical revolutions are exactly alike ; and therefore it is very difficult to decide what the real mean values are.

To obtain accuracy, in astronomy, observations must be carried through a long series of years. The following is an example : and it will explain how accuracy can be attained in relation to any other planet.

On the 7th of November, 1631, M. Cassini observed Mercury passing over the sun ;* and from his observations then taken, deduced the time of conjunction to be at 7h. 50m., mean time, at Paris, and the true longitude of Mercury 44° 41′ 35″.

Comparing this occultation with that which took place in 1723, the true time of conjunction was November 9th, at 5h. 29m. P. M., and Mercury's longitude was 46° 47′ 20″.

The elapsed time was 92 years, 2 days, 9 hours, 39 minutes.

* The times when Mercury and Venus are seen in the same part of the heavens from the sun as from the earth, can only be observed from the earth when these planets are in a line between the earth and some part of the sun. The planet will then appear on the sun as a black spot, and then it is called an *occultation.*

Why is accuracy as to the times of revolution of the planets never attempted to be deduced from a synodic revolution? How then is accuracy attained? Why did the author introduce a method that could not be relied upon for accuracy?

Twenty-two of these years were bissextile; therefore the elapsed time was (92×365) days, plus 24d. 9h. 39m.

In this interval, Mercury made 382 revolutions, and $2^\circ\ 5'\ 45''$ over. That is, in 33604,402 days, Mercury described 137522.095826 degrees; and therefore, by *division*, we find that in one day it would describe $4^\circ.0923$, at a mean rate.

Thus, knowing the mean daily rate to great accuracy, the mean revolution, in time, must be expressed by the fraction

$$\frac{360}{4.0923}=87.9701 \text{ days, or } 87 \text{ days } 23\text{ h. } 15\text{ m. } 57\text{ s.}$$

The following is another method of observing the periodical times of the planets, *to which we call the student's special attention.*

The orbits of all the planets are a little inclined to the plane of the ecliptic.

The planes of all the planetary orbits pass through the center of the sun; the plane of the ecliptic is one of them, and therefore the plane of the ecliptic and the plane of any other planet must intersect each other by some line passing through the center of the sun. *The intersection of two planes is always a straight line.* (See Geometry.)

The reader must also recognize and acknowledge the following principle:

That a body cannot appear to be in the plane of an observer, unless it really is in that plane.

For example: an observer is always in the plane of his meridian, and no body can appear to be in that plane unless it really is in that plane; it cannot be projected in or out of that plane, by parallax or refraction.

Hence, when any one of the planets appears to be in the plane of the ecliptic, it actually is in that plane; and let the time be recorded when such a thing takes place.

The planet will immediately pass out of the plane, because the two planes do not coincide. Passing the plane of the

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Do the planets appear to pass along in the heavens in the plane of the ecliptic? Can a planet appear to be in the ecliptic unless it is really in that place?

ecliptic is called passing the *node.* Keep track of the planet until it comes into the same plane; that is, crosses the other *node:* in this interval of time the planet has described just 180°, as *seen from the sun* (unless the nodes themselves are in motion, which in fact they are; but such motion is not sensible for one or two revolutions of Venus or Mars.)

Continue observations on the same planet, until it comes into the ecliptic the second time after the first observation, or to the same node again; and *the time elapsed, is the time of a revolution of that planet round the sun.* From such observations the periodical time of Venus became well known to astronomers, long before they had opportunities to decide it by comparing its transits across the sun's disc; and by thus knowing its periodical time and motion, they were enabled to calculate the times and circumstances of the transits which happened in 1761, and in 1769; save those resulting from parallax alone.

From observations long continued and accurately made, the following results were long since established:

	Sidereal Revolutions.	Mean distances from ☉
Mercury, - -	87.969258	0.387098
Venus, - -	224.700787	0.723332
Earth, - - -	365.256383	1.000000
Mars, - -	686.979646	1.523692
Jupiter, - -	4332.584821	5.202776
Saturn, - -	10759.219817	9.538786
Uranus, -	30686.820830	19.182390

By inspecting this table, we shall perceive that the greater the distance from the sun the greater the time of revolution, but the increase of the times of revolution is much greater than the increase of distances. This shows that the greater the distance a planet is from the sun, the slower is its *actual motion.**

* Let the reader be careful not to confound *real* or *actual* motion with *angular* motion.

By what observation can the periodical revolution of a planet be observed directly? Do the times of revolution, and the distances from the sun, increase in the same ratio?

Kepler, a Danish philosopher, about the year 1617, after various comparisons of the increase of time with the increase of distance, found that the square of the revolution corresponded to the cube of the distance, and thus established his third law.

We may now recapitulate the three laws of the solar system, called Kepler's laws.

1st. *The orbits of the planets are ellipses, of which the sun occupies one of the foci.*

2d. *The radius vector in each case describes areas about the focus, which are proportional to the times.*

3d. *The squares of the times of revolution are to each other as the cubes of the mean distances from the sun.*

The first of these laws is nothing more than an observed fact:— the second and third are also observed facts, and are susceptible of mathematical demonstration on philosophical principles, as may be seen in our University Edition of Astronomy, and in our Mathematical Sequel.

Kepler's third law is of great practical utility in finding the mean distances of any newly discovered planets from the sun.

Thus, suppose a new planet should be discovered, whose time of revolution round the sun was just five years, what would be its mean distance from the sun?

Let x represent the distance sought.

Then $1^2 : 5^2 :: 1^3 : x^3$.

Whence $x^3=25$, or $x=2.924$.

That is, the distance of that planet from the sun must be 2.924 times the distance between the sun and the earth.

Repeat Kepler's laws. Make a proportion with the numbers taken from the table, to show that you understand the enunciation of the third law.

CHAPTER VII.

THE TRANSITS OF VENUS AND MERCURY — THE SUN'S HORIZONTAL PARALLAX — THE REAL MAGNITUDE AND DISTANCE TO THE SUN.

We have thus far been very patient in our investigations — groping along — finding the form of the planetary orbits, and their relative magnitudes; but, as yet, we know nothing of the distance to the sun, save the indefinite fact, that it must be very great, and its magnitude great; but how great, we can never know, without the sun's parallax. Hence, to obtain this element, has always been an interesting problem to astronomers.

The ancient astronomers had no instruments sufficiently refined to determine this parallax by direct observation, in the manner of finding that of the moon, and hence the ingenuity of men was called into exercise to find some artifice to obtain the desired result.

After Kepler's laws were established, and the relative distances of the planets made known, it was apparent that their *real* distance could be deduced, provided, the distance between the earth and any planet could be made known.

The relative distances of the earth and Mars, from the sun (as determined by Kepler's law) are as 1 to 1.5237; and hence it follows that Mars, in its oppositions to the sun, is but about one half as far from the earth as the sun is; and therefore its parallax must be about double that of the sun; and several partially successful attempts were made to obtain it by observations.

On the 15th of August, 1719, Mars being very near its opposition to the sun, and very near a star of the 5th magnitude, its parallax became sensible; and Mr. Maraldi, an Italian

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When Mars is in opposition to the sun, how much greater is its parallax than the parallax of the sun?

astronomer, pronounced it to be 27″. The relative distance of Mars, at that time, was 1.37, as determined from its position and the eccentricity of its orbit.

But horizontal parallax is the angle under which the semi-diameter of the earth appears; and, at a greater distance, it will appear under a less angle. The distance of Mars from the earth, at that time, was .37, and the distance of the sun was 1;

Therefore, 1 : .37 : : 27″ : 9″.99, or 10″ nearly, for the sun's horizontal parallax.

On the 6th of October, 1751, Mars was attentively observed by Wargentin and Lacaille (it being near its opposition to the sun), and they found its parallax to be 24″.6, from which they deduced the mean parallax of the sun, 10″.7. But at that time, if not at present, the parallax of Mars could not be *observed directly*, with sufficient accuracy to satisfy astronomers; for no observer could rely on an angular measure within 2″.

Not being satisfied with these results, Dr. Halley, an English astronomer, very happily conceived the idea of finding the sun's parallax by the comparisons of observations made from different parts of the earth, on a *transit of Venus* over the sun's disc. If the plane of the orbit of Venus coincided with the orbit of the earth, then Venus would come between the earth and sun at every inferior conjunction, at intervals of 584.04 days. But the orbit of Venus is inclined to the orbit of the earth by an angle of 3° 23′ 28″; and, in the year 1800, the planet crossed the ecliptic from south to north, in longitude 74° 54′ 12″, and from north to south, in longitude 254° 54′ 12″: the first mentioned point is called the *ascending node;* the last, the *descending node.* The nodes retrograde 31′ 10″ in a century.

The mean synodical revolution of 584 days corresponds with no aliquot part of a year; and therefore, in the course of time, these conjunctions will happen at different points along the ecliptic. The sun is in that part of the ecliptic near the *nodes*

Who conceived the idea of deducing the sun's parallax from a transit of Venus? Why is there not a transit at every inferior conjunction of Venus with the sun?

of Venus, June 5th and December 6th or 7th; and the two last transits happened in 1761 and 1769; and from these periods we date our knowledge of the solar parallax.

The periodical revolution of the earth is 365.256383 days, and that of Venus is 224.700787 days; and as numbers they *are nearly* in proportion of 13 to 8; more nearly as 382 to 235.

From this it follows, that eight revolutions of the earth require nearly the same time as thirteen revolutions of Venus; and, of course, whenever a conjunction takes place, eight years afterward, another conjunction will take place very near the same point in the ecliptic.

If the proportional revolutions were exactly as 13 to 8, then the conjunctions at these periods would always take place exactly in the same point in the heavens; but as it is, conjunctions take place east and west of that point, and approximate nearer to it in periods more nearly proportional to the revolution of the planets.

To be more practical, however, the intervals between conjunctions are such, combined with a *slight motion of the nodes*, that the geocentric latitude of Venus, at inferior conjunctions near the ascending node, changes about 19′ 30″ to the north, in a period of about eight years. At the descending node, it changes about the same quantity to the southward, in the same period; and as the disc of the sun is but little over 32′, it is impossible that a third transit should happen sixteen years after the first; hence, only two transits can happen, at the same node, separated by the short interval of eight years.

If at any transit we suppose Venus to pass directly over the center of the sun, as seen from the center of the earth — that is, pass conjunction and node at the same time — at the end of another period of about eight years, Venus would be 19′ 30″ north or south of the sun's center; but as the semi-diameter of the sun is but about 16′, no transit could happen in such a

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If Venus should pass over the center of the sun at any inferior conjunction, should we have another transit in eight years after? How far would Venus then pass from the limb of the sun?

case; and there would be but one transit at that node until after the expiration of a long period of 235 or 243 years.

After passing the period of eight years, we take a lapse of 105 or 113 years, or thereabouts, to look for a transit at the other node.

Knowing the relative distances of Venus, and the earth, from the sun — the positions and eccentricities of both orbits — also their angular motions and periodical revolutions — every circumstance attending a transit, as seen from the earth's center, can be calculated; and Dr. Halley, in 1677, read a paper before the London Astronomical Society, in which he explained the manner of deducing the parallax of the sun from observations taken on a transit of Venus or Mercury across the sun's disc, compared with computations made for the earth's center, or by comparing observations made on the earth at great distances from each other.

The transits of Venus are much better, for this purpose, than those of Mercury; as Venus is larger, and nearer the earth, and its parallax at such times much greater than that of Mercury; and so important did it appear, to the learned world, to have correct observations on the last transit of Venus, in 1769, at remote stations, that the British, French, and Russian governments were induced to send out expeditions to various parts of the globe, to observe it. "The famous expedition of Captain Cook, to Otaheite, was one of them."

The mean result of all the observations made on that memorable occasion, gave the sun's parallax, on the day of the transit, (3d of June,) 8″.5776. The horizontal parallax, at mean distance, may be taken at 8″.6; which places the sun, at its mean distance, no less than 23984 times the length of the earth's semi-diameter, or about 95 millions of miles.

This problem of the sun's horizontal parallax, as deduced from observations on a transit of Venus, we regard as the most

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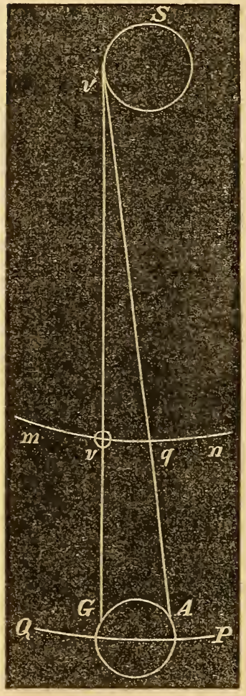
Why are transits of Venus better for this object than those of Mercury? What is the amount of the sun's parallax? What is then the distance to the sun, in miles?

important, for a student to understand, of any in astronomy; for without it, the dimensions of the solar system, and the magnitudes of the heavenly bodies, must be taken wholly on trust; and we have often protested against mere facts being taken for knowledge.

We shall now attempt to explain this whole matter on general principles, avoiding all the little minutiæ which render the subject intricate and tedious; for our only object is to give a clear idea of the nature and philosophy of the problem.



Let S represent the sun, and $m\,n$ and $P\,Q$ small portions of the orbits of Venus, and the earth.

As these two bodies move the same way, and nearly in the same plane, we may suppose the earth stationary, and Venus to move with an angular velocity equal to the difference of the two.

When the planet arrives at v, an observer at G would see the planet projected on the sun, making a dent at v'.

But an observer at A would not see the same thing until after the planet had passed over the small arc $v\,q$, with a velocity equal to the difference between the angular motion of the two bodies; and as this will require quite an interval of absolute time, it can be detected; and it measures the angle $A\,v'\,G$; an angle under which a definite portion of the earth appears as seen from the sun.

To have a more definite idea of the practicability of this

If two observers are at a distance from each other, will they see the beginning or end of the transit at the same time? Is it the object of the observations to determine the difference in the time?

method, let us suppose the parallactic angle, $Av'G$, equal to $10''$, and inquire how long Venus would be in passing the *relative* arc vq.

Venus, at its mean rate, passes -	1° 36′ 8″ in a day.	
The earth, " " " - -	59′ 8″	"

The relative, or excess motion of Venus for a mean solar day, is then 37′.

Now as 37′ is to 24h. so is 10″ to a fourth term ; or as

$$2220'' : 1440\text{m.} :: 10'' : 6\text{m. } 29\text{s.}$$

Now if observation had given more than 6 minutes and 29 seconds, we should conclude that the parallactic angle was more than 10″; if less, less. But this is an abstract proposition. When treating of an actual case in place of the mean motion, we must take the actual angular motions of the earth and Venus at that time, and we must know the actual position of the observers A and G in respect to each other, and the position of each in relation to a line joining the center of the sun ; and then by comparing the local time of observation made at A, with the time at G, and referring both to one and the same meridian, we shall have the interval of time occupied by the planet in passing from v to q, from which we deduce the parallactic angle $Av'G$, and from thence the horizontal parallax, or the magnitude that the angle $Av'G$ would be, in case the distance AG were equal to the semi-diameter of the earth.

The same observations can be made when the planet passes off the sun, and a great many stations can be compared with A, as well as the station G. In this way, the mean result of a great many stations was found in 1761, and in 1769, and the mean of all cannot materially differ from the truth.

The first transit known to have been observed was in 1639, December 4th; to this add 225 years, and we have the time of the next transit, at the same node, 1874, December 8th; and eight years after that will be another, 1882, December 6th.

Has the parallax of the sun been deduced from one observation, or is it the result of many? Can this result be far from the truth? When will the next transit occur?

CHAPTER VIII.

TO FIND THE DIAMETER AND MAGNITUDE OF A PLANET.

Having now found the solar horizontal parallax, and consequently the real distance to the sun, we have sufficient data to find the real distance, diameter, and magnitude of each and every planet in the solar system.

Let the reader bear in mind that the horizontal parallax of any body is the angle under which the semi-diameter of the earth appears, as seen from that body. The apparent semi-diameter of the body, and the earth's horizontal parallax, as seen from that body, is one and the same thing; therefore,

As the diameter of the earth
Is to the diameter of any other planet,
So is the horizontal parallax of the planet
To its apparent semi-diameter.

The mean horizontal parallax of the sun, as determined by the transit of Venus, is 8″.6, and the semi-diameter of the sun at the corresponding mean distance, is 16′ 1″, or 961″. Now let d represent the real diameter of the earth, and D that of the sun, then we shall have the following proportion:

$$d : D :: 8''.6 : 961''.0$$

But d is 7912 miles; and the ratio of the last two terms is 111.66; therefore $D=(111.66)(7912)=883454$ miles.

The sun's horizontal parallax is the angle at the vertex of a right angled triangle, and the base opposite, is the semi-diameter of the earth; and if we call that distance unity, and compute the distance of one of the other sides by trigonometry, we shall find it equal to 23984 units, or semi-diameters of the

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What element must astronomers obtain before they can determine the magnitudes and distances of the planets? State the rule to find the diameter of the sun or a planet?

earth; but to aid the memory, we may say that the distance is 24000 times the earth's semi-diameter.

If we *change the unit*, from the semi-diameter of the earth, to an English mile, then the mean distance between the earth and sun must be

$$(3956)(24000)=94.944000 \text{ miles.}$$

In round numbers we may say 95 millions of miles.

By Kepler's third law, we know the relative distances of the planets from the sun, and now knowing the *real* distance, in miles, of one of them (the earth), we can determine the real distances of the others by multiplying each relative distance by 94.944000.

	Relative distances.		True distances.
Mercury,	0.3871		36.752.822
Venus,	0.7233		68.672.995
Earth,	1.0000	94.944000=	94.944.000
Mars,	1.5237		144.666.172
Jupiter,	5.2028		493.974.643
Saturn,	9.5388		905.651.827
Uranus,	19.1824		1814.417.800

By observations taken on the transit of Venus, in 1769, it was concluded that the horizontal parallax of that planet was 30″.4; and its semi-diameter, at the same time, was 29″.2. Hence, 304 : 292 : : 7912 : to a fourth term; which gives 7599 miles for the diameter of Venus.

We cannot observe the horizontal parallax of Jupiter, Saturn, or any other very remote planet: if known at all, it becomes known by computation; but the parallax of the sun being now known, and the relative distances of the earth and all the planets from the sun being known, the horizontal parallax of any planet can be computed as follows. *Once more* we remind the reader that the sun's horizontal parallax is the angle under which the earth appears, as seen from the sun—seen from a

What is the multiplier to the relative distances of the planets from the sun, to obtain the distances in miles? Do we observe the horizontal parallax of a remote planet, or compute it?

greater distance, the angle must be *proportionally less.* Seen from a distance equal to the mean distance of Jupiter from the sun, the angle would be $\frac{8''.6}{5.2028}$. This, then, is the horizontal parallax of Jupiter, when Jupiter is at a distance from the earth equal to the mean distance of Jupiter from the sun. The apparent semi-diameter of Jupiter, when at the same distance, as determined by observation, is 18″.35; therefore the diameter of Jupiter can be determined by the following proportion

$$7912 : D :: \frac{8.6}{5.2028} : 18.35,$$

in which D represents the magnitude sought.

Whence $D = \frac{7912 \times 18.35 \times 5.2028}{8.6} = 7912 \times 11.1 = 87823$ miles

In the same manner we can find the diameter of any other planet whose apparent diameter can be distinctly measured, and whose relative distance to the sun is known. The diameter may also be computed directly by plane trigonometry.

We have just seen that the diameter of Jupiter is 11.1 times the diameter of the earth; but this is the equatorial diameter of the planet. Its polar diameter is less, in the proportion of 167 to 177, as determined by the mean of many micrometrical measurements; which proportion gives 82930 miles, for the polar diameter of Jupiter. These extremes give the mean diameter of Jupiter, to the mean diameter of the earth, as 10.8 to 1.

But the magnitudes of similar bodies are to one another as the cubes of their like dimensions; therefore the magnitude of Jupiter is to that of the earth, as $(10.8)^3$ to 1, and from thence we learn that Jupiter is 1260 times greater than the earth.

In this manner are found the magnitudes, distances, velocity, &c. &c. of the planets, which appear in tables in various astronomical works.

State the proportion to find the diameter of a planet when its horizontal parallax and apparent semi-diameter are both known. How much greater is the diameter of Jupiter than the earth? How much greater then is the magnitude of Jupiter than that of the earth?

CHAPTER IX.

A GENERAL DESCRIPTION OF THE SOLAR SYSTEM.

The solar system is so called because the sun occupies the central position, and apparently holds and governs the motion of all the planets which revolve around him.

We shall commence our description with

THE SUN.

This body, as we have seen in the preceding pages, is of immense magnitude, much greater than all the planets taken together, comparatively stationary, the dispenser of light and heat, and apparently at least, the repository of that attractive force which holds the system together, and regulates the planetary motions.

"Spots on the sun seem first to have been observed in the year 1611, since which time they have constantly attracted attention, and have been the subject of investigation among astronomers."

A spot first appears on the eastern limb of the sun, and by degrees comes forward to the middle, and passes off to the west. After being absent about the same length of time, the same spot appears in the same place as before, thus indicating a revolution of the sun on an axis, in 25 days 14 hours, the synodical revolution of the spots being 27 days 12$\frac{1}{3}$ hours.

These spots change their appearance, "and become greater or less, to an observer on the earth, as they are turned to, or from him; they also change in respect to real magnitude and number; one spot, seen by Dr. Herschel, was estimated to be

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Whereabouts in the solar system is the sun? Does it revolve on an axis — and if so, how did the fact become known? What is the time of revolution? What is said of the size of some of these spots?

more than six timés the size of our earth, being 50000 miles in diameter. Sometimes forty or fifty spots may be seen at the same time, and sometimes only one. They are often so large as to be seen with the naked eye; this was the case in 1816.

"In two instances, these spots have been seen to burst into several parts, and the parts to fly in several directions, like a piece of ice thrown upon the ground.

"Dr. Herschel, from many observations with his great telescope, concludes, that the shining matter of the sun consists of a mass of phosphoric clouds, and that the spots on his surface are owing to disturbances in the equilibrium of this luminous matter, by which openings are made through it. There are, however, objections to this theory, as indeed there are to all the others, and at present it can only be said, that no satisfactory explanation of the cause of these spots has been given."

MERCURY.

This planet is the nearest to the sun, and has been the subject of considerable remark in the preceding pages. It is rarely visible, owing to its small size and proximity to the sun, and it never appears larger to the naked eye than a star of the fifth magnitude.

Mercury is seen through a telescope sometimes in the form of a half moon, and sometimes a little more or less than half its disc is seen; hence it is inferred, that it has the same phases as the moon, except that it never appears quite round, because its enlightened side is never turned directly towards us, unless when it is so near the sun as to become invisible, by reason of the splendor of the sun's rays. The enlightened side of this planet being always towards the sun, and its never appearing round, are evident proofs that it shines not by its own light; for, if it did, it would constantly appear round. The best observations of this planet are those made when it is seen on the sun's disc, called its transit; for in its lower con-

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How large does Mercury appear? What is its position when the best observations can be made on it?

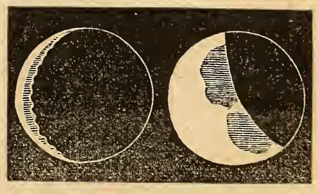
junction, he sometimes passes before the sun, like a little spot, eclipsing a small part of the sun's body.

Mercury is too near the sun to admit of any observations on the spots on its surface; but its period of rotation has been determined by the variations in its *horns* — the same *ragged* corner comes round at regular intervals of time — 24h. 5m.

The best time to see Mercury, in the *evening*, is in the spring of the year, when the planet is at its greatest elongation *east* of the sun. It will then be visible to the naked eye about fifteen minutes, and will set about an hour and fifty minutes after the sun. When the planet is *west* of the sun, and at its greatest distance, it may be seen in the morning, most advantageously in August and September. The symbol for the greatest elongation of Mercury, as written in the common almanac, is ☿ Gr. Elon.

VENUS.

This planet is second in order from the sun, and in relation to its position and motion, it has been sufficiently described. The period of its rotation on its axis is 23h. 21m. The position of the axis is always the same, and is not at right angles to the plane of its orbit, which gives it a change of seasons. The tangent position of the sun's light across this planet shows a very rough surface; indeed, high mountains. By the radiating and glimmering nature of the light of this planet. we infer that it must have a deep and dense atmosphere.



These figures present a telescopic view of this planet; the narrow crescent appears when the planet is near its inferior conjunction, the other when the planet is near its greatest elongation.

The enlightened side is always towards the sun, which shows

How was the revolution of Mercury, on an axis, determined? Does Venus revolve on an axis, and in what time?

that it shines not by its own light, but by reflecting the light from the sun; and indeed, observations show that this is true of all the planets. For the magnitude, motion, inclination of orbit, &c. of Venus, see tables.

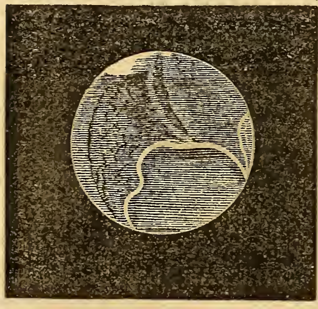
THE EARTH

Is the next planet in the system; but it would be only formality to give any description of it in this connection. As a planet, it seems to be highly favored above its neighboring planets, by being furnished with an attendant, the *moon;* and insignificant as this latter body is, compared to the whole solar system, it is the most important to the inhabitants of our earth. The two bodies, the *earth* and the *moon,* as seen from the sun, are very small: the former subtending an angle of about 17″ in diameter, and the latter about 4″, and their distance asunder never greater than between seven and eight minutes of a degree.

We shall give a particular description of the moon, its orbit, motion, &c. &c. in a future chapter.

MARS.

The fourth planet from the sun is Mars; its orbit is nearest the orbit of the earth, or it is the first superior planet. It is of a fiery red color, and very variable in its apparent magnitude corresponding with its variable distance. About every other year, when it comes to the meridian near midnight, it is then most conspicuous; and the next year it is scarcely noticed by the common observer.



The figure in the margin represents the telescopic appearance of Mars when its apparent magnitude is greatest, near its opposition to the sun.

Does Venus shine by its own light? and if not, how is that fact known? What heavenly body is most important to the inhabitants of the earth, (the sun excepted)? What is the position of Mars in the solar system? Describe that planet. Why is it much more conspicuous sometimes than others? When most conspicuous, what is its position in respect to the sun?

"The physical appearance of Mars is somewhat remarkable. His polar regions, when seen through a telescope, have a brilliancy so much greater than the rest of his disc, that there can be little doubt that, as with the earth so with this planet, accumulations of ice or snow take place during the winters of those regions. In 1781 the south polar spot was extremely bright; for a year it had not been exposed to the solar rays. The color of the planet most probably arises from a dense atmosphere which surrounds him, of the existence of which there is other proof depending on the appearance of stars as they approach him; they grow dim and are sometimes wholly extinguished as their rays pass through that medium."

The next planet known to ancient astronomers, is Jupiter; but its distance is so great beyond the orbit of Mars, that the void space between the two had often been considered as an *imperfection*, and it was a general impression among astronomers that a *planet ought to occupy* that vacant space.

For complete symmetry in the solar system, a planet ought to exist at about 2.8 distance from the sun, calling the distance of the earth *unity*, and that planet two or three times the magnitude of the earth,—but certainly no such planet existed, for such an one could not possibly have escaped observation.

Mere *human reason* had long decided that a planet ought to exist in this void space, and in this case, reason has triumphed. On the 1st of January, 1801, M. Piazzi, an astronomer of Palermo, in Sicily, discovered a small planet, which he called *Ceres*, which was soon found to occupy this very vacant space. This set other astronomers on the alert, and three other small planets were discovered between January, 1801, and April, 1807. The following table gives much information in a very small compass:

Planets.	Names of Discoverers.	Residence of Discoverers.	Date of Discovery.
Ceres,	M. Piazzi,	Palermo, Sicily,	1st January, 1801.
Pallas,	Dr. Olbers,	Bremen, Germany,	28th March, 1802.
Juno,	M. Harding,	Lilienthal, near Bremen,	1st September, 1804.
Vesta,	Dr. Olbers,	Bremen,	29th March, 1807.

For complete symmetry, whereabouts in the solar system should a large planet exist? When was the first planet discovered in that space?

These planets revolving at nearly the same mean distance from the sun, and performing their revolutions in times of near the same duration—and being very small, Dr. Olbers suggested that they might be but fragments of one large planet that burst asunder by its internal fires.

This bold and original idea was received as visionary, and by some, with sneers, as all bold and original ideas always have been received at first, but time and reflection have gradually brought this theory into favor.

If a planet has really burst, it is but reasonable to suppose that it separated into many fragments; and, agreeably to this view of the subject, astronomers have been constantly on the alert for new planets, in the same regions of space; and every discovery of the kind greatly increases the probability of the theory.

On the 8th of December, 1845, Mr. Hencke, of Dresden, discovered a planet called *Astrea*, and the same observer discovered another in 1847, called *Hebe*.

The success of Mr. Hencke induced others to like examinations in the heavens, and Mr. Hind, of London, in 1848, discovered two other planets, *Iris* and *Flora*.

Since this time, seven other small planets have been discovered, *Egeria*, *Eunomia*, *Irene*, *Metis*, *Parthenope*, *Hygeria*, and *Victoria*. Thus, we have *fifteen** miniature worlds, all located in that space where reason called for a planet; and, *is it* unreasonable then to suppose that these fifteen, and perhaps others yet unseen, are but fragments of a planet? *all of them together* would not make one planet larger than the earth.

* This chapter was written in 1854, since which time, and up to the present, some seventeen others have been added to the list. At this time, 1857, thirty-one have been tabulated in the Nautical Almanac; but all of them put together would not make a very large planet, and they are of no interest to readers of this work. We have tabulated some on the next page.

On finding four planets in this region, what theory was advanced by Dr. Olbers? Is it reasonable to suppose that all of these small bodies at about the same mean distance from the sun, could be originally distinct and independent planets?

For further information, we give the following tabular facts, which will be verified, or modified and corrected, by subsequent observations:

Planets.	Mean distance from the sun.	Mean time of Revolution.	Eccentricity of orbits.	Lon. of the Ascending node.	Inclination of orbit.
	Earth's dis. 1	Days.			To Ecliptic.
Flora,	2.2014	1193.16	0.15677	110° 21′	5° 53′
Victoria,	2.3348	1303.08	0.21854	235° 40′	8° 23′
*Vesta,	2.3627	1326.26	0.08945	103° 24′	7° 8′
Iris,	2.3858	1345.66	0.23232	259° 44′	5° 28′
Metis,	2.3868	1346.90	0.12274	68° 28′	5° 36′
Hebe,	2.4256	1379.68	0.20200	138° 32′	14° 47′
Parthenope,	2.4483	1399.06	0.09800	125° 0′	4° 37′
Irene,	2.5805	1515.40	0.16974	86° 51′	9° 6′
Astrea,	2.6173	1547.58	0.18880	141° 28	5° 19′
Egeria,	2.5829	1515.82	0.08628	43° 18′	16° 33′
*Juno,	2.6679	1591.68	0.25637	170° 58′	13° 3′
*Ceres,	2.7653	1679.86	0.07904	80° 49′	10° 36′
*Pallas,	2.7715	1686.22	0.23894	172° 37′	34° 42′
Eunomia,	2.6483	1574.08	0.18856	293° 54′	11° 44′
Hygeia,	3.1512	2043.38	0.10090	287° 38′	3° 47′
Psyche,	2.9771	1834.61	0.13082	150° 36′	3° 4′
Fortuna,	2.5342	1440.80	0.17023	211° 17′	1° 32′
Melpomene,	2.3292	1269.81	0.21644	150° 0′	10° 9′
Thetis,	2.4718	1419.31	0.12736	125° 25′	5° 35′
Lutetia,	2.4353	1387.77	0.16104	80° 34′	3° 5′
Calliope,	2.9054	1809.00	0.10308	66° 38′	13° 45′
Amphitrite,	2.5521	1489.22	0.06716	356° 27′	6° 8′

The hypothesis that the small planets, Ceres and Pallas, were originally one planet, and must, therefore, by the laws of motion and inertia, have two common points in the heavens, near which all of them must pass, led to the discovery of *Juno* and *Vesta*, by carefully observing in these two portions of the heavens for other fragments which might exist; and as this theory came more and more into favor, observations were made

* We made an effort to arrange these planets in the order of their distances from the sun, and we have done so, as far as Hygeia. The following ones were subsequent discoveries. Some future day, when these elements will be better known, by more varied and extended observations, a re-arrangement can be made.

with greater and greater care, and the result has been, these recent interesting and singular discoveries.

The apparent diameters of these planets are too small to be accurately measured; and therefore we have only a very rough or conjectural knowledge of their diameters.

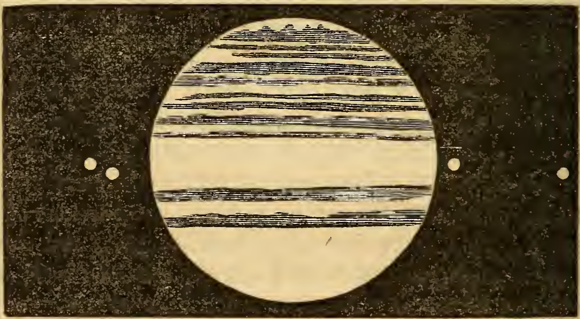
All of these planets are invisible to the naked eye, except Vesta, which sometimes can be seen as a star of the 5th or 6th magnitude.

The fact that these bodies have never caused any sensible perturbations in the motion of Mars, is a physical demonstration that they must be very small, separately considered, and their aggregate influence must be nearly frittered away, in consequence of their dispersed positions.

JUPITER.

We now come to the most magnificent planet in the system —the well-known Jupiter—which is nearly 1300 times the magnitude of the earth.

The disc of Jupiter is always observed to be crossed, in an eastern and western direction, by dark bands, as represented in the annexed figure.



What is said of the diameters and real magnitudes of these planets? Which planet is the most magnificent in the system?

"These belts are, however, by no means alike at all times; they vary in breadth and in situation on the disc (though never in their general direction). They have even been seen broken up, and distributed over the whole face of the planet: but this phenomenon is extremely rare. Branches running out from them, and subdivisions, as represented in the figure, as well as evident dark spots, like strings of clouds, are by no means uncommon; and from these, attentively watched, it is concluded that this planet revolves in the surprisingly short period of 9h. 55m. 50s. (sid. time), on an axis perpendicular to the direction of the belts. Now, it is very remarkable, and forms a most satisfactory comment on the reasoning by which the spheroidal figure of the earth has been deduced from its diurnal rotation, that the outline of Jupiter's disc is evidently not circular, but elliptic, being considerably flattened in the direction of its axis of rotation.

"The parallelism of the belts to the equator, of Jupiter, their occasional variations, and the appearances of spots seen upon them, render it extremely probable that they subsist in the atmosphere of the planet, forming tracts of comparatively clear sky, determined by currents analogous to our tradewinds, but of a much more steady and decided character, as might indeed be expected from the immense velocity of its rotation. That it is the comparatively darker body of the planet which appears in the belts, is evident from this, — that they do not come up in all their strength to the edge of the disc, but fade away gradually before they reach it.

"When Jupiter is viewed with a telescope, even of moderate power, it is seen accompanied by four small stars, nearly in a straight line parallel to the ecliptic. These always accompany the planet, and are called its *Satellites*. They are continually

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In what time does Jupiter revolve on its axis? Those dark belts on Jupiter, are they on the body of the planet, or are they probably clouds in its atmosphere? Is Jupiter exactly spherical? How many moons has Jupiter?

changing their positions with respect to one another, and to the planet, being sometimes all to the right, and sometimes all to the left; but more frequently some on each side. The greatest distances to which they recede from the planet, on each side, are different for the different satellites, and they are thus distinguished: that being called the *First* satellite, which recedes to the least distance; that the *Second*, which recedes to the next greater distance, and so on. The satellites of Jupiter were discovered by Galileo, in 1610.

"Sometimes a satellite is observed to pass between the sun and Jupiter, and to cast a shadow which describes a chord across the disc. This produces an eclipse of the sun, to Jupiter, analogous to those which the moon produces on the earth. It follows that Jupiter and its satellites are opake bodies, which shine by reflecting the light of the sun.

"Careful and repeated observations show that the motions of the satellites are from west to east, in orbits nearly circular, and making small angles with the plane of Jupiter's orbit. Observations on the eclipses of the satellites make known their synodic revolutions, from which their sidereal revolutions are easily deduced. From measurements of the greatest apparent distances of the satellites from the planet, their real distances are determined.

"A comparison of the mean distances of the satellites, with their sidereal revolutions, proves that Kepler's third law, with respect to the planets, applies also to the satellites of Jupiter. The squares of their sidereal revolutions are as the cubes of their mean distances from the planet.

"The planets Saturn and Uranus are also attended by satellites, and the same law has place with them."

By the eclipses of Jupiter's satellites, the progressive nature

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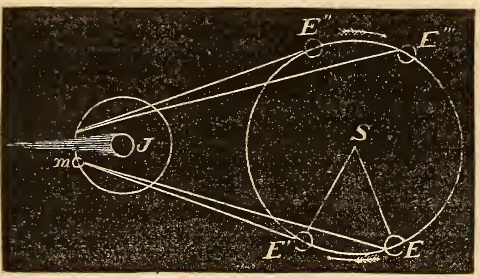
Do the revolutions of these moons correspond to Kepler's third law? Repeat the law. What discovery was made in relation to light, by the aid of the eclipses of Jupiter's moons? Explain this by a figure on the black board.

of light was discovered; which we illustrate in the following manner:



Let *S* represent the sun, *J* Jupiter, *E* Earth, and *m* Jupiter's first satellite. By careful and accurate observations astronomers have decided that the mean revolution of this satellite round its primary, is performed in 42h. 28m. and 35s.; that is, the mean time from one eclipse to another.

But when the earth is at *E*, and moving in a direction toward, or nearly toward, the planet as represented in the figure, the mean time between two consecutive eclipses is shortened about fifteen seconds; and we can explain this on no other hypothesis than that the earth has advanced and met the successive progression of light. When the earth is in position as respects the sun and Jupiter, as represented in our figure at *E″*, and moving from Jupiter, then the interval between two consecutive eclipses of Jupiter's first satellite is prolonged or increased about fifteen seconds.

But during the interval of one revolution of Jupiter's first satellite, the earth moves in its orbit about 2880000 miles; this, divided by 15, gives 192000 miles for the motion of light in one second of time; and this velocity will carry light from the sun to the earth in about eight and one-fourth minutes.

As an eclipse of one of Jupiter's satellites may be seen from all places where the planet is then visible, two observers viewing it will have a signal for the same moment, at their respective

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How do astronomers find the difference of longitude between two places by means of the eclipses of Jupiter's satellites?

places; and their difference in local time, will give their difference in longitude. For example, if one observer saw one of these eclipses at 10h. in the evening, and another at 8h. 30m., the difference of longitude between the observers would be 1h. 30m. in time, or 22° 30′ of arc.

The absolute time that the eclipse takes place, is the same to all observers; and he who has the latest local time is the most eastward.

These eclipses cannot be observed at sea, by reason of the motion of the vessel. The telescope cannot be held sufficiently steady.

SATURN.

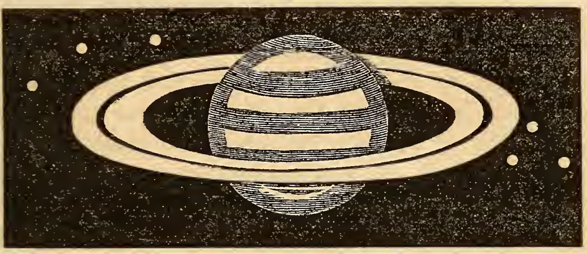
The next planet in order of remoteness from the sun, is Saturn, the most wonderful object in the solar system. Though less than Jupiter, it is about 79000 miles in diameter, and 1000 times greater than our earth.

"This stupendous globe, besides being attended by no less than seven satellites, or moons, is surrounded with two broad, flat, extremely thin rings, concentric with the planet and with each other; both lying in one plane, and separated by a very narrow interval from each other throughout their whole circumference, as they are from the planet by a much wider. The dimensions of this extraordinary appendage are as follows:

		Miles.
Exterior diameter of exterior ring,............	=	176418
Interior ditto,............................	=	155272
Exterior diameter of interior ring,............	=	151690
Interior ditto,............................	=	117339
Equatorial diameter of the body,..............	=	79160
Interval between the planet and interior ring,..	=	19090
Interior of the rings,......................	=	1791
Thickness of the rings not exceeding..........	=	100

Can these eclipses be used at sea? Why not? What is the next planet in the system? What is the magnitude of Saturn? What is there remarkable about the planet? How many moons has it?

"The figure represents Saturn surrounded by its rings, and having its body striped with dark belts, somewhat similar, but



broader and less strongly marked than those of Jupiter, and owing, doubtless, to a similar cause. That the ring is a solid opake substance, is shown by its throwing its shadow on the body of the planet, on the side nearest the sun, and on the other side receiving that of the body, as shown in the figure. From the parallelism of the belts with the plane of the ring, it may be conjectured, that the axis of rotation of the planet is perpendicular to that plane; and this conjecture is confirmed by the occasional appearance of extensive dusky spots on its surface, which when watched, like the spots on Mars or Jupiter, indicate a rotation in 10h. 29m. 17s. about an axis so situated.

"It will naturally be asked how so stupendous an arch, if composed of solid and ponderous materials, can be sustained without collapsing and falling in upon the planet? The answer to this is to be found in a swift rotation of the ring, in its own plane, which observation has detected, owing to some portions of the ring being a little less bright than others, and assigned its period at 10h. 29m. 17s., which, from what we know of its dimensions, and of the force of gravity in the Saturnian system, is very nearly the periodic time of a satellite revolving at the same distance as the middle of its breadth. It is the centrifugal force, then, arising from this rotation, which sustains it; and, although no observation nice enough to exhibit a

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Which is most probable, that the rings are solid, or consist of vapor? Do the rings revolve? In what length of time?

difference of periods between the outer and inner rings, have hitherto been made, it is more than probable that such a difference does exist, so as to place each, independently of the other, in a similar state of equilibrium.

"Although the rings are, as we have said, very nearly concentric with the body of Saturn, yet recent micrometrical measurements, of extreme delicacy, have demonstrated that the coincidence is not mathematically exact, but that the center of gravity of the rings oscillates round that of the body, describing a very minute orbit, probably under laws of much complexity. Trifling as this remark may appear, it is of the utmost importance to the stability of the system of the rings. Supposing them mathematically perfect in their circular form, and exactly concentric with the planet, it is demonstrable that they would form (in spite of their centrifugal force) a system in a state of *unstable equilibrium*, which the slightest external power would subvert — not by causing a rupture in the substance of the rings — but by precipitating them, *unbroken*, on the surface of the planet. For the attraction of such a ring or rings on a point or sphere eccentrically situate within them, is not the same in all directions, but tends to draw the point or sphere toward the nearest part of the ring, or away from the center. Hence, supposing the body to become, from any cause, ever so little eccentric to the ring, the tendency of their mutual gravity is, not to correct, but to increase this eccentricity, and to bring the nearest parts of them together."

URANUS.

This planet, the next beyond Saturn, was discovered by Sir W. F. Herschel, in 1781, and, for a time, was called Herschel, in honor of its discoverer; but, according to custom, the name of a heathen deity has been substituted, and the planet is now called Uranus — *the father of Saturn.*

Is it probable that the rings revolve around Saturn, as moons in orbits slightly eccentric? Is this necessary to preserve the existence of the rings unbroken? What is the next planet in the system? When, and by whom was it discovered?

This planet is rarely to be seen, without a telescope. In a clear night, and in the absence of the moon, when in a favorable position above the horizon, it may be seen as a star of about the sixth magnitude. Its real diameter is about 35000 miles, and about 80 times the magnitude of the earth.

The existence of this planet was suggested by some of the perturbations of Saturn ; which could not be accounted for by the action of the then known planets ; but it does not appear that any computations were made, as a guide to the place where the unknown disturbing body ought to exist ; and, as far as we know, the discovery by Herschel was merely accidental.

Not so in respect to the discovery of the most remote planet now known in the solar system — the planet

NEPTUNE.

This planet was discovered in the latter part of September, 1846, by a French astronomer, *Leverrier;* and also a Mr. Adams, of Cambridge, England, who has put in his claim as discoverer. The truth is, that the attention of the astronomers of Europe had been called to some extraordinary perturbations of *Uranus;* which could not be accounted for without supposing an attracting body to be situated in space, beyond the orbit of Uranus ; and so distinct and clear were these irregularities, that both geometers, Leverrier and Adams, fixed on the same region of the heavens, for the then position of their *hypothetical* planet ; and by diligent search, the planet was actually discovered about the same time, in both France and England. All that is known of this planet is comprised in the following table :

Epoch 1852, Sept. 3d, mean time at Berlin.

Mean longitude, - - -	341° 1′ 55″	From mean Equinox.
Longitude of the Perihelion,	47° 16′ 36″	
Longitude of Ascending Node,	130° 8′ 50″	
Inclination of the orbit, -	1° 46′ 59′	

What observed facts suggested the existence of Uranus ? Was the discovery the result of such an hypothesis ? What other planet was discovered by similar facts, and a similar theory ? When and by whom was that planet discovered ?

Eccentricity of the orbit, - - 0.008718
Mean daily sidereal motion, - 21″.5545
Mean time of revolution, 60126.65 days, or 165 yrs. nearly.

Mean distance from the sun, 30.048, (the earth's distance being unity.) Future observations will undoubtedly modify and correct these results.

We shall close this chapter with the following extract from Herschel's Astronomy, "which will convey to the minds of our readers a general impression of the relative magnitudes and distances of the parts of our system. Choose any well-leveled field or bowling green. On it place a globe, two feet in diameter; this will represent the sun; Mercury will be represented by a grain of mustard seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus a pea, on a circle 284 feet in diameter; the earth also a pea, on a circle 430 feet; Mars a rather large pin's head, on a circle of 654 feet; Juno, Ceres, Vesta, and Pallas, grains of sand, in orbits of from 1000 to 1200 feet; Jupiter a moderate-sized orange, in a circle nearly half a mile across; Saturn a small orange, on a circle of four-fifths of a mile; and Uranus a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half in diameter. As to getting correct notions on this subject by drawing circles on paper, or still worse, from those very childish toys called orreries, it is out of the question. To imitate the motions of the planets in the above mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus, in 4m. 14s.; the earth, in 7 minutes; Mars, in 4 m. 48s.; Jupiter, in 2h. 56m.; Saturn, in 3h. 13m.; and Uranus, in 2h. 16m."

From this description it will be seen that the true reason why the solar system cannot be accurately represented on paper, is this: That if we give the earth any sensible magnitude, there will not be space enough on any paper to represent the sun, or to extend to the planets.

What does Herschel say about representing the solar system on paper? What term does he apply to orreries? Why can we not make a proper map of the solar system?

SECTION III.

CHAPTER I.

THE MOON, ITS PERIODICAL REVOLUTIONS, AND APPEARANCES.

NEXT to the sun, the moon is the most interesting and important heavenly body, to the inhabitants of the earth, and we made that a reason for omitting an exposition of its motion, path, and other phenomena, until the student acquired a little astronomical discipline. In Section II, chapter I, we have explained parallax in general, and the moon's parallax in particular, and found it to vary from 53′ 50″ to 61′ 29″, the amount when the moon is at its mean distance from the earth, being 57′ 3″, corresponding to a distance of 60.26 semi-diameters from the earth.

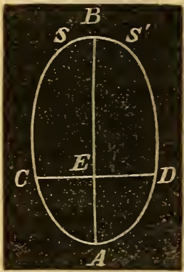
The position of the moon, in right ascension and declination, can be determined almost daily, at any observatory, when it passes the meridian; and before observatories were established, the more rude observations of its approximate positions among the stars, from time to time, were sufficient to establish its periods with tolerable accuracy. Observations long continued, have established the fact that the average, or *mean time*, of the revolution of the moon from the longitude of any fixed star to the longitude of the same star again, is 27 days, 7 hours, 43 minutes, 11 seconds; this is called its sidereal revolution. Its revolution in respect to the *equinoxes* is 7 seconds less, because the equinox itself runs back, or westward among the stars. This revolution is called the tropical revolution.

What is the moon's mean parallax and mean distance? By what kind of observations have the moon's periods been established? What is the mean revolution of the moon?

The mean daily motion of the moon from west to east is 13° 10′ 35″. The mean daily motion of the sun, in the same direction is 0° 59′ 08″, hence the mean daily motion of the moon exceeds that of the sun by 12° 11′ 27″, which will give a revolution in 29 days 12 hours 44 minutes and 3 seconds, which is called the synodic revolution. This is the *average* time from new moon to new moon again, and from full moon to full moon again.

This interval is also called a *lunation*. Some lunations do not exceed 29 days and 7 hours, and others come near 29 days and 18 hours.

The *minimum* lunations take place when the moon changes a day or two after the moon has passed its *perigee*, and the *maximum* lunations take place when the moon changes a day or two after the moon has passed its *apogee*. If all lunations were alike in length of time, any one who can work problems in proportion, could compute the times of new and full moon. As it is, the computations are quite troublesome, as every disturbing cause of motion has to be separately considered and allowed for.



To illustrate one of the principal causes of the inequality of lunations, we give the figure in the margin. Let E be the position of the earth, and $CADB$ the moon's orbit, the moon moving in the direction from A to D and from D to B, and so on, round the ellipse.

Let S' be the direction of the sun; then when the moon is near B, it is in conjunction with the sun. In 27d. 7h. 43m., or thereabouts, the moon will be round to the same point B again, but during that time the sun has apparently moved from S' to S, about 27°, and the moon, to come again in range with the sun,

What is the mean daily motion of the moon, in longitude? What is the time from new moon to new moon again? Why is this interval not always the same? When is the interval the longest? When the shortest?

must pass over about 27°; but now, the moon being at its greatest distance from the earth, its motion is much slower than its mean motion, and therefore the time required to describe *this excess* arc, will be greater than the mean time, and thus cause a *long lunation.*

When the new moon takes place at *B*, the full moon will take place at *A*, and along in that part of the moon's orbit, the excess arc will be passed over by the moon in less than the average time, and thus cause the interval from full moon to full moon again, to be less than the average time, or a *short lunation.*

By observing the moon's altitude when it comes on to the meridian, from time to time, it was early ascertained, that its pathway through the heavens among the stars, was not the same as that of the sun, but that the plane of its orbit was inclined to the plane of the ecliptic by an angle varying from 4° 58′ to 5° 18′, the mean inclination being 5° 8′; the variation being caused by the disturbing action of the sun's attraction, that being different under different circumstances. The points where the moon's path crosses the ecliptic (the sun's path) are called the *moon's nodes;* the one where the moon passes from the south side of the ecliptic to the north side, is called the *ascending node,* and the one on the opposite side of the sphere where the moon crosses from the north side of the ecliptic to the south side, is called the *descending node.* The nodes are not stationary in the heavens — they move backward on the ecliptic on an average of 19° 19′ 44″ in a year, which will cause a complete revolution of the nodes in 18 years 228 days and 9 hours; the result of the following division: $\left(\frac{360°}{19°\ 19'\ 44''}\right)$

This period is nearer 19 than 18 years, and it is a period in which the path of the moon through the heavens is very nearly

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By what observation was the inclination of the moon's orbit to the ecliptic determined? What is that inclination? What are these points called, when the moon crosses the ecliptic? Are these points stationary? In what time, and in what direction do they make a revolution?

the same as it was 19 years before, and it is called *the lunar cycle* or *golden number.** This period has a governing influence over solar and lunar eclipses, but we reserve that subject for the next chapter.

When the sun is in, or near the moon's nodes, its attraction on the moon has no tendency to draw the moon out of the plane of its orbit, and at those times the natural inclination of the lunar orbit to the ecliptic is about 5° 18′. When the sun is 90° from the moon's node, then the inclination of the lunar orbit to the ecliptic is often not more than 5°, because the tendency of the sun's attraction is then to draw the moon towards the ecliptic, and this same tendency actually causes the moon to run into the ecliptic sooner than it otherwise would, thus producing a retrograde motion of the nodes themselves.

The points in the heavens where the moon arrives at its *apogee* and *perigee*, are generally opposite to each other, but rarely exactly so, — nor are these points stationary in the heavens — but make a direct revolution in $3231.\frac{47}{100}$ days, nearly 9 years, — but the true motion is very variable, sometimes backward, sometimes forward, and sometimes stationary, but the forward or direct motion towards the east prevails, making a revolution in the time just noted.

The lunar apogee is much influenced by the position of the sun ; it is *dragged* after the sun (so to speak), when the sun is a little in advance of it, and retarded in its motion, and even retrograde in its motion, when the sun is a little west of it. In short, the lunar orbit is not *an ellipse*, but resembles that figure more nearly than any other, and it is continually varying in its general eccentricity.

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* The Athenians, 433 before Christ, inscribed this number in letters of gold on the walls of the temple of Minerva. Hence it is denominated the Golden Number.

What is the golden number ? What makes the period ? Why so called? What causes the retrocession of the nodes ? Is the longer axis of the moon's orbit stationary in the heavens ? In what direction and in what time do the apogee and perigee points revolve ?

The revolution of the apogee is called the anomalactic period.

The fact that the same face of the moon is always towards the earth, shows that it turns on an axis in the same time it revolves round the earth, otherwise all sides of it would in time be presented to our view.

The mean motion on its axis, and the mean motion or revolution round the earth, is exactly the same,—but the motion on its axis is uniform, and the motion in its orbit is variable, and this gives the face of the moon an apparent vascillating motion, which is called the moon's *libration.*

There is a *libration in longitude* caused by the moon's unequal motion in longitude, and a *libration in latitude* caused by the varying inclination of its orbit with the ecliptic.

"The moon, like the planets, is an opake body, and shines entirely by the light received from the sun, a portion of which is reflected to the earth. As the sun can only enlighten one-half of a spherical surface at once, it follows that according to the situation of an observer, with respect to the illuminated part of the moon, he will see more or less of the light reflected from her surface. At the conjunction, or time of new moon, the moon is between the earth and the sun, and consequently that side of the moon which is never seen from the earth, is enlightened by the sun; and that side which is constantly turned towards the earth is wholly in darkness. Now, as the mean motion of the moon in her orbit exceeds the apparent motion of the sun by about 12° 11′ in a day, it follows that, about four days after the new moon, she will be seen in the evening a little to the east of the sun, after he has descended below the western part of the horizon. A spectator will see the convex part of the moon towards the west, and the horns or cusps towards the east: or if the observer live in north latitude, as he looks at the moon the horns will appear to the left hand; for if the line joining the cusps of the moon be

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What truth is revealed by the fact that the same face of the moon is always towards the earth? What is meant by libration, and from what does it arise? How do we know that the moon does not shine by its own light?

bisected by a perpendicular passing through the enlightened part of the moon, that perpendicular will point directly to the sun. As the moon continues her motion eastward, a greater portion of her surface towards the earth becomes enlightened; and when she is 90 degrees eastward of the sun, which will happen about $7\frac{1}{3}$ days from the time of new moon, she will come to the meridian about six o'clock in the evening, having the appearance of a bright semi-circle. Advancing still to the eastward, she becomes more enlightened towards the earth, and at the end of about $14\frac{3}{4}$ days, she will come to the meridian at midnight, being diametrically opposite to the sun; and consequently she appears a complete circle, and it is said to be *full moon.* The earth is now between the sun and the moon, and that half of her surface, which is constantly turned towards the earth, is wholly illuminated by the direct rays of the sun; whilst that half of her surface, which is never seen from the earth, is involved in darkness. The moon continuing her progress eastward, she becomes deficient on her western edge, and about $7\frac{1}{3}$ days from the full moon she is again within 90 degrees of the sun, and appears a semi-circle with the convex side turned towards the sun: moving on still eastward, the deficiency on her western edge becomes greater, and she appears a crescent, with the convex side turned towards the east, and her cusps or horns turned towards the west: and about $14\frac{1}{2}$ days from the full moon she has again overtaken the sun, this period being performed in 29 days 12 hours 44 minutes 3 seconds, at a mean rate, as has been mentioned before. Hence, from the new moon to the full moon, the phases are *horned*, *half-moon*, and *gibbous;* and as the convex or well-defined side of the moon is always turned towards the sun, the horns or irregular side will appear to the east, or towards the left hand of a spectator in north latitude. From the full moon to the change, the phases

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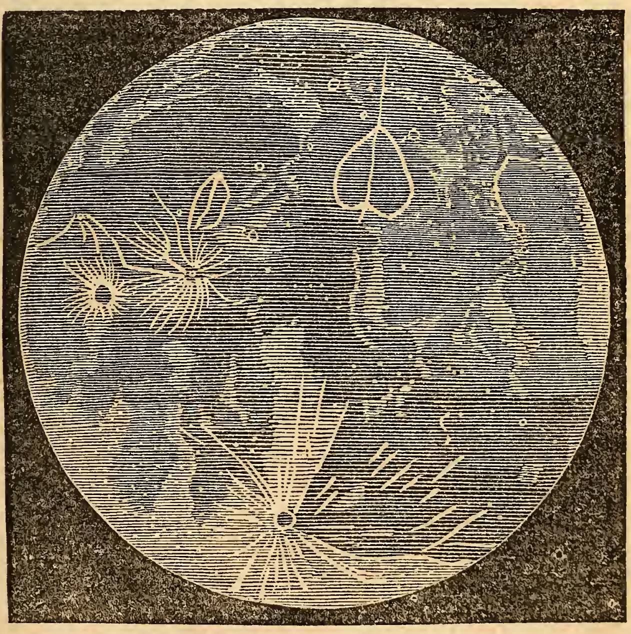
When the moon is full, what is its position in respect to the sun? When the moon is at the first quarter, what is its position in respect to the sun? When at the last quarter, what is its position, and about what time would it come to the meridian?

are *gibbous*, *half-moon*, and *horned;* the convex or well-defined side of her face will appear to the east, and her horns or irregular side towards the west, or to the right hand of a spectator.

"As the full moons always happen when the moon is directly opposite to the sun, all the full moons, in our winter, happen when the moon is on the north side of the equinoctial. The moon, while she passes from Aries to Libra, will be visible at the north pole, and invisible during her progress from Libra to Aries; consequently, at the north pole, there is a fortnight's moonlight and a fortnight's darkness by turns. The same phenomena will happen at the south pole during the sun's absence in our summer."

The surface of the moon is greatly diversified with inequali-



What is said of the full moons in winter? Do the full moons of summer run high, or low?

ties, which, through a telescope, have all the appearances of hills, mountains, and valleys. Many attempts have been made, with considerable success, to delineate the face of the moon on paper, as it appears through a telescope, and the figure on the preceding page is a copy of one of them.

Dr. Herschel informs us that, on the 19th of April, 1787, he discovered three volcanoes in the dark part of the moon, two of them apparently extinct, the third exhibited an actual eruption "of fire, or luminous matter. On the subsequent night it appeared to burn with greater violence, and might be computed to be about three miles in diameter. The eruption resembled a piece of burning charcoal, covered by a thin coat of white ashes; all the adjacent parts of the volcanic mountain were faintly illuminated by the eruption, and were gradually more obscure at a greater distance from the crater. That the surface of the moon is indented with mountains and caverns, is evident from the irregularity of that part of her surface which is turned from the sun: for, if there were no parts of the moon higher than the rest, the light and dark parts of her disc at the time of her quadratures, would be terminated by a perfectly straight line; and at all other times the termination would be an elliptical line, convex towards the enlighted part of the moon, in the first and fourth quarters, and concave in the second and third: but instead of these lines being regular, and well defined, when the moon is viewed through a telescope, they appear notched, and broken in innumerable places. It is rather singular that the edge of the moon, which is always turned towards the sun, is regular and well defined, and at the time of full moon no notches or indented parts are seen on her surface. In all situations of the moon, the elevated parts are constantly found to cast a triangular shadow with its vertex turned from the sun; and, on the contrary, the cavities are always dark on the side next the sun, and illuminated on the opposite side: these appearances are exactly conformable to what we observe of hills

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How long are the winter full moons visible from the north pole? What full moons are visible more than 24 hours, as seen from the north pole?

and valleys on the earth : and even in the dark part of the moon's disc, near the borders of the lucid surface, some minute specks have been seen, apparently enlightened by the sun's rays: these shining spots are supposed to be the summits of high mountains, which are illuminated by the sun, while the adjacent valleys nearer the enlightened part of the moon are entirely dark.

Whether the moon has an atmosphere or not, is a question that has long been controverted by various astronomers ; some endeavor to prove that the moon has neither an atmosphere, seas, nor lakes ; while others contend that she has all these in common with our earth, though her atmosphere is not so dense as ours."

Whenever our own atmosphere is clear and transparent, every appearance of hill, and valley — all the varieties of light, and shade — indeed, all the spots on the moon are equally well defined and distinct, and this could not be, were the moon surrounded with an atmosphere capable of holding vapors, and clouds, like the atmosphere of our earth. Therefore, most astronomers conclude that such an atmosphere does not there exist.

On the other hand, we must not forget — that volcanoes have been observed on the moon — and we can have no distinct idea of combustion, without an atmosphere or a gas, to support it. An atmosphere might exist, having no affinity for vapors, one that would be transparent, and, in that case we could always see through it, as though it did not exist; and if the moon has an atmosphere, it must be one of that kind.

But of all this, nothing is positively known.

What is the appearance of the edge of the moon between the illuminated and unilluminated parts? What does this appearance surely indicate? Why have astronomers contended that the moon has no atmosphere? Are you sure the moon has no atmosphere? What kind of an atmosphere may it have?

CHAPTER II.

ECLIPSES.

THE path of the sun through the heavens is the same every year. It is the ecliptic, so called, because all eclipses of the sun, and moon, take place when the moon is in or near this line.

If the moon's path round the sphere were the same as the sun's, that is, if the moon were all the while in the ecliptic, there would be an eclipse of the sun at every new moon, and an eclipse of the moon at every full moon. The moon's orbit or path, as we have seen in the preceding chapter, intersects the ecliptic or sun's path at an angle of 5° 8′; the points of intersection are called the moon's nodes; and when the sun is in that part of the ecliptic near the moon's nodes, the moon cannot pass its conjunction with the sun without falling in range between some part of the ecliptic, and some part of the earth, and that produces an eclipse of the sun. The two nodes are opposite to each other, and when the sun is near one node, the full moon will take place when the moon is near the other node; and the *sun*, earth, and *moon* will be near one right line — the earth between the sun and moon — and then the moon must fall into some portion of the earth's shadow, and this produces an eclipse of the moon.

If the moon's nodes were always at the same points on the ecliptic, eclipses would take place in the same months every year, but the nodes moving backward about 19° 19′ each year, the eclipses, *on an average*, come about 19 days earlier each succeeding year. Because the two nodes are opposite to each

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Why is the path of the sun among the stars called the ecliptic? If the sun and moon passed round the earth in the same circle or path, how often would eclipses occur? At what angle does the moon's path intersect the ecliptic? Where must the sun be on the ecliptic at the time eclipses occur? If the moon's nodes were stationary, would eclipses then occur at the same seasons of the year continually?

other, eclipses must happen about six months asunder. For instance, if an eclipse occurs in the month of March, in any year, there will certainly be one in September, or on some of the last days of August, at the new or full moon. If an eclipse occurs in June, there will certainly be another in December. If one occurs in May there will be another in November, and so on continually, *the average* being a few days less than six months, and from year to year, the average time being at intervals of about 346 days.

Whenever the moon changes within 17° of either of the moon's nodes, there must be an eclipse of the sun. That is, the sun must then be within 17° of one of the nodes, because at the time of change, the longitude of both sun and moon is then the same.

Whenever the moon fulls, when the sun is within 12° of either node, there must be an eclipse of the moon.

Hence, the number of eclipses of the sun which take place in any long interval of time, (say 19 years) must be to the number of eclipses of the moon as 17 to 12. But, an eclipse of the sun is visible from only a very small portion of the earth at any one time, while an eclipse of the moon is visible from a whole hemisphere ; hence there are more visible eclipses of the moon than of the sun, as seen from any one place.

The least number of eclipses that can take place in any one year is *two*, the greatest number *seven*, the average number is *four*.

When but two eclipses occur in a year, they are both of the sun, and are central as seen from some portion of the earth near the plane of the ecliptic. That is, a central eclipse would be seen from some latitude near the sun's declination. For example : if in a certain year there were but two eclipses, both

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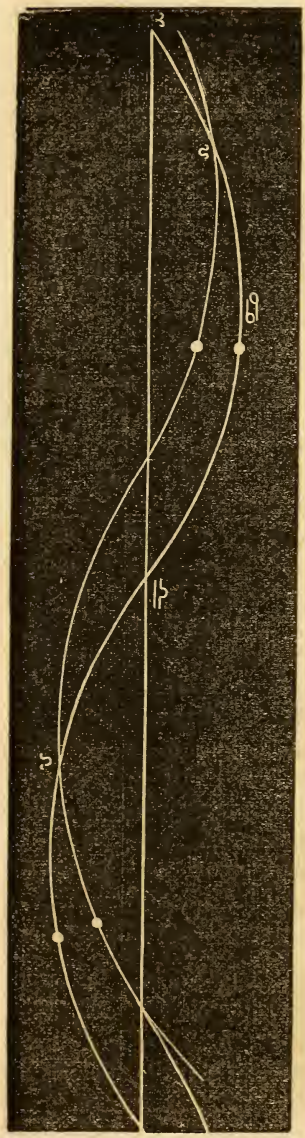
Why do eclipses occur at opposite months of the year? Give the limits within which the sun must be at the time of the lunar changes, to produce eclipses ? Give the ratio between the number of eclipses of the sun and moon that take place in any long interval ? State the least and greatest number of eclipses that can take place in any one year.



would be of the sun, and suppose one of them should take place in June, the other would take place in December, and the one which took place in June would be central as seen from some latitude not far from 20° north, and the one in December would be central as seen from some latitude not far from 20° south. Eclipses of the sun which take place when the sun is 10 or more degrees from the node, are partial eclipses, visible from places not far from the poles of the earth.

To show more clearly that the sun and moon must come in conjunction near the moon's node, we give the figure in the margin.

The right line through the center represents the equator, the curved line ♈ ♋ ♎ the ecliptic, and the other curved line represents the moon's path crossing the ecliptic at ☋ and ☊. The sun and moon are represented in conjunction a little beyond the sign ♋, but the two paths are here so far asunder, that the sun and moon cannot come in range with each other and produce an eclipse. It is obviously not so, on the paths near their intersections, that is, near the nodes.

As here represented the ascending node is in longtitude about 210°, and the descending node is in longitude about 30°, and this was the position of the nodes in the year 1846, and the sun is at these points of the ecliptic in April and October, and therefore the eclipses in that year must have been and really were in those months.

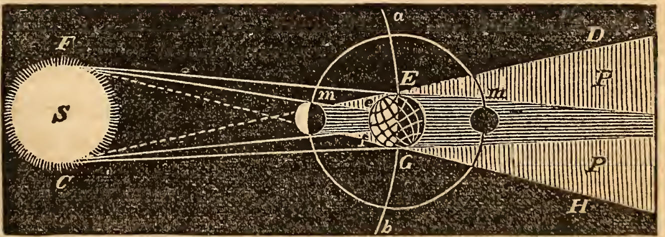
To make a general and rough computation of the times that eclipses will occur, all we have to do is to get the position of one of the moon's nodes, by observation or otherwise, and then trace it back at the rate of 19° 19′ for 365 days, or at the rate of 3′.18 per day.

On the 1st of January, 1850, the mean longitude of the moon's ascending node was 146° 7′, the opposite node was therefore in longitude 326°. The sun attains the longitude of 326° on or about the 15th day of February in each year, and the longitude of 146° on or about the 19th of August. Therefore the new and full moons that took place within twelve days of these times, must and did produce eclipses.

Diminishing 146° 7′ at the rate of 19° 19′ for each 365 days, brought the moon's ascending node to 68° 47′.8 on the 1st of January, 1854, and to 61° 23′ on the 21st of May, 1854.

The sun attains this longitude on the 22d of May, and on the 26th of May the moon changed. There must then have been an eclipse. The sun and moon at that time were about 4° past the moon's ascending node, just sufficient to cast the moon's shadow into the northern hemisphere, making a central eclipse at noon, in latitude 45° 33′ north, in longitude 134° 45′ west.

The following figure may assist some learners to form a distinct and general idea of eclipses.



How far does the node run back in 365 days? How much in one day? If I give you the longitude of the node, can you tell me at what times of the year eclipses will occur?

When an observer is in the moon's shadow, the dark body of the moon appears to him on the face of the sun. When an observer on the earth is in a certain space adjoining the shadow, as at *e* and *f*, a part of the sun is obscured by a part of the moon. When the moon is in the earth's shadow, it cannot shine because the direct rays of the sun are intercepted by the earth, and the moon is said to be in an eclipse. Nevertheless when the moon is near the center of the earth's shadow, a sufficient amount of light is refracted through the earth's atmosphere to render the moon *darkly visible.*

When the moon is eclipsed to the inhabitants of the earth, the sun must be eclipsed to an observer on the moon. An observer on the moon will see the sun partially eclipsed, when the moon falls into the partial shadow marked *P P.* Although this figure answers our purpose *to a certain extent,* it also illustrates and verifies the remarks made about figures on page 142. The distance from the center of the earth to the moon's orbit, is 30 diameters of the earth, but in the figure it is not three diameters. The distance to the sun is 400 times the distance to the moon, but in the figure it is not five times that distance. When the earth is made of any apparent magnitude, there is not space enough on any paper for a true representation of any of these things.

In reality, the moon's shadow comes to a point at about the distance of the earth from the moon, sometimes before it extends to the earth, and then we have an *annular,* and not a total eclipse.

When the moon is near her perigee, her shadow will extend beyond the earth; when near her apogee, it will not extend to the earth.

As we have before seen, the mean motion of the moon exceeds that of the sun by such an amount as to bring the two

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Can the moon be seen when in a total eclipse? Is the figure on page 155 a true representation of the distances of the sun and moon? and if not, why was it not made so? Is the moon's shadow always of the same length? and if not, what causes its variation?

bodies in conjunction or opposition at the average interval of 29d. 12h. 44m. 3s., and the retrograde motion of the node is such as to bring the sun to the same node at intervals of 346d. 14h. 52m. 16s.

Now let us suppose the *sun*, *moon*, and *node* are together at any point of time, and in a certain *unknown* interval of time, which we represent by P, they will be together again. In this time P, we will suppose the moon to have accomplished m lunations, and the sun to have returned to the same node n times.

These suppositions give the following equations:

$$(29d.\ 12h.\ 44m.)m=P. \qquad (1)$$

And $$(346d.\ 14h.\ 52m.)n=P. \qquad (2)$$

Neglecting the seconds and reducing to minutes, we have

$$42524m=P. \qquad (3)$$

$$499132n=P. \qquad (4)$$

Dividing (3) by (4), and reducing the numerator and denominator in the first member, gives us

$$\frac{10631m}{124783n}=1.$$

Or $$\frac{10631}{124783}=\frac{n}{m}$$

As this fraction is irreducible, and as m and n must be whole numbers to answer the *assumed conditions*, therefore the smallest whole number for m is 124783, and for n 10631.

That is, we see by equations (1) and (2), that to bring the sun, moon, and node a second time into conjunction, requires 124783 lunations, or 10631 returns of the sun to the node, which is 10088 years, and about 197 days.

We say about, because we neglected seconds in the periods of revolution, and because the mean motions will change in some slight degree in a period of so long a duration.

What number of lunations are required for the sun, moon, and node, to come in the same position a second time? Even then, will the coincidences be exact?

This period, however, contemplates an exact return to the same positions of the *sun, moon,* and *node,* so that a line drawn from the center of the sun, through the center of the moon, will strike the earth at the same distance from the plane of the ecliptic; but to produce an eclipse, it is not necessary that *an exact return* to former positions should be attained; a greater or less approximation to former circumstances will produce a greater or less approximation to a former eclipse; but *exact* coincidences, in all particulars, can never take place, however long the period.

To determine the time when a return of eclipses may happen, (if we reckon from the most favorable positions), that is, commence with the *supposition* that the sun, moon, and node are together, it is sufficient to find the first approximate values of the fraction $\frac{10631}{124783}$.

If we find the successive approximate fractions, by the rule of continued fractions in arithmetic, we shall have the successive periods of eclipses which will happen about the same node.

The approximate fractions are

$$\frac{1}{11} \quad \frac{1}{12} \quad \frac{3}{35} \quad \frac{4}{47} \quad \frac{19}{223} \quad \frac{156}{1831}.$$

These fractions show that at 11 lunations from the time an eclipse occurs, we may look for another; but if not at 11, it must be at 12, and it may be at both 11 and 12 lunations.

At 5 and 6 lunations we shall find eclipses at the other node. To be more certain when an eclipse will occur, we take 35 lunations from a preceding eclipse, which is 1033 days and 14 hours nearly. There was a total eclipse of the moon, 1851, July 12th, 19 hours. Add to this 1033 days 14 hours, will bring up to May 12th, 1854, the time of another lunar eclipse.

If an eclipse occurs within 10° of the node, it is certain that an eclipse will again happen at the lapse of 47 lunations.

The period, however, which is most known and most remark-

What do the numerators of the series of fractions indicate on page 158? What do the denominators indicate? Lunations between what events?

able appears in the next fraction, which shows that 223 lunations have a very close approximate value to 19 revolutions of the sun to the node.

223 lunations equal - 6585.32 days.
19 returns of ☉ to node =6585.78 days.

The difference is but a fraction of a day ; and if the sun and moon were at the node in the first instance, they would be only 20′ from the node at the expiration of the period, and the difference in the moon's latitude less than 2′; and, therefore, the eclipse at the close of this period must be nearly of the same magnitude as the eclipse at the beginning ; and hence, the expression *"a return of the eclipse,"* as though the same eclipse could occur twice.

This period was early discovered by the Chaldean astronomers, and hence, it is sometimes called the Chaldean period, and by it they were enabled to give general and indefinite predictions of eclipses that were to happen ; and by it any learner, however crude his mathematical knowledge, can designate the day on which an eclipse will occur, from simply knowing the date of some former eclipse.

The period of 6585 days is 18 years (including four leap years) and 11 days over.

Therefore, if we add 18 years and 11 days to the date of some former eclipse, we shall come within one day of the time of an eclipse — and it will be an eclipse of about the same magnitude as the one we reckon from.

EXAMPLES.

In the year	1806	16	June, the sun was eclipsed.
Add	18	11	
	1824	27	June, the sun was eclipsed.
Add	18	10	

How near do 19 revolutions of the sun to the node correspond to 223 lunations? What is meant by the Chaldean period? What is its length and its use? An eclipse of the moon occurred July 1st, 1852 ; when may we look for another?

	1842	8	July, the sun was eclipsed.
Add	18	10	
	——	—	(In this period are 5 leap years.)
	1860	18	July, the sun will be eclipsed.
Add	18	11	
	——	—	
	1878	29	July, the sun will be eclipsed.

And thus we might go on over a great number of periods.

The present year, 1854, May 26, a very remarkable eclipse of the sun will appear as visible in the north eastern part of the United States. From this we can predict the days for some future eclipses, as follows:

	1854	26	May.
Add	18	11	
	——	—	
	1872	6	June, the sun will be eclipsed.
Add	18	11	
	——	—	
	1890	17	June, the sun will be eclipsed.

Thus we might go on, forward or backward, but to determine on what portion of the earth any future eclipse will be visible, we must compute the time of day when the moon changes, and other circumstances, which in this work we do not *pretend* to take into account.

These periods will not occur continually, because the returns are not exact, and the small variations which occur at each period, will gradually wear the eclipse away, and another eclipse will as gradually come on and take its place.

In respect to these periods, those eclipses which take place about the moon's ascending node, commence near the north pole, and at each period come a little further south, and finally leave the earth at the south pole, after the lapse of 96 periods, or about 1729 years.

Will an eclipse occur continually at periods of 18 years and 11 days? How many periods are required to work one of these periods over the earth?

Those eclipses which take place about the moon's descending node, commence near the south pole and pass over the earth to the northward, in the same interval of time.

Eclipses of the moon are visible at all places where the moon is above the horizon, from the time the moon enters the earth's shadow until it leaves it; but eclipses of the sun are visible only to a limited distance from the center of the moon's shadow, and that limit does not exceed 60° on the earth. Eclipses of the sun, which occur in March, pass over the earth in a northeasterly direction; those which occur in September, pass over the earth in a southeasterly direction; and those which occur in June and December, pass over in nearly an eastern direction.

The moon eclipses other heavenly bodies as well as the sun. In its passage through the heavens the moon must occasionally pass between us and the planets, and between us and all those fixed stars that are situated within 6° of the ecliptic on either side. For in the period of 18 years, the moon must some time or other cover each portion of this space in the heavens.

Such eclipses are called *occultations*, and if we include all the stars from the first to the sixth magnitude, about 40 *occultations* take place each month, and on an average about two are visible from any one point each month. Unless it be an occasional eclipse of some of the larger planets by the moon, occultations are not visible to the naked eye, as the light of the moon obscures that of the stars, when the moon is near them, and therefore none but astronomers who have telescopes, can observe these eclipses, and no others seem to be aware of their existence.

A list of occultations can be found each year in the English Nautical Almanac.

In what direction do solar eclipses pass over the earth? Does the moon eclipse other bodies than the sun? What are occultations, and about how many occur each month?

CHAPTER III.

THE TIDES.

THE alternate rise and fall of the surface of the sea, as observed at all places directly connected with the waters of the ocean, is called tide; and before its cause was definitely known, it was recognized as having some *hidden and mysterious connection with the moon,* for it rose and fell twice in every lunar day. High water and low water had no connection with the hour of the day, but it always occurred in *about such an interval* of time after the moon had passed the meridian.

When the sun and moon were in conjunction, or in opposition, the tides were observed to be higher than usual.

When the moon was nearest the earth, in her perigee, other circumstances being equal, the tides were observed to be higher than when, under the same circumstances, the moon was in her apogee.

The space of time from one tide to another, or from high water to high water (when undisturbed by wind), is 12 hours and about 24 minutes, thus making two tides in one lunar day; showing high water on opposite sides of the earth at the same time.

The declination of the moon, also, has a very sensible influence on the tides. When the declination is high in the north, the tide in the northern hemisphere, which is next to the moon, is greater than the opposite tide; and when the declination of the moon is south, the tide opposite to the moon is greatest.

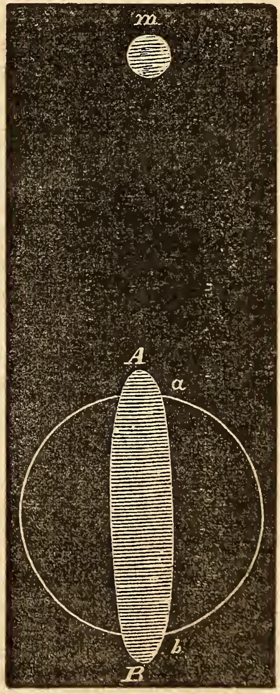
It is considered mysterious, by most persons, that the moon

Give a definition of tides. What connection was observed, in early times, between the moon and times of high water? When were tides higher than usual? What is the time from one high tide to another?

by its attraction should be able to raise a tide on the opposite side of the earth.

That the moon should attract the water on the side of the earth next to her, and thereby raise a tide, seems rational and natural, but that the same simple action also raises the opposite tide, is not as readily admitted; and, in the absence of clear illustration, it has often excited mental rebellion — and not a few popular lecturers have attempted explanations from false and inadequate causes.

But the true cause is the sun and moon's attraction; and until this is clearly and decidedly understood — not merely assented to, but fully comprehended — it is impossible to understand the common results of the theory of gravity, which are constantly exemplified in the solar system.



We now give a rude, but striking, and we hope, a satisfactory explanation.

Conceive the frame-work of the earth to be an inflexible solid, as it really is, composed of rock, and incapable of changing its form under any degree of attraction; conceive also that this solid protuberates out of the sea, at opposite points of the earth, at *A* and *B*, as represented in the figure, *A* being on the side of the earth next to the moon, *m*, and *B* opposite to it. Now, in connection with this solid, conceive a great portion of the earth to be composed

What is the true course of the tides? Explain the true cause of the tide rising on the side of the earth opposite the moon?

of water, whose particles are inert, but readily move among themselves.

The solid AB cannot expand under the moon's attraction, and if it move, the whole mass moves together, in virtue of the moon's attraction *on its center of gravity.* But the particles of water at a, being free to move, and being under a more powerful attraction than the center of the solid, rise toward A, producing a tide.

The particles of water at b being *less* attracted toward m than the center of the solid, will not move toward m as fast as the solid, and being *inert,* they will be, as it were, left behind. The solid is drawn toward the moon more powerfully than the particles of water at b, and the solid sinks in part into the water, but the observer at B, of course, conceives it the water rising upon the shore (which in effect it is), thereby producing a tide.

Mathematicians have found, by analytical investigation, that the power of the moon's attraction to produce the tides, varies as the inverse cube of the distance to the moon.

The sun's attraction on the earth is vastly greater than that of the moon; but by reason of the great distance to the sun, that body attracts every part of the earth nearly alike, and, therefore, it has much less influence in raising a tide than the moon.

From a long course of observations made at Brest, in France, it has been decided that the medium high tides, when the sun and moon act together in the syzigies, is 19.317 feet; and when they act against each other (the moon in quadrature), the tides are only 9.151 feet. Hence the efficacy of the moon, in producing the tides, is to that of the sun, as the number 14.23 to 5.08.*

* These numbers are found as follows: Let m represent the effective force of the moon, and s that of the sun.

Then $m+s=19.317$, and $m-s=9.151$.

Whence $m=14.23$, and $s=5.08$.

Is the sun's attraction on the earth greater than that of the moon? If so, why do we not have greater tides from the action of the sun than from the action of the moon?

Among the islands in the Pacific ocean, observations give the proportion of 5 to 2.2, for the relative influences of these two bodies; and, as this locality is more favorable to accuracy than that of Brest, it is the proportion generally taken.

Having the relative influences of two bodies in raising the tides, we have the relative masses of those two bodies, provided they were at the *same* distance. But the influence of the moon on the tides has a variation corresponding with the *inverse cube* of the distance, and the distance to the sun is 397.2 times the mean distance to the moon. Hence, to have the influence of the moon on the tides, when that body is removed to the distance of the sun, we must divide its observed influence by the cube of 397.2. That is, the mass of the moon, is to the mass of the sun, as the number $\frac{5}{(397.2)^3}$ is to the number 2.2.

If the mass of the earth is assumed to be *unity*, the mass of the sun, is found by its attraction, to be 354945; and now if we represent the mass of the moon by m, we shall have the following proportion:

$$m : 354945 :: \frac{5}{(397.2)^3} : 2.2.$$

This proportion makes m, the mass of the moon, to be nearly $\frac{1}{77}$. The more correct value is $\frac{1}{75}$, computed from other and more reliable data, which is to be found in our larger work.

The time of high water at any given point is not commonly at the time the moon is on the meridian, but two or three hours after, owing to the inertia of the water; and places, not far from each other, have high water at very different times on the same day, according to the distance and direction that the tide wave has to undulate from the main ocean.

The interval between the meridian passage of the moon and the time of high water, is nearly constant at the same place. It is about fifteen minutes less at the syzigies than at the quad-

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Is the time of high water when the moon is on the meridian?

ratures; but whatever the mean interval is at any place, it is called the *establishment of the port.*

It is high water at Hudson, on the Hudson river, before it is high water at New York, on the same day; but the tide wave that makes high water one day at Hudson, made high water at New York the day before; and the tide-waves that make high water now, were, probably, raised in the ocean several days ago; and the tides would not instantly cease on the annihilation of the sun and moon.

The actual rise of the tide is very different in different places, being greatly influenced by local circumstances, such as the distance and direction to the main ocean, the shape and depth of the bay or river, &c. &c.

In the Bay of Fundy the tide is sometimes fifty and sixty feet; in the Pacific ocean, it is about two feet; and in some places in the West Indies, it is scarcely fifteen inches. In inland seas and lakes there are no tides, because the moon's attraction is equal, or nearly so, over their whole extent of surface.

The following table shows the hight of the tides at the most important points along the coast of the United States, as ascertained by recent observation:

	Feet.
Annapolis, (Bay of Fundy),	60
Apple River,	50
Chicneito Bay, (north part of the Bay of Fundy,).	60
Passamaquoddy River,	25
Penobscot River,	10
Boston,	11
Providence, R. I.,	5
New Bedford,	5
New Haven,	8
New York,	5
Cape May,	6
Cape Henry,	4½

Why do we have no tides on inland seas and lakes? What is meant by the establishment of the port?

CHAPTER IV.

ON COMETS.

Besides the planets, and their satellites, there are great numbers of other bodies, which gradually come into view, increasing in brightness and velocity, until they attain a maximum, and then, as gradually diminish, pass off, and are lost in the distance.

"*These bodies are comets.* From their singular and unusual appearance, they were for a long time objects of terror to mankind, and were regarded as harbingers of some great calamity.

"The luminous train which accompanied them was particularly alarming, and the more so in proportion to its length. It is but little more than half a century since these superstitious fears were dissipated by a sound philosophy; and comets, being now better understood, excite only the curiosity of astronomers and of mankind in general. These discoveries, which give fortitude to the human mind, are not among the least useful.

"It was formerly doubted whether comets belonged to the class of heavenly bodies, or were only meteors engendered fortuitously in the air, by the inflammation of certain vapors. Before the invention of the telescope, there were no means of observing the progressive increase and diminution of their light. They were seen but for a short time, and their appearance and disappearance took place suddenly. Their light and vapory tails, through which the stars were visible, and their whiteness often intense, seemed to give them a strong resem-

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What is the general appearance of a comet? Like the planets, are they observed to traverse the whole circumference of the heavens, or do they appear only for a season, in limited spaces?

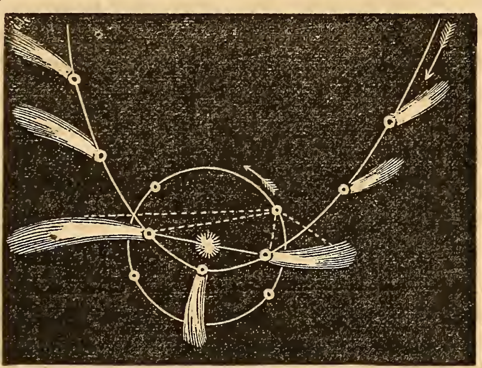
blance to those transient fires, which we call shooting stars. Apparently, they differed from these only in duration. They might be only composed of a more compact substance capable of retarding for a longer time their dissolution. But these opinions are no longer maintained ; more accurate observations have led to a different theory.

"All the comets hitherto observed have a small parallax, which places them far beyond the orbit of the moon ; they are not, therefore, formed in our atmosphere. Moreover, their apparent motion among the stars is subject to regular laws, which enable us to predict their whole course from a small number of observations. This regularity and constancy evidently indicate durable bodies ; and it is natural to conclude that comets are as permanent as the planets, but subject to a different kind of movement.

"When we observe these bodies with a telescope, they resemble a mass of vapor, at the center of which is commonly seen a nucleus, more or less distinctly terminated. Some, however, have appeared to consist of merely a light vapor, without a sensible nucleus, since the stars are visible through it. During their revolution, they experience progressive variations in their brightness, which appear to depend upon their distance from the sun, either because the sun inflames them by its heat, or simply on account of a stronger illumination. When their brightness is greatest, we may conclude from this very circumstance that they are near their perihelion. Their light is at first very feeble, but becomes gradually more vivid, until it sometimes surpasses that of the brightest planets ; after which it declines by the same degrees until it becomes imperceptible. We are hence led to the conclusion that comets, coming from the remote regions of the heavens, approach, in many instances, much nearer the sun than the planets, and then recede to much greater distances."

How is it known that some comets are merely vapor ? Do comets increase and decrease in real brightness ?

The following figure we give to illustrate the foregoing description.



"Since comets are bodies which seem to belong to our planetary system, it is natural to suppose that they move about the sun like planets, but in orbits extremely elongated. These orbits must, therefore, still be ellipses, having their foci at the center of the sun, but having their major axes almost infinite, especially with respect to us, who observe only a small portion of the orbit, namely, that in which the comet becomes visible as it approaches the sun. Accordingly, the orbits of comets must take the form of a *parabola*, for we thus designate the curve into which the ellipse passes, when indefinitely elongated.

"About 120 comets have been calculated upon the theory of the parabolic motion, and the observed places are found to answer to such a supposition. We can have no doubt, therefore, that this is conformable to the law of nature. We have thus obtained precise knowledge of the motions of these bodies, and are enabled to follow them in space. This discovery has given additional confirmation to the laws of Kepler, and led to several other important results.

Are the orbits of the comets elliptical or parabolic? If not parabolic, why are computations made on that hypothesis? Do the comets all move in the same direction as the planets?

"Comets do not all move from west to east like the planets. Some have a direct, and some a retrograde motion.

"Their orbits are not comprehended within a narrow zone of the heavens, like those of the principal planets. They vary through all degrees of inclination. There are some whose planes nearly coincide with that of the ecliptic, and others have their planes nearly perpendicular to it.

"It is farther to be observed that the tails of comets begin to appear, as the bodies approach near the sun; their length increases with this proximity, and they do not acquire their greatest extent, until after passing the perihelion. The direction is generally opposite to the sun, forming a curve slightly concave, the sun on the concave side.

"The portion of the comet nearest to the sun must move more rapidly than its remoter parts, and this will account for the lengthening of the tail.

"The tail, however, is by no means an invariable appendage of comets. Many of the brightest have been observed to have short and feeble tails, and not a few have been entirely without them. Those of 1585 and 1763 offered no vestige of a tail; and Cassini describes the comet of 1682 as being as round and as bright as Jupiter. On the other hand, instances are not wanting of comets furnished with many tails, or streams of diverging light. That of 1744 had no less than six, spread out like an immense fan, extending to a distance of nearly 30 degrees in length.

"The smaller comets, such as are visible only in telescopes, or with difficulty by the naked eye, and which are by far the most numerous, offer very frequently no appearance of a tail, and appear only as round or somewhat oval vaporous masses, more dense toward the center; where, however, they appear to have no distinct nucleus, or any thing which seems entitled to be considered as a solid body.

"The tail of the comet of 1456 was 60 degrees long. That

Mention the apparent lengths of the tails of some of the comets? Do any of the comets have more than one tail?

of 1618, 100 degrees, so that its tail had not all risen when its head reached the middle of the heavens. The comet of 1680 was so great, that though its head set soon after the sun, its tail, 70 degrees long, continued visible all night. The comet of 1689 had a tail 68 degrees long. That of 1769 had a tail more than 90 degrees in length. That of 1811 had a tail 23 degrees long. The recent comet of 1843 had a tail 60 degrees in length.

"When we have determined the elements of a comet's orbit, we compare them with those of comets before observed, and see whether there is an agreement with respect to any of them. If there is a perfect identity as to the elements, we should have no hesitation in concluding that they belonged to different appearances of the same comet. But this condition is not rigorously necessary; for the elements of the orbit may, like those of other heavenly bodies, have undergone changes from the perturbations of the planets, or from their mutual attractions. Consequently, we have only to see whether the actual elements are nearly the same with those of any comet before observed, and then, by the doctrine of chances, we can judge what reliance is to be placed upon this resemblance.

"Dr. Halley remarked that the comets observed in 1531, 1607, 1682, had nearly the same elements; and he hence concluded that they belonged to the same comet, which, in 151 years, made two revolutions, its period being about 76 years. It actually appeared in 1759, agreeably to the prediction of this great astronomer; and again in 1835, by the computation of several eminent astronomers. According to Kepler's third law, if we take for unity half the major axis of the earth's orbit, the mean distance of this comet must be equal to the cube root of the square of 76, that is, to 17.95. The major axis of its orbit must, therefore, be 35.9; and as its observed perihelion distance is found to be 0.58, it follows that its aphelion distance is equal to 35.32. It departs, therefore, from the sun to thirty-five times the distance of the earth, and after-

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From what data do astronomers predict the return of comets?

ward approaches nearly twice as near the sun as the earth is, thus describing an ellipse extremely elongated.

"The intervals of its return to its perihelion are not constantly the same. That between 1531 and 1607 was three months longer than that between 1607 and 1682; and this last was 18 months shorter than the one between 1682 and 1759. It appears, therefore, that the motions of comets are subject to perturbations, like those of the planets, and to a much more sensible degree.

"Comets, in passing among and near the planets, are materially drawn aside from their courses, and in some cases, have their orbits entirely changed. This is remarkably the case with Jupiter, which seems, by some strange fatality, to be constantly in their way, and to serve as a perpetual stumbling-block to them. In the case of the remarkable comet of 1770, which was found by Lexell to revolve in a moderate ellipse in the period of about five years, and whose return was predicted by him accordingly, the prediction was disappointed by the comet actually getting entangled among the satellites of Jupiter, and being completely thrown out of its orbit by the attraction of that planet, and forced into a much larger ellipse. By this extraordinary renconter, *the motions of the satellites suffered not the least perceptible derangement* — a sufficient proof of the smallness of the comet's mass."

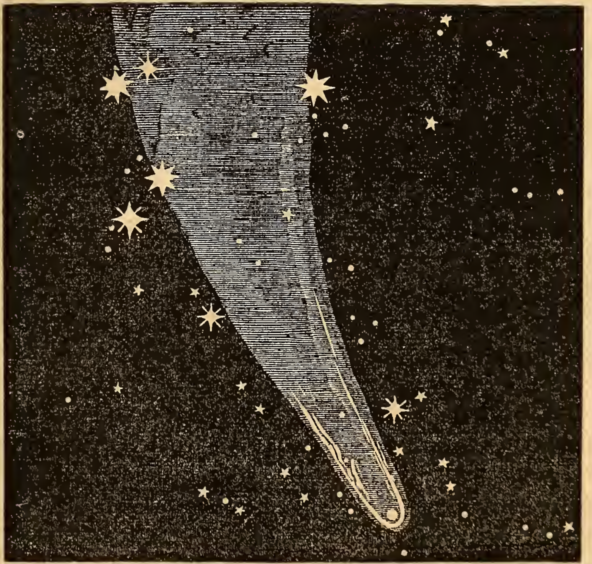
The comet of 1456, represented as having a tail of 60° in length, is now found to be Halley's comet, which has made several returns — in 1531, 1607, 1682, 1759, and recently, in 1835. In 1607 the tail was said to have been over 30 degrees in length; but in 1835 the tail did not exceed 20 degrees. Does it lose substance, or does the matter composing the tail condense? or, have we received only exaggerated and distorted accounts from the earlier times, such as fear, superstition, and awe, always put forth? We ask these questions, but cannot answer them.

Does the same comet return at equal intervals? and if not, why? What circumstances show us that comets have small masses?

"Professor Kendall, in his Uranography, speaking of the fears occasioned by comets, says: Another source of apprehension, with regard to comets, arises from the possibility of their striking our earth. It is quite probable that even in the historical period, the earth has been enveloped in the tail of a comet. It is not likely that the effect would be sensible at the time. The actual shock of the head of a comet against the earth is extremely improbable. It is not likely to happen once in a million of years.

"If such a shock should occur, the consequences might perhaps be very trivial. It is quite possible that many of the comets are not heavier than a single mountain on the surface of the earth. It is well known that the size of mountains on the earth is illustrated by comparing them to particles of dust on a common globe."

The following cut represents a telescopic view of the comet of 1811:



Is there a possibility that a comet may strike the earth? If such a thing should occur, would it cause the destruction of the earth?

CHAPTER V.

ON THE PECULIARITIES OF THE FIXED STARS.

For the facts as contained in the subject matter of this chapter, we must depend wholly on authority; for that reason we give only a compilation, made in as brief a manner as the nature of the subject will admit.

In the first part of this work it was soon discovered that the fixed stars were more remote than the sun or planets; and now, having determined their distances, we may make further inquiries as to the distances to the stars, which will give some index by which to judge of their magnitudes, nature, and peculiarities.

"It would be idle to inquire whether the fixed stars have a sensible parallax, when observed from different parts of the earth. We have already had abundant evidence that their distance is almost infinite. It is only by taking the longest base accessible to us, that we can hope to arrive at any satisfactory result.

"Accordingly, we employ the major axis of the earth's orbit, which is nearly 200 millions of miles in extent. By observing a star from the two extremities of this orbit, at intervals of six months, and applying a correction for all the small inequalities, the effect of which we have calculated, we shall know whether the longitude and latitude are the same or not at these two epochs.

"It is obvious, indeed, that the star must appear more elevated above the plane of the ecliptic when the earth is in the part of its orbit which is nearest to the star, and more depressed when the contrary takes place. The visual rays drawn

What base is taken to measure the distance to the fixed stars? Do the fixed stars appear in the same direction from each extremity of this base? And if so, what does that prove?

from the earth to the star, in these two positions, differ from the straight line drawn from the star to the center of the earth's orbit; and the angle which either of them forms with this straight line, is called the *annual parallax.*

"As the earth does not pass suddenly from one point of its orbit to the opposite, but proceeds gradually, if we observe the positions of a star at the intermediate epochs, we ought, if the annual parallax is sensible, to see its effects developed in the same gradual manner. For example, if the star is placed at the pole of the ecliptic, the visual rays drawn from it to the earth, will form a conical surface, having its apex at the star, and for its base, the earth's orbit. This conical surface being produced beyond the star, will form another opposite to the first, and the intersection of this last with the celestial sphere, will constitute a small ellipse, in which the star will always appear diametrically opposite to the earth, and in the prolongation of the visual rays drawn to the apex of the cones.

"But notwithstanding all the pains that have been taken to multiply observations, and all the care that has been used to render them perfectly exact, we have been able to discover nothing which indicates, with certainty, even the existence of an annual parallax, to say nothing of its magnitude. Yet the precision of modern observations is such, that if this parallax were only 1″, it is altogether probable that it would not have escaped the multiplied efforts of observers, and especially those of Dr. Bradley, who made many observations to discover it, and who, in this undertaking, fell unexpectedly upon the phenomena of aberration* and nutation. These admirable discoveries have themselves served to show, by the perfect agreement which is thus found to take place among observations, that it is hardly to be supposed that the annual parallax can amount to 1″. The numerous observations on the polar star, employed in measuring an arc of the meridian, through France,

* Subjects which will come in the next chapter.

What is meant by annual parallax? Has such a parallax been observed? And if not, why?

have been attended with a similar result, as to the amount of the annual parallax. From all this we may conclude, that as yet there are strong reasons for believing that the annual parallax is less than 1″, at least with respect to the stars hitherto observed.

"Thus the semi-diameter of the earth's orbit, seen from the nearest star, would not appear to subtend an angle of 1″; and to an observer placed at this distance, our sun, with the whole planetary system, would occupy a space scarcely exceeding the thickness of a spider's thread.

"It is evident that the stars undergo considerable changes, since these changes are sensible even at the distance at which we are placed. There are some which gradually lose their light, as the star δ of Ursa Major. Others, as β of Cetus, become more brilliant. Finally, there are some which have been observed to assume suddenly a new splendor, and then gradually fade away. Such was the new star which appeared in 1572, in the constellation Cassiopeia. It became all at once so brilliant that it surpassed the brightest stars, and even Venus and Jupiter, when nearest the earth. It could be seen at mid-day. Gradually this great brilliancy began to diminish, and the star disappeared in sixteen months from the time it was first seen, without having changed its place in the heavens. Its color, during this time, suffered great variations. At first it was of a dazzling white, like Venus; then of a reddish yellow, like Mars and Aldebaran; and lastly, of a leaden white, like Saturn. Another star which appeared suddenly in 1604, in the constellation Serpentarius, presented similar variations, and disappeared after several months. These phenomena seem to indicate vast flames, which burst forth suddenly in these great bodies. Who knows that our sun may not be subject to similar changes, by which great revolutions have perhaps taken place in the state of our globe, and are yet to take place.

"Some stars, without entirely disappearing, exhibit varia-

Do the fixed stars undergo any changes? What is said of new stars, and in what constellations did they happen?

tions not less remarkable. Their light increases and decreases alternately, in regular periods. They are called, for this reason, *variable stars.* Such is the star Algol, in the head of Medusa, which has a period of about three days; δ of Cepheus, which has one of five days; β of Lyra, six; $\varkappa$ of Antinous, seven; o of Cetus, 334; and many others.

"Several attempts have been made to explain these periodical variations. It is supposed that the stars which are subject to them, are, like to all the other stars, self-luminous bodies, or true suns, turning on their axes, and having their surfaces partly covered with dark spots, which may be supposed to present themselves to us at certain times only, in consequence of their rotation. Other astronomers have attempted to account for the facts under consideration by supposing these stars to have a form extremely oblate, by which a great difference would take place in the light emitted by them under different aspects. Lastly, it has been supposed that the effect in question is owing to large opake bodies, revolving about these stars, and occasionally intercepting a part of their light. Time, and the multiplication of observations, may perhaps decide which of these hypotheses is the true one.

One of the best methods of observing these phenomena is to compare the stars together, designating them by letters or numbers, and disposing of them in the order of their brilliancy. If we find, by observation, that this order changes, it is a proof that one of the stars thus compared, has likewise changed; and a few trials of this kind will enable us to ascertain which it is that has undergone a variation. In this manner, we can only compare each star with those which are in the neighborhood, and visible at the same time. But by afterward comparing these with others, we can, by a series of intermediate terms, connect together the most distant extremes. This method, which is now practiced, is far preferable to that of the ancient astronomers, who classed the stars after a very vague

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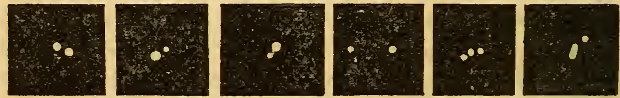
What is understood by variable stars? How have astronomers attempted to account for these appearances?

comparison, according to what they called the *order of their magnitudes*, but which was, in reality, nothing but that of their brightness, estimated in a very imperfect manner."

DOUBLE AND MULTIPLE STARS.

"There are stars which, when viewed by the naked eye, and even by the help of a telescope of moderate power, have the appearance of only a single star; but, being seen through a good telescope, they are found to be double, and in some cases, a very marked difference is perceptible, both as to their brilliancy and the color of their light. These Sir W. Herschel supposed to be so near each other, as to obey, reciprocally, the power of each other's attraction, revolving about their common center of gravity, in certain determinate periods.



Castor. γ Leonis. Rigel. Pole Star. π Monoc. ζ Cancri.

"The two stars, for example, which form the double star Castor, have varied in their angular situation more than 45° since they were observed by Dr. Bradley, in 1759, and appear to perform a retrograde revolution in 342 years, in a plane perpendicular to the direction of the sun. Sir W. Herschel found them in intermediate angular positions, at intermediate times, but never could perceive any change in their distance. The retrograde revolution of γ in Leo, another double star, is supposed to be in a plane considerably inclined to the line in which we view it, and to be completed in 1200 years. The stars ε of Bootes, perform a direct revolution in 1681 years, in a plane oblique to the sun. The stars ζ of Serpens, perform a retrograde revolution in about 375 years; and those of γ in Virgo in 708 years, without any change of their distance. In 1802, the large star ζ of Hercules, eclipsed the smaller one, though

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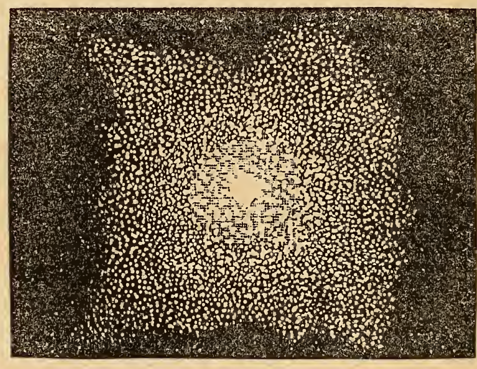
What is understood by double stars? Do double stars revolve about each other? Mention the times of revolution of some of them.

they were separate in 1782. Other stars are supposed to be united in triple, quadruple, and still more complicated systems.

"With respect to the determination of the real magnitude of the stars, and their respective distances, we have as yet made but little progress. Researches of this kind must be left to future astronomers. It appears, however, that the stars are not uniformly distributed over the heavens, but collected into groups, each containing many millions of stars. We can form some idea of them, from those small whitish spots called Nebulæ, which appear in the heavens as represented in the accompanying illustration. By means of the telescope, we distinguish in these collections an almost infinite number of small stars,



so near each other, that their rays are ordinarily blended by irradiation, and thus present to the eye only a faint uniform sheet of light. That large, white, luminous track, which traverses the heavens from one pole to the other, under the name of the Milky Way, is probably nothing but a nebula of this kind, which appears larger than the others, because it is nearer to us. With the aid of the telescope we discover in this zone of light such a prodigious number of stars that the imagination is bewildered in attempting to represent them. Yet, from the angular distances of these stars, it is certain that the space which separates those which seem nearest to each other, is at least a hundred thousand times as great as the radius of the

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What is meant by Nebulæ? What is said of the Milky Way? What is its appearance through a telescope?

earth's orbit. This will give us some idea of the immense extent of the group. To what distance then must we withdraw, in order that this whole collection may appear as small as the other nebulæ which we perceive, some of which cannot, by the assistance of the best telescopes, be made to present any thing but a bright speck, or a simple mass of light, of the nature of which we are able to form some idea only by analogy? When we attempt, in imagination, to fathom this abyss, it is in vain to think of prescribing any limits to the universe, and the mind reverts involuntarily to the insignificant portion of it which we are destined to occupy."

Before we close this chapter, we think it important to call the attention of the reader to Table II, in which will be seen, at a glance (in the columns marked annual variation), the general effect of the precession of the equinoxes; we here notice that all the stars, from the 6th to the 18th hour of right ascension, have a progressive motion to the southward (—), and all the stars from the 18th to the 6th hour of right ascension, have a progressive motion to the northward (+), and the greatest variations are at 0h. and 12h. But these motions are not, in reality, the motions of the stars; they result from motions of the earth. Whenever the annual motion of any star does not correspond with this common displacement of the equinox, we say the star has a proper motion; and by such discrepancy it has been decided, that those stars marked with an asterisk, in the catalogue, have proper motions; and the star 61 Cygni, near the close of the table, has the greatest proper motion.

From this circumstance, and from the fact of its being a double star, it was selected by Bessel as a fit subject for the investigation of stellar parallax; and it is now contended, and in a measure granted, that the annual parallax of this star is $0''.35$, which makes its distance more than 592,000 times the radius of the earth's orbit; a distance that light could not traverse in less than nine and one-fourth years.

What is to be noticed in Table II? How do astronomers determine what stars have a proper motion? What is said of the star 61 Cygni?

CHAPTER VI.

ABERRATION, NUTATION, AND PRECESSION OF THE EQUINOXES.

About the year 1725, Dr. Bradley, of the Greenwich observatory, commenced a very rigid course of observations on the fixed stars, with the hope of detecting their parallax. These observations disclosed the fact, that all the stars which come to the upper meridian near midnight, have an increase of longitude of about 20″; while those opposite, near the meridian of the sun, have a decrease of longitude of 20″; thus making an annual *displacement* of 40″. These observations were continued for several years, and found to be the same at the same time each year; and, what was most perplexing, the results were directly opposite from such as would arise from parallax.

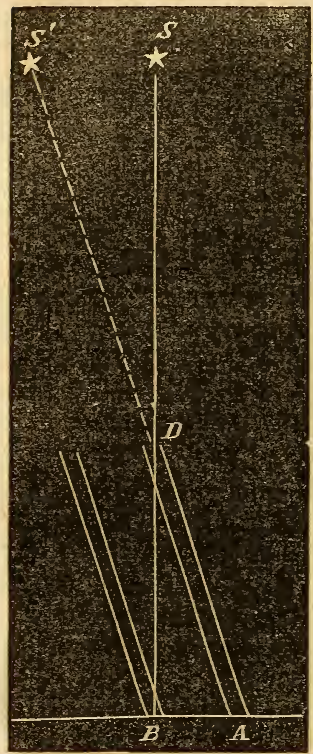
These facts were thrown to the world as a problem demanding solution, and, for some time, it baffled all attempts at explanation; but it finally occurred to the mind of the Doctor, that it might be an effect produced by the progressive motion of light combined with the motion of the earth; and, on strict examination, this was found to be a satisfactory solution.

A person standing still in a shower of rain. When the rain falls perpendicularly, the drops will strike directly on the top of his head; but if he starts and runs in *any direction*, the drops will strike him in the face; and the effect would be the same, in relation to the *direction* of the drops, as if the person stood still and the rain came inclined from the direction he ran.

This is a full illustration of the principle of these changes in the positions of the stars, which is called *aberration;* but the following explanation is more appropriate.

When and by whom was Aberration, and Nutation discovered? Were such results anticipated? Illustrate aberration.

Conceive the rays of light to be of a material substance, and its particles progressive, passing from the star *S* to the earth at *B*; passing directly through the telescope, while the telescope itself moves from *A* to *B* by the motion of the earth. And if *D B* is the motion of light, and *A B* the motion of the earth, then the telescope must be inclined in the direction of *AD*, to receive the light of the star, and the apparent place of the star would be at *S′*, and its true place at *S*, and the angle *ADB* is 20″.36, at its maximum, called the angle of aberration.



By the known motion of the earth in its orbit, we have the value of *AB* corresponding to one second of time: we have the angle *ADB* by observation: the angle at *B* is a right angle, and (from these data), computing the side *BD*, we have the velocity of light, corresponding to one second of time. To make the computation, we have

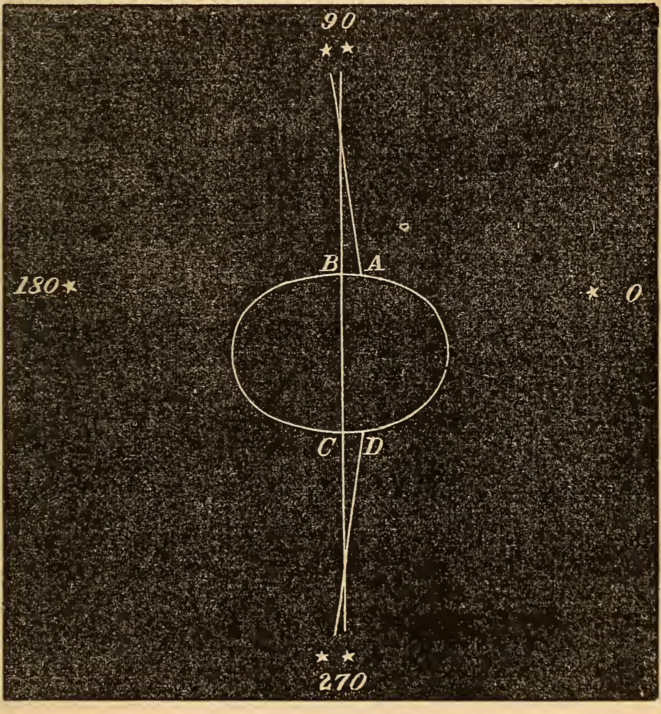
$$DB : BA :: Rad. : tan.\ 20''.36.$$

But *BA*, the distance which the earth moves in its orbit in one second of time, is within a very small fraction of 19 miles; the logarithm of the distance is 1.378802, and, from this, we find that *BD* must be 192600 miles, the velocity of light in a second; a result very nearly the same as before deduced from observations on the eclipses of Jupiter's moons.

What is the greatest angle of aberration? What truth has been demonstrated by the aberration of light?

The agreement of these two methods, so disconnected and so widely different, in disclosing such a far-hidden and remarkable truth, is a striking illustration of the power of science, and the order, harmony, and sublimity that pervades the universe.

To show the effects of aberration on the whole starry heavens, we give the figure below. Conceive the earth to be moving in its orbit from *A* to *B*. The stars in the line *AB*, whether at



0 or 180, are not affected by aberration. The stars, at right angles to the line *AB*, are most affected by aberration, and it

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When, and in what position in respect to the sun, is a star when it is most affected by aberration ?

is obvious that the general effect of aberration is to give the stars an apparent inclination to that part of the heavens, toward which the earth is moving. Thus the star at 90 has its longitude increased, and the star opposite to it, at 270, has its longitude decreased, by the effect of aberration; both being thrown more toward 180. The effect on each star is 20″.36. But when the earth is in the opposite part of its orbit, and moving the other way, from C to D, then the star at 90 is apparently thrown nearer to 0; so also is the star at 270, and the whole annual variation of each star, in respect to longitude, is 40″.72.

The supposition of the earth's annual motion fully explains aberration; conversely, then, the observed variations of the stars, called aberration, *are decided proofs of the earth's annual motion.*

In consequence of aberration, each star appears to describe a small ellipse in the heavens, whose semi-major axis is 20″.36, and semi-minor axis is 20″.36 multiplied by the sine of the latitude of the star. The true place of the star is the center of the ellipse. If the star is on the ecliptic, the ellipse, just mentioned, becomes a straight line of 40″.72 in length.

If the star is at either pole of the ecliptic, the ellipse becomes a circle of 40″.72 in diameter, in respect to a great circle; but a circle, however small, around the pole, will include all degrees of longitude; hence it is possible for stars very near either pole of the ecliptic, to change longitude very considerably, each year, by the effect of aberration; but no star is sufficiently near the pole to cause an apparent revolution round the pole by aberration; and the same is true in relation to the poles of the celestial equator.

All these ellipses have their longer axis parallel to the ecliptic, and for this reason it is easy to compute the aberration of a star in latitude and longitude, but it is a far more complex

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What does aberration explain? What is the apparent motion of a star on the ecliptic in consequence of aberration? What is the apparent motion of other stars?

problem to compute the effects in respect to right ascension and declination.

The effects of aberration on the moon, are too small to be noticed, as light passes that distance in about one second of time.

NUTATION.

While Dr. Bradley was continuing his observations to verify his theory of aberration, he observed other small variations, in the latitudes and declinations of the stars, that could not be accounted for on the principle of aberration.

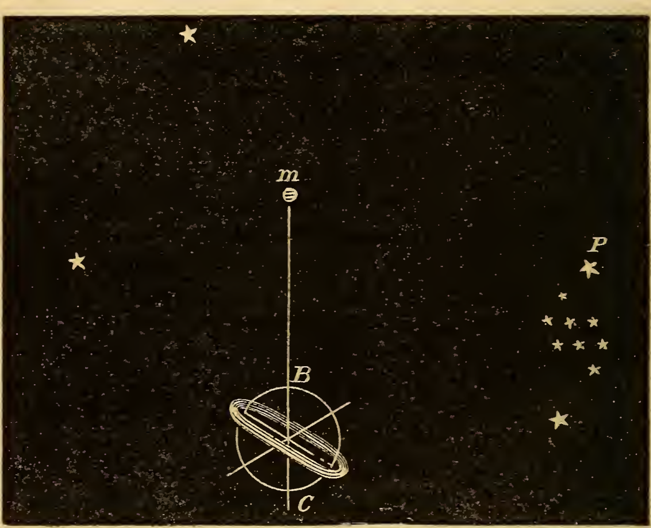
The period of these variations was observed to be about the same as the revolution of the moon's node, and the amount of the variation corresponded with particular situations of the node; and, in short, it was soon discovered that the cause of these variations was a slight vibration in the earth's axis, caused by the action and reaction of the sun and moon on the protuberant mass of matter about the equator, which gives the earth its spheroidal form, and the effect itself, is called NUTATION.

To illustrate this subject, we give the following figure on the next page. Let *m* represent the moon, or any body of matter; its attraction on the ring has a tendency to cause the plane of the ring to incline towards the attracting body, *m*. Let the plane of the ring, in the figure, also be the plane of the equator, and the ring the protuberant mass of matter around the equator. Let *m* be the moon at its greatest declination, and, of course, without the plane of the ring.

Let *P* be the polar star. The attraction of *m* on the ring inclines it to the moon, and causes it to have a slight motion on its center; but the motion of this ring is the motion of the whole earth, which must cause the earth's axis to change its position in relation to the star *P*, and in relation to all the stars.

What are the small vibrations of the stars, in latitude and declination, called? What is the period of these vibrations? What causes them?

When the moon is on the other side of the ring, that is, opposite in declination, the effect is to incline the equator to the opposite direction, which must be, and is, indicated by *an apparent motion of all the stars.*



A slight alternate motion of all the stars *in declination, corresponding to the declinations* of the sun and moon, was carefully noted by Dr. Bradley, and since his time, has been fully verified and definitely settled: this vibratory motion is known by the name of *nutation,* and it is fully and satisfactorily explained on the principles of universal gravity; and conversely, these minute and delicate facts, so accurately and completely conforming to the theory of gravity, served as one of the many strong points of evidence to establish the truth of that theory.

By inspecting the figure, it will be perceived that when the sun and moon have their greatest northern declinations, all the stars north of the equator and in the *same hemisphere* as these bodies, will incline toward the equator; or all the stars in that

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What theory is confirmed by nutation?

hemisphere will incline southward, and those in the opposite hemisphere will incline northward; the amount of vibration of the axis of the earth is only 9″.6 (as is shown by the motion of the stars), and its period is 18.6, or about nineteen years, the time corresponding to the revolution of the moon's node. When the moon is in the plane of the equator, its attraction can have no influence in changing the position of that plane; and it is evident that the greatest effect must be when the moon's declination is greatest.

The moon's declination is greatest when the longitude of the moon's *ascending* node is 0, or at the first point of Aries. The greatest declination is then 28° on each side of the equator; but when the *descending* node is in the same point, the moon's greatest declination is only 18°. Hence there will be times, *a succession of years*, when the moon's action on the *protuberant matter* about the equator must be greater than in an opposite succession of years, when the node is in the opposite position. Hence, the amount of *lunar* nutation depends on the position of the moon's nodes.

The *mean* course of the moon is along the ecliptic: its variation from that line is only about five degrees on each side; hence, the *medium* effect of the moon, on the protuberant mass of matter at the equator, is the same as though the moon were all the while in the ecliptic. But, in that case, its effect would be the same at every revolution of the moon; and the earth's equator and axis would then have an equilibrium of *position*, and there would be *no nutation*, save a slight monthly nutation, which is too small to be sensible to observation; and the nutation which we observe, is only an *inequality* of the moon's attraction on the protuberant equatorial ring; and, however great that attraction might be, it would cause no vibration in the position of the earth, if it were constantly the same.

We have, thus far, made particular mention of the moon, but there is also a *solar nutation;* its period is, of course, a year;

What must be the position of the moon to have the greatest effect on nutation? In what position does the moon have no effect on nutation?

and it is very trifling in amount, because the sun attracts all parts of the earth nearly alike; and the short period of one year, or half a year (which is the time that the unequal attraction tends to change the plane of the ring in one direction), is too short a time to have any great effect on the inertia of the earth.

The solar nutation, in respect to declination, is *only one second.*

Hitherto we have considered only one effect of nutation — that which changes the *position* of the plane of the equator — or, what is the same thing, that which changes the position of the earth's axis; but there is another effect, of greater magnitude, earlier discovered, and better known, resulting from the same physical cause, — we mean the

PRECESSION OF THE EQUINOXES.

We again return to first principles, and consider the mutual attraction between a ring of matter and a body situated out of the plane of the ring; the effect, as we have several times shown, is to incline the ring to the body, or (which is the same in respect to relative positions), the body inclines to run to the plane of the ring.

The mean attraction of the moon is in the plane of the ecliptic. The sun is all the while in the ecliptic. Hence, the *mean* attraction of both sun and moon is in one plane, the ecliptic; but the equator, considered as a ring of matter surrounding a sphere, is inclined to the plane of the ecliptic by an angle of $23\frac{1}{2}$ degrees, and hence the sun and moon have a constant tendency to draw the equator to the ecliptic, and actually do draw it to that plane; and the visible effect is, to make both sun and moon, in revolutions, cross the equator sooner than they otherwise would, and thus the equinox falls back on the ecliptic, called the precession of the equinoxes.

Is there a monthly nutation? Is there a solar nutation, and how great is it? What other effect arises from the attraction of the sun and moon, on the protuberant mass of matter about the equator?

The annual mean precession of the equinoxes is 50″.1 of arc, as is shown by the sun coming into the equinox, or crossing the equator at a point 50″.1 before it makes a revolution in respect to the stars.

If the moon were all the while in the ecliptic, the precession of the equinoxes would then be a *constantly flowing quantity*, equal to 50″.1 for each year; but, for a succession of about nine years, the moon runs out to a greater declination than the ecliptic, and, during that time, its action on the equatorial matter is greater than the *mean* action, and then comes a succession of about nine years, when its action is less than its mean; hence, for nine years, the precession of the equinoxes will be *more* than 50″.1 per year, and, for the nine years following, the precession will be *less* than 50″.1 for each year; *and the whole amount of variation, for this inequality, in respect to longitude*, is 17″.3, and its period is half a revolution of the moon's nodes. This inequality is called the equation of the equinoxes, and varies as the sine of the longitude of the moon's nodes.

The precession of the equinoxes causes a variation of the right ascensions and declinations of all the fixed stars, as may be seen by inspecting the catalogue of stars in Table II. When any particular star is observed to have a greater or less variation than the quantity corresponding to the precession, that star is said to have a proper motion, as we have before observed, when treating of the stars.

We close this volume, after calling the attention of the reader to our first page of tables.

In common parlance, we say that the sun has no latitude — it is all the while in the ecliptic — but then it will be found that the sun has latitude, it deviates north and south, by a quantity *too small even to be observed;* it is, therefore, a quantity wholly determined by theory, and, as the sun's latitude changes

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What is the annual mean precession of the equinoxes? Has it an equation? and if so, to what amount? What is the period of this equation?

nearly with the latitude of the moon, we must seek for its cause principally in the lunar motions.*

To understand the fact of the sun having latitude, we must admit that it is the center of gravity between the earth and moon, that moves in an elliptical orbit round the sun; and that center is always in the ecliptic; and the sun, viewed from that point, would have no latitude. But when the moon, *m*, is on one side of the plane of the ecliptic, *SC*, the earth, *E*, would be on the other side, and the sun, seen from the center of the earth, would appear to lie on the same side of the ecliptic as the moon. *Hence, the sun will change his latitude, when the moon changes her latitude.*

If the moon were all the while in the plane of the ecliptic, the sun would have no latitude (save some *extremely minute* quantities, from the action of the planets, when not in the plane of the ecliptic); but the moon does not deviate more than 5° 20′ from the ecliptic, and of course, the earth makes but a proportional deviation on the other side; but in longitude, the moon deviates to a right angle on both sides, in respect to the sun, and when the moon is in advance in respect to longitude, the sun appears to be in advance also; and when the moon is at her third quarter, the longitude of the sun is apparently thrown back by her influence: the greatest variation in the sun's longitude, arising from the motion of the earth and moon about their center of gravity, is about 6″ each side of the mean.

* In fact the sun is not immovably fixed in the plane of the ecliptic: it vibrates round the common center of gravity of the solar system.

Jupiter is by far the most ponderous planet in the system, hence the center of gravity between the sun and that planet, is always extremely near the plane of the ecliptic, and the sun's latitude, in the Nautical Almanac, is computed from the positions of the moon and Jupiter,— the result of each taken separately, and united.

SEQUEL.

A KNOWLEDGE of astronomy embraces a knowledge of the earth as a whole, — and the external appearance of the heavens.

The earth is very accurately represented by a globe, and the external appearance of the heavens can also be very accurately represented by the projection of each star, and the imaginary lines in the heavens, on a *globe*.

Thus we have a terrestrial and a celestial globe. Those whose minds are at all cultivated, understand the terrestrial globe, or the globe which represents the earth, at sight, — but atlases and maps, of any large portions of the earth, require some study, as the several parts must be more or less distorted, as it is impossible to represent the surface of a sphere, accurately, on a plane surface. Hence, no one can comprehend maps, unless the mind refers them to a globe, whether the pupil has ever actually seen a globe, or not.

Years ago, when spherical trigonometry was very rarely taught, problems on the globes were more attended to, than they are at present. Yet, solutions of these problems on the globes are *very important*, as they furnish a sure test of the comprehension of the pupil, and this is our principal object in giving them.

Results obtained by the globes are, at best, but rough approximations, and no one, properly disciplined, will claim any thing more for them; but even this does not diminish their real importance; for this kind of solution must go through the mind, to guide us through the more exact, scientific, and numerical computations.

CHAPTER I.

PROBLEMS TO BE PERFORMED ON THE TERRESTRIAL GLOBE.

PROBLEM 1. *To find the latitude of any place.*

RULE.—Find the place on the globe, and turn the globe so as to bring the place to that part of the brass meridian, which is numbered from the equator to the poles.

The degree marked on the meridian above the place will be the latitude. If the place be on the north side of the equator, the latitude will be north; if on the south side, the latitude is south.

EXAMPLES.

1. What is the latitude of the eastern point of Newfoundland? *Ans.* 46° 30′.

2. Required the latitudes of the following places:

Florence, Italy.	New York, U. S.
Rome, Italy.	Boston, U. S.
Bencoolon, Sumatra.	Havana, Cuba.
Cadiz, Spain.	Cape Town, Africa.
Smyrna, Turkey.	Buenos Ayres, S. America.

3. What places have no latitude?

4. What places have no longitude?

5. What are the latitudes of those places that have no longitude?

6. What places have the same length of days as the inhabitants of Edinburgh?

Ans. All places that have the same latitude as Edinburgh. A circle round the pole in which Edinburgh is situated, locates the places.

7. What places have the same seasons of the year as New York?

PROBLEM 2. *To find the longitude of any place on the globe.*

RULE.—Bring the place to the brass meridian, the number of degrees on the equator, reckoned from the meridian which passes through Greenwich (England), is the longitude.

If the globe be placed north of the operator, to the right of the brass meridian is east, to the left hand is west.

REMARK. Some American globes take the meridian of Washington for the first meridian. But all our instructions refer to the meridian of Greenwich, because both the English and American Nautical Almanac refer to that meridian. Indeed, all practical men who use the English language, have adopted that meridian, in whatever part of the world they are, or wherever they may have been born.

EXAMPLES.

1. What is the longitude of St. Petersburgh?

Ans. 30° east.

2. What is the longitude of Cape St. Roque?

Ans. 37° west, nearly.

3. Required the longitudes of the following places:

Aberdeen, Scotland.	Canton, China.
Albany, U. S.	Gibralter, Spain.
Boston, U. S.	Leghorn, Italy.
Bombay, E. Indias.	Muscat, Arabia.

PROBLEM 3. *To find all those places that have the same longitude as any given place.*

RULE.—Bring the given place to the brass meridian, then all places under the edge of the meridian from pole to pole, have the same longitude.

N. B. Places in the same longitude have the same hour of the day at the same instant of absolute time.

EXAMPLES.

1. What places have the same, or nearly the same, longitude as Stockholm?

Ans. Dantzic, Presburg, Toronto, Cape of Good Hope, &c.

2. What inhabitants of the earth have midnight when the inhabitants of Jamaica have noon?

Ans. Pekin, in China, Borneo, the western part of Australia, &c.

3. What places have 7 o'clock P. M. when it is 11 o'clock A. M. at London?

Ans. All places having the longitude of 90° west.

PROBLEM 4. *To find the latitude and longitude of any place.*

RULE.—Bring the given place to that part of the brass meridian which is numbered from the equator towards the poles; the degree above the place is the latitude, and the degree on the equator, cut by the brass meridian, is the longitude.

N. B. This problem is but a union of the *first* and *second.*

EXAMPLES.

1. What is the latitude and longitude of Cape Frio, on the eastern coast of South America?

Ans. Lat. 23° S. Lon. 42° W.

2. Find the latitudes and longitudes of the following places:

Algiers, in Africa.	Batavia, in Java.
Aleppo, in Turkey.	Belfast, in Ireland.
Abo, in Finland.	Boston, U. S.
Calcutta, India.	Cape Desolation, Greenland.

PROBLEM 5. *Latitude and Longitude being given, to find the corresponding point on the globe.*

RULE.—Find the longitude of the given place on the equator, and bring it to that part of the brass meridian which is numbered from the equator to the poles; then under the given latitude on the brass meridian, you will find the place. [Provided the place is marked on the globe.]

EXAMPLES.

1. What place has 151° east longitude, and 34° south latitude?

Ans. Botany Bay.

2. What places have the following latitudes and longitudes?

Lat.	Lon.	Lat.	Lon.
50° 6′ N.	5° 54′ W.	19° 26′ N.	100° 6′ W.
48° 12 N.	16° 16′ E.	59° 56′ N.	30° 19′ E.
55° 58′ N.	3° 12′ W.	5° 9′ S.	119° 49 E.

PROBLEM 6. *To find the difference of latitude between any two places.*

RULE.—If the two places are on the same meridian, that is, have the same longitude, and are both north or both south of the equator, subtract one from the other, and the difference will be the difference of latitude. If the latitude of one of the places is north and the other south, add the two latitudes together, and the sum will be their difference of latitude.

If the two places are not in the same longitude, find the latitude of each place by Problem 1, and subtract or add them, as above directed, and you will have their difference of latitude.

EXAMPLES.

1. What is the difference of latitude between Philadelphia and St. Petersburgh? *Ans.* 20 degrees.

2. What difference of latitude between Greenwich and Cape Town, Cape of Good Hope? *Ans.* 85° 24′.

3. Required the difference of latitude between the following places:

London and Rome.	New York and New Orleans.
Cape Spartel and Cape Verde.	Boston and Cape Horn.
Vera Cruz and Cape Horn.	Canton and Batavia.

PROBLEM 7. *To find the least distance between any two places on the globe.*

RULE.—Extend a thread from one point to the other. Apply that extent to the equator, and find the corresponding number of degrees. Multiply the number of degrees thus found, by 60, for geographical miles, and by 69.1 for English miles.

EXAMPLES.

1. What is the direct distance between New York and Liverpool?

Ans. The length of a thread between the two places, applied to a meridian, or to the equator, extends over 49 degrees, as near as we can determine by sight. Hence the distance must be $49 \times 60 = 2940$ geographical miles, or $49 \times 69.1 = 3385.9$ English miles.

2. What is the distance from Cape Cod to Cape Spartel, the north west point of Africa?

Ans. 3055 geo. miles, or 3435 Eng. miles.

3. Required the distances between the following places:

Smyrna and Boston. London and Havana.
Cape Town and Java Head. Rome and Paris.
From Africa to South America—nearest points.

REMARK. Problems like the foregoing are solved by the rules of plane trigonometry, in works of Navigation. Every student should comprehend a globe sufficiently well to form, or conceive, of the spherical triangle formed by the latitudes and longitudes of the places: thus, for example,

The latitude of New York is 40° 40′ N. and longitude 74° W., and Liverpool is in latitude 53° 25′ N. and 3° W.; what triangle unites them?

Conceive each locality to be at the angular point of a spherical triangle, and the north pole to be the third point.

From the north pole to New York, is 49° 20′, and to Liverpool it is 36° 35′, and the angle at the pole between these two meridians is 71°. Here, then, we have two sides, and the included angle of a spherical triangle, from which the third side can be computed, which is the distance, in degrees, between the two places.

To solve some of the following problems, with or without a globe, the right ascension and the declination of the sun must be known. These elements are computed and published, annually, in the American Nautical Almanac.

For those who have no access to an Ephemeris, we subjoin the following table of the sun's declination for every other day of the year 1858, that being the second year after leap year. The results in this table are given to the nearest minute of arc, and they will not differ *many minutes* for the same day, for any other year, for thirty or forty years to come. In short, results will be sufficiently near the truth to teach principles.

The table for the sun's right ascension is given on page 6 of tables in this volume.

SUN'S DECLINATION FOR 1858,

But will serve for corresponding days, in other years, for the purposes here intended.

D.	January.	February.	March.	April.	May.	June.
1	23° 1′ S	17° 6′ S	7° 35′ S	4° 32′ N	15° 4′ N	22° 4′ N
3	22° 50′	16° 31′	6° 49′	5° 18′	15° 40′	22° 19′
5	22° 37′	15° 55′	6° 3′	6° 4′	16° 15′	22° 33′
7	22° 23′	15° 18′	5° 16′	6° 49′	16° 49′	22° 46′
9	22° 7′	14° 40′	4° 30′	7° 34′	17° 21′	22° 57′
11	21° 49′	14° 1′	3° 43′	8° 19′	17° 53′	23° 6′
13	21° 29′	13° 21′	2° 55′	9° 3′	18° 23′	23° 14′
15	21° 8′	12° 40′	2° 8′	9° 46′	18° 52′	23° 20′
17	20° 45′	11° 58′	1° 21′	10° 28′	19° 20′	23° 24′
19	20° 20′	11° 16′	33′ S	11° 10′	19° 46′	23° 27′
21	19° 54′	10° 33′	14′ N	11° 51′	20° 11′	23° 27′
23	19° 26′	9° 49′	1° 2′	12° 32′	20° 35′	23° 27′
25	18° 58′	9° 5′	1° 49′	13° 11′	20° 57′	23° 25′
27	18° 27′	8° 20′	2° 36′	13° 50′	21° 18′	23° 20′
29	17° 56′		3° 23′	14° 27′	21° 37′	23° 15′

D.	July.	August.	Septe'ber.	October.	November.	December.
1	23° 8′ N	18° 3′ N	8° 19′ N	3° 11′ S	14° 27′ S	21° 50′ S
3	22° 59′	17° 32′	7° 35′	3° 57′	15° 5′	22° 7′
5	22° 49′	17° 1′	6° 50′	4° 44′	15° 42′	22° 23′
7	22° 37′	16° 28′	6° 6′	5° 30′	16° 18′	22° 38′
9	22° 23′	15° 53′	5° 20′	6° 16′	16° 53′	22° 51′
11	22° 8′	15° 18′	4° 35′	7° 1′	17° 27′	23° 1′
13	21° 52′	14° 42′	3° 49′	7° 46′	17° 59′	23° 10′
15	21° 33′	14° 5′	3° 3′	8° 31′	18° 30′	23° 17′
17	21° 14′	13° 27′	2° 16′	9° 15′	19° 0′	23° 23′
19	20° 53′	12° 49′	1° 30′	9° 59′	19° 29′	23° 26′
21	20° 30′	12° 9′	43′ N	10° 42′	19° 56′	23° 27½′
23	20° 7′	11° 29′	4′ S	11° 25′	20° 22′	23° 27
25	19° 41′	10° 48′	50′	12° 6′	20° 46′	23° 25′
27	19° 15′	10° 6′	1° 37′	12° 48′	21° 9′	23° 21′
29	18° 47′	9° 23′	2° 24′	13° 28′	21° 30′	23° 15′

Declination in the heavens is the same as latitude on the earth. When the sun is on the meridian of Greenwich, in 1858, the preceding table of declination shows in what latitude the sun will be in the zenith at noon.

This table also enables us to solve all problems like the following, with or without the use of the globes.

1. *On the 3d day of July, where on the earth will the sun be vertical (or nearly so), when it is 3 P. M., apparent time, at New York?*

The longitude of New York is 74° west, and when the sun is on the meridian of New York, it is then apparent noon. Three hours afterwards, the sun will be on the meridian, which is 45° west of New York, or in the longitude 119° west.

The sun passes the meridian of Greenwich in lat. 22° 59′ north, and the variation for one day, or 360° of longitude is 5′, therefore, the variation for 119° is 1′ 40″ nearly.

Whence, when it is 3 P. M. at New York, the sun is vertical over that point, on the earth, whose lat. is 22° 57′ 20″ north, and lon. 119° west.

2. *On the 27th day of February,* 1858, *at 9h. 12m. P. M., apparent time at Greenwich, the sun and moon will be in opposition,* at which time there will be an eclipse of the moon. Determine, by the globe, where the eclipse will be visible.*

When it is 9h. 12m. at Greenwich, the sun is on the meridian 138° west, (computing 15° to each hour,) and the moon is 180° from that, counting either way. Therefore the moon must be on the meridian in longitude 42° east.

The declination of the sun at that time will be 8° 11′ 14″ S.
The declination of the moon, - - - 9° 5′ 3″ N.

The one is not exactly opposite to the other in declination, therefore the moon will not pass through the center of the earth's shadow, but 53′ 49″ north of that center, making a partial eclipse on the moon's southern limb.

The moon will be in the zenith of lat. 9° 7′ north, and lon. 42° east. Find that point on the globe; it lies in upper Egypt.

That point is the pole of the visible eclipse, — that is, the visibility will extend over all places within 90° of that point. Hence, it will be visible from all parts of Africa, Europe, Asia

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* This was written in 1857, therefore in the future tense.

as far as Japan, and the western part of New Holland. It will be visible in the eastern part of Brazil, and invisible to all western America and the Pacific ocean.

3. *July 23d,* 1888, *at* 6*h. A. M., apparent time at Greenwich, the sun and moon will come in opposition, and there will be an eclipse of the moon. Where will that eclipse be visible, or where will the moon be nearly vertical?*

Ans. The moon will be nearly vertical in lat. 20° 16′ south, and in longitude 90° west.

And this point is the pole of visibility. Hence, the eclipse will be visible to all South and North America to lat. 70° north, and invisible in the opposite hemisphere.

4. *What other day of the year has the same length as the 5th of May?* *Ans.* August 7th.

On the 5th of May, the sun's declination is 16° 15′ N., and by inspecting the table, we find nearly the same declination on the 7th of August.

5. *What other day of the year has the same length as the* 1*st day of March?* *Ans.* October 13th.

PROBLEM 8. *Given the meridian altitude of the sun, and the sun's declination at the same time, to determine the latitude.*

Solved with or without a globe, first with a globe. Suppose the latitude to be north.

RULE.—Take that part of the brass meridian which is numbered from the equator to the poles; and take the degree on that meridian corresponding to the sun's declination, north or south, as the case may be. Turn the meridian, or so adjust it, that the given point of declination, shall correspond to the given meridian altitude of the sun.

Then the elevation of the pole above the horizon will be the latitude required.

EXAMPLE.

1. *Suppose the sun's declination was* 20° *N., and the sun's true meridian altitude at the same time, was* 70° *from the southern horizon. What was the latitude?* *Ans.* 40° N.

I place the 20th degree of north declination 70 degrees from the southern horizon. The equator then is 50° above the horizon, and consequently the southern pole must be 40° below the southern horizon, and the northern pole 40° above the northern horizon, or the latitude is 40° N.

Without a globe, the latitude is computed by the following formula:

$$(90° - A) \pm D = Lat.$$

In this equation, A represents the observed meridian altitude corrected for refraction, semi-diameter, and index error, if any. D is the declination computed to the precise time of observation, $(90° - A)$, is the meridian zenith distance, and if we represent it by Z, the formula becomes

$$Z \pm D = Lat.$$

The plus sign is used when the declination is north, and the minus sign when it is south. Z is minus when the meridian altitude is measured from the northern horizon — and in all cases when the result is minus, the latitude is south.

EXAMPLES.

1. *The true meridian altitude of the sun was* 27° 32′, *measured from the southern horizon, when its declination was* 6° 43′ *north. What was the lalitude?* *Ans.* 69° 11′ north.

2. *The true meridian altitude of the sun was* 76° 10′ *from the south, when the sun's declination was* 21° 2′ *north. What was the latitude?* *Ans.* 34° 52′ north.

3. *The true meridian altitude of the sun was* 13° 18′ *from the south, when the sun's declination was* 19° 47′ *south. What was the latitude?* *Ans.* 56° 55′ north.

4. *The true meridian altitude of the sun was* 76° 17′ *from the northern horizon, when the sun's declination was* 23° 4′ *north. What was the latitude?* *Ans.* 9° 21′ north.

N. B. In all the preceding examples D is plus. In the 4th example, Z is 13° 43′ minus.

5. *The true meridian altitude of the sun was* 53° 10′ *from the north, when the sun's declination was* 23° 4′ *north. What was the latitude?*
Aus. 12° 48′ south.

6. *The true meridian altitude of the sun was* 68° 20′ *from the north, when the sun's declination was* 22° 10′ *south. What was the latitude?*
Ans. 30′ south.

7. *The true meridian altitude of the sun was* 57° 35′ *from the south, when the sun's declination was* 22° 10′ *south. What was the latitude?*
Ans. 10° 15′ north.

Thus we might give examples without end, but we think that we have sufficiently illustrated the principle of finding latitude by meridian altitudes.

No matter what heavenly body is used, moon, star, or planet, provided the declination of the object used is known, and the observer can see the horizon. Stars are rarely used for this purpose, because the horizon can rarely be seen at sea when the stars are visible.

If the object be the moon, its parallax in altitude must be taken into the account ; hence, that body is seldom used by the common navigator, and the unscientific observer.

In observatories, zenith distances can be directly observed. Observers there, do not depend on the horizon.

We give a few examples of finding the latitude by the meridian zenith distances of some of the stars.

8. *The fixed star Spica, was observed to pass the meridian of one observer* 21° 3′ *from the zenith towards the south : to another observer it passed the meridian* 13° 41′ *from the zenith towards the north. What was the latitude of each observer?*
Ans. Lat. of one, 10° 42′ N.; of the other, 34° 2′ S.

(N. B. For the declination of the stars, see Table II.)

9. *The fixed star Castor, was observed to pass the meridian* 12° 13′ *to the north of the zenith. What was the latitude?*
Ans. 20° north.

10. *Suppose the meridian distance had been the same toward the south, what would have been the latitude?*

Ans. 44° 46′ north.

11. *The star* a, *in Cassiopea, whose right ascension is* 31*m.* 49*s.* *and declination* 55° 42′ *north, was observed to pass the meridian* (*below the pole*) 64° 20′ *from the zenith. What was the latitude?*

Ans. 59° 58′ north.

12. *Had the zenith distance been the same when the star was above the pole, measured towards the north, what then would have been the latitude?* *Ans.* 8° 38′ south.

PROBLEMS ON THE CELESTIAL GLOBE.

Problem 1. *To find the natural appearance of the heavens as seen from any given latitude at any given hour on any given day.*

Rule.—Elevate or depress the north pole to correspond to the given latitude. Find the sun's place in the ecliptic for the given day, and bring that point to the brass meridian. Set the index at 12. Then turn the globe to correspond to the given hour. (Turn westward if the given hour is after noon — and eastward if before noon.)

The position of the globe will now represent the true position of the heavens. Those stars that are near the brass meridian on the globe, will be found to be near the meridian in the heavens — and those stars that are near the eastern horizon on the globe, will be found to be near the eastern horizon in the heavens, &c. &c.

EXAMPLES.

1. *At London, lat.* 51° 30′ N. at 2 *A. M. on the* 20*th day of January, what stars are rising, what stars are setting, and what stars are on the meridian?*

Ans. Lyra and Spica are rising, Regulus is near the meridian, and all stars near the western horizon, on the globe, are setting.

2. *Find the position of the stars to an observer in* 40° *of north latitude, on the* 7*th of November, at* 10 *o'clock in the evening, apparent time.* *Ans.* The R. A. of the meridian is 51m.

That is, whatever stars, or planets have the right ascension of 51 minutes, are near the meridian, at that time. As the right ascension of Aldebaran is 4h. 27m., therefore Aldebaran is 3h. 36m. east of the meridian, or Aldebaran will be on the meridian at 1.36 A. M. on the 8th of November.

The position of the globe shows the true position of the stars.

N. B. Find the sun's right ascension for the given time, and add the given hour to it. Subtracting 24h. if the sum exceeds 24. Thus, on the 7th of November, the right ascension of the sun is 14h. 51m., adding 10h. and rejecting 24h., produces 51 minutes.

3. *What stars never set in latitude 40° north?*

Ans. All stars, within 40 degrees of the north pole; and the same is true for any other latitude.

PROBLEM 2. *To find the position of any particular star in reference to the meridian, on any given day, at any given hour of that day, by the globe. The latitude may, or may not, be given.*

RULE.—Find the sun's postion on the globe by its place in the ecliptic on the given day, or find its right ascension and declination, and bring that point to the brass meridian. That is the position of the globe at noon. Set the index at 12, and turn the globe east or west, to correspond to the given hour of the day. Then look for the star, and wherever it be found on the globe, the corresponding point in the heavens will be its place. And if the globe be placed where a fair view of the heavens can be had, and the brass meridian placed north and south, and the pole elevated to correspond with the latitude of the place, then a line from the center of the globe through the star, on the globe, continued to the heavens, will point out the star, or pass very near it.

WITHOUT THE GLOBE.

RULE.—Subtract the right ascension of the sun from the right ascension of the star, and the remainder is the apparent time when the star comes to the meridian. This time, compared with the given time, will determine whether the star is east or west of the meridian, and how far.

EXAMPLES.

1. *On the 10th of January, what is the position of the dog star Sirius, at 9 P. M., apparent time?*

Ans. 2h. 14m. east of the meridian.

N. B. On the 10th of January, at 9 P. M., the right ascension of the sun is never far from 19h. 25m., and the right ascension of Sirius is 6h. 39m. Whence 24+(6+39), or 30h. 39m.—19h. 25m.=11h. 14m. That is, on that day of the year, Sirius comes to the meridian not far from 14m. past *eleven*, apparent time ; therefore, at 9 P. M. it must be 2h. and 14m. east of the meridian — whatever be the latitude of the observer.

2. *What is the position of Antares at* 10 *P. M. on the* 4*th of July?* *Ans.* It is 35m. west of the meridian.

Remark.—We find the time when the moon or a planet will pass the meridian, on the same principle as we find the time for a star, except that we must be more particular — as the right ascensions of the moon and planets change, and the stars are supposed to be fixed.

We must have the right ascension of sun and planet at the exact time when the planet passes the meridian.

But we can illustrate more clearly by the following example :

On the 5th of August, at noon, Greenwich time, the right ascension of the sun was, by the Nautical Almanac, 9*h.* 2*m.* 35*s*.36, *and the hourly variation was* 9*s*.59.

The right ascension of the moon, at the same time, was 12*h.* 19*m.* 38*s*.2, *and the hourly increase was* 1*m.* 44*s*.4. *At what time did the moon pass the meridian of* 75° *west longitude, on that day?*

	h.	m.	s.
From ☽ right ascension, - - -	12	19	38.20
Subt. ☉ right ascension, - -	9	2	35.36
Approx. time ☽ passes Gr. - - -	3	17	2.84
Add for Lon. 75° W. - - -	5		
Correction to be made for - - -	8	17	2

☽ R. A. increases, per hour, 1m. 44s.4
☉ R. A. increases, per hour, 9s.59

Variation per hour, - 1m. 34s.81 and this for 8$\frac{17}{60}$h. gives a variation of 13m. 5s.28.

	h.	m.	s.	
Whence, to the approx. time at Gr.	3	17	2.84	
Add - - - - -		13	5.28	
☽ passes merid. in Lon. 75° W. at	3	30	8.12	app. time.*
Equation of time, add - -		5	40	
☽ passes merid. of Lon. 75° W. at	3	35	48	mean time.

* To be perfectly accurate, we should correct for 8h. 30m. 8s., or correct twice.

Problem 3. *To find the time, on any particular day, when any heavenly body, whose declination is given, will rise and set.*

We must first find the time that the given body passes the meridian, as taught in the foregoing examples. Then we must obtain the *semi-diurnal arc*, which is the time required for a body to pass from the horizon to the meridian, or from the meridian to the horizon, and this interval depends on the declination of the body, and the latitude of the place from which it is observed.

When the declination of a body is zero. that is, on the celestial equator, the semi-diurnal arc is six hours, observed from all localities.

When the latitude and declination are both north, or both south, that interval is greater than six hours.

When the latitude and declination are on opposite sides of the equator, the semi-diurnal arc is always less than six hours.

The difference between *six hours* and the semi-diurnal arc is called *Ascensional Difference*, and its values will be found in the following table, corresponding to various declinations, from 1° to 27°. Under the declination, and opposite the latitude, will be found the corresponding ascensional difference.

For a practical work, a more complete table would be given.

Delination of ☉, ☽, ✳, or Planet.

Lat.	1	3°	6°	9°	10°	12°	14°	16°	18°	20°	22°	23°	24°	25°	26°	27°
	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
18	1	4	8	12	13	16	19	21	29	27	40	32	33	35	36	38
21	2	5	9	14	16	19	22	25	33	32	96	38	39	41	43	45
24	2	5	11	16	18	22	26	29	39	37	41	44	46	68	50	52
27	2	6	12	19	21	25	29	34	43	43	48	50	52	53	58	50
30	2	7	14	21	23	28	33	38	49	49	54	57	h 1 0	h 1 2	h 1 5	h 1 8
33	3	8	16	24	26	32	37	43	55	55	h 1 1	h 1 4	1 7	1 11	1 14	1 17
36	3	9	48	26	29	36	42	48		h 1 1	1 8	1 12	1 16	1 19	1 23	1 27
39	3	10	20	29	33	40	47	54	h 1 1	1 9	1 16	1 20	1 25	1 29	1 33	1 37
42	4	11	22	33	37	44	52	h 1 0	1 8	1 17	1 25	1 30	1 35	1 39	1 44	1 48
45	4	12	24	39	41	49	58	1 7	1 16	1 25	1 35	1 40	1 46	1 51	1 57	2 3
48	4	13	28	44	45	55	h 1 4	1 14	1 25	1 35	1 47	1 53	1 59	2 5	2 11	2 28
51	5	14	30	45	50	h 1 1	7 12	1 23	1 35	1 47	2 0	2 6	2 13	2 21	2 24	2 36
52	5	15	31	47	52	1 3	1 14	1 26	1 38	1 51	2 5	2 12	2 19	2 27	2 35	2 43
53	5	16	32	49	54	1 6	1 17	1 29	1 42	1 56	2 10	2 17	2 25	2 33	2 49	2 58
54	6	17	33	50	56	1 8	1 20	1 33	1 46	2 0	2 15	2 23	2 31	2 40	2 57	3 7

EXAMPLES.

1. *On the* 10*th day of January*, 1858, *the right ascensisn of the planet Jupiter will be* 2*h.* 16*m.* 52*s., and declination* 12° 32′ *north. The right ascension of the sun, at the same time, will be* 19*h.* 28*m. nearly. What time will the planet pass the meridian, and what time will it rise and set, observed from latitude* 42° *north?*

	h. m. s.	
From the R. A. of Jupiter, +24h.	26 16 52	
Subt. the R. A. of sun, - -	19 28	
Apparent time that Jupiter passes mer.	6 48 52	P. M.
To 6h. add Ascensional diff. 45m. -	6 45	
Jupiter rises, (apparent time,) -	3 52	P. M.
Jupiter sets, (next morning,) at -	1 33 52	A. M.

2. *What time (approximately) will Sirius rise, pass the meridian, and set, on* 4*th of March, observed from New York?*

	h. m.	
From R. A. Sirius +24h. (see Tab. II,)	30 39	nearly.
Subt. R. A. of sun, (see p. 6, of Tables)	23 1	nearly.
Sirius passes meridian, apparent time,	7 38	P. M.
From 6h. take 1h. nearly, (semi-diur. arc,)	5	
Sirius rises at - - - -	2 38	P. M.
Sirius sets next morning at - -	0 38	A. M.

Thus we might operate with any planet, or star.

The moon requires more care ; we must have its right ascension and declination, at times, as near that of rising and setting, as we can procure, and also, take parallax into account.

EXTRACTS FROM THE NAUTICAL ALMANAC FOR JANUARY, 1846.

Day of the Month.	THE SUN'S Apparent Longitude. Noon.	THE SUN'S Apparent Latitude. Noon.	Logar. of the Radius Vector of the Earth. Noon.	THE MOON'S Longitude. Noon.	THE MOON'S Latitude. Noon.	THE MOON'S Semi-diam. Noon.	THE MOON'S Hor. Paral. Noon.
	° ′ ″	″		° ′ ″	° ′ ″	′ ″	′ ″
1	280 46 15.3	N.0.49	9.99266	330 42 13.9	N.4 54 8.5	16 21.6	60 2.3
2	281 47 26.1	0.45	9.99266	345 7 12.0	4 24 8.7	16 8.3	59 13.5
3	282 48 36.5	0.37	9.99267	359 4 55.4	3 39 5.9	15 53.9	58 20.5
4	283 49 46.5	0.27	9.99267	12 35 34.7	2 43 1.9	15 39.8	57 28.7
5	284 50 56.1	0.16	9.99268	25 41 31.5	1 39 55.7	15 26.7	56 40.8
6	285 52 5.3	N.0.03	9.99268	38 26 25.0	N.0 33 28.3	15 15.2	55 58.7
7	286 53 13.9	S. 0.11	9.99270	50 54 23.2	S. 0 33 3.6	15 5.6	55 23.3
8	287 54 22.0	0.25	9.99271	63 9 30.1	1 36 46.8	14 57.6	54 54.1
9	288 55 29.7	0.38	9.99272	75 15 21.8	2 35 8.6	14 51.5	54 31.6
10	289 56 36.8	0.49	9.99274	87 14 56.3	3 25 55.4	14 46.9	54 14.6
11	290 57 43.4	0.58	9.99277	99 10 31.3	4 7 13.7	14 43.8	54 3.3
12	291 58 49.5	0.65	9.99279	111 3 50.8	4 37 30.7	14 42.1	53 57.0
13	292 59 55.3	0.70	9.99282	122 56 17.6	4 55 38.9	14 41.7	53 55.7
14	294 1 0.5	0.71	9.99285	134 49 7.9	5 0 56.4	14 42.8	53 59.8
15	295 2 5.4	0.69	9.99288	146 43 48.4	4 53 7.6	14 45.5	54 9.7
16	296 3 9.9	0.64	9.99292	158 42 11.3	4 32 23.1	14 50.0	54 26.0
17	297 4 14.0	0.57	9.99295	170 46 44.8	3 59 17.1	14 56.3	54 49.0
18	298 5 17.8	0.47	9.99299	183 0 38.7	3 14 47.1	15 4.6	55 19.7
19	299 6 21.2	0.35	9.99304	195 27 41.8	2 20 14.2	15 15.2	55 58.4
20	300 7 24.2	0.23	9.99308	208 12 10.4	1 17 27.8	15 27.7	56 44.4
21	301 8 26.7	S. 0.09	9.99313	221 18 27.5	S. 0 8 53.1	15 42.0	57 37.0
22	302 9 28.9	N.0.04	9.99318	234 50 26.7	N.1 2 20.5	15 57.3	58 32.9
23	303 10 30.4	0.15	9.99323	248 50 42.5	2 12 11.7	16 12.5	59 28.8
24	304 11 31.3	0.25	9.99328	263 19 30.4	3 15 50.9	16 26.2	60 19.0
25	305 12 31.5	0.33	9.99334	278 13 48.8	4 8 2.8	16 36.8	60 57.9
26	306 13 30.9	0.38	9.99339	293 26 49.2	4 43 49.4	16 42.9	61 20.2
27	307 14 29.3	0.40	9.99345	308 48 22.8	4 59 32.4	16 43.5	61 22.6
28	308 15 26.8	0.40	9.99351	324 6 34.0	4 53 45.4	16 38.7	61 4.9
29	309 16 23.3	0.37	9.99357	339 9 55.3	4 27 32.9	16 28.9	60 29.1
30	310 17 18.5	0.30	9.99363	353 49 32.0	3 44 8.2	16 15.6	59 40.2
31	311 18 12.6	0.21	9.99369	8 0 13.1	2 47 58.7	16 0.2	58 43.7
32	312 19 5.3	N.0.10	9.99375	21 40 34.3	N.1 43 50.6	15 44.2	57 45.1

TABLE I.

MEAN ASTRONOMICAL REFRACTIONS.

Barometer 30 in. Thermometer, Fah. 50°.

Ap. Alt.	Refr.	Ap. Alt.	Refr.	Ap. Alt.	Refr.	Alt.	Refr.
0° 0′	33′ 51″	4° 0′	11′ 52″	12° 0′	4′ 28.1″	42°	1 4.6′
5	32 53	10	11 30	10	4 24.4	43	1 2.4
10	31 58	20	11 10	20	4 20.8	44	1 0.3
15	31 5	30	10 50	30	4 17.3	45	0 58.1
20	30 13	40	10 32	40	4 13.9	46	56.1
25	29 24	50	10 15	50	4 10.7	47	54.2
30	28 37	5 0	9 58	13 0	4 7.5	48	52.3
35	27 51	10	9 42	10	4 4.4	49	50.5
40	27 6	20	9 27	20	4 1.4	50	48.8
45	26 24	30	9 11	30	3 58.4	51	47.1
50	25 43	40	8 58	40	3 55.5	52	45.4
55	25 3	50	8 45	50	3 52.6	53	43.8
1 0	24 25	6 0	8 32	14 0	3 49.9	54	42.2
5	23 48	10	8 20	10	3 47.1	55	40.8
10	23 13	20	8 9	20	3 44.4	56	39.3
15	22 40	30	7 58	30	3 41.8	57	37.8
20	22 8	40	7 47	40	3 39.2	58	36.4
25	21 37	50	7 37	50	3 36.7	59	35.0
30	21 7	7 0	7 27	15 0	3 34.3	60	33.6
35	20 38	10	7 17	15 30	3 27.3	61	32.3
40	20 10	20	7 8	16 0	3 20.6	62	31.0
45	19 43	30	6 59	16 30	3 14.4	63	29.7
50	19 17	40	6 51	17 0	3 8.5	64	28.4
55	18 52	50	6 43	17 30	3 2.9	65	27.2
2 0	18 29	8 0	6 35	18 0	2 57.6	66	25.9
5	18 5	10	6 28	19	2 47.7	67	24.7
10	17 43	20	6 21	20	2 38.7	68	23.5
15	17 21	30	6 14	21	2 30.5	69	22.4
20	17 0	40	6 7	22	2 23.2	70	21.2
25	16 40	50	6 0	23	2 16.5	71	19.9
30	16 21	9 0	5 54	24	2 10.1	72	18.8
35	16 2	10	5 47	25	2 4.2	73	17.7
40	15 43	20	5 41	26	1 58.8	74	16.6
45	15 25	30	5 36	27	1 53.8	75	15.5
50	15 8	40	5 30	28	1 49.1	76	14.4
55	14 51	50	5 25	29	1 44.7	77	13.4
3 0	14 35	10 0	5 20	30	1 40.5	78	12.3
5	14 19	10	5 15	31	1 36.6	79	11.2
10	14 4	20	5 10	32	1 33.0	80	10.2
15	13 50	30	5 5	33	1 29.5	81	9.2
20	13 35	40	5 0	34	1 26.1	82	8.2
25	13 21	50	4 56	35	1 23.0	83	7.1
30	13 7	11 0	4 51	36	1 20.0	84	6.1
35	12 53	10	4 47	37	1 17.1	85	5.1
40	12 41	20	4 43	38	1 14.4	86	4.1
45	12 28	30	4 39	39	1 11.8	87	3.1
50	12 16	40	4 35	40	1 9.3	88	2.0
55	12 3	50	4 31	41	1 6.9	89	1.0

CORRECTION OF MEAN REFRACTION.

Hight of the Thermometer.

App. Alt.	24°	28°	32°	36°	40°	44°	52°	56°	60°	64°	68°	72°	76°	80°
° ′	′ + ″	′ + ″	′ + ″	′ + ″	′ + ″	′ + ″	′ — ″	′ — ″	′ — ″	′ — ″	— ″	′ — ″	′ — ″	′ — ″
0.10	2.18	1.55	1.33	1.11	51	31	10	29	48	1.07	1.25	1.43	2.01	2.19
0.00	2.12	1.49	1.28	1.08	48	29	9	27	45	1.04	1.21	1.38	1.54	2.12
0.20	2.05	1.44	1.24	1.04	46	28	9	26	44	1.01	1.17	1.33	1.49	2.05
0.30	1.59	1.39	1.20	1.01	44	26	8	25	41	58	1.13	1.28	1.43	1.59
0.40	1.53	1.34	1.16	58	42	25	8	24	39	55	1.10	1.24	1.38	1.53
0.50	1.48	1.29	1.12	55	40	24	8	23	37	52	1.06	1.20	1.34	1.48
1.00	1.43	1.25	1.09	53	38	23	7	21	36	50	1.03	1.17	1.30	1.43
1.10	1.38	1.21	1.06	50	36	22	7	20	34	48	1.00	1.13	1.26	1.38
1.20	1.33	1.17	1.03	48	34	21	6	19	32	45	57	1.09	1.21	1.33
1.30	1.29	1.14	1.00	46	32	20	6	18	31	43	54	1.06	1.18	1.29
1.40	1.25	1.11	57	44	31	18	6	18	30	41	52	1.04	1.15	1.25
1.50	1.21	1.08	55	42	30	17	6	17	28	39	50	1.01	1.11	1.21
2.00	1.18	1.05	53	39	29	17	5	16	27	37	48	58	1.08	1.18
2.20	1.11	1.00	48	37	26	16	5	15	25	35	44	54	1.03	1.11
2.40	1.06	55	44	34	24	14	5	14	23	32	41	50	58	1.06
3.00	1.01	51	41	32	22	13	4	13	21	30	38	46	54	1.01
3.20	57	47	38	29	21	13	4	12	20	28	35	43	50	57
3.40	53	44	36	28	20	12	4	11	18	26	33	40	47	53
4.00	49	41	33	26	18	11	4	10	17	24	31	37	44	50
4.30	45	38	31	24	17	10	3	9	16	22	28	34	40	45
5.00	41	35	28	22	16	9	3	9	14	20	26	31	36	40
5.30	38	32	26	20	14	9	3	8	13	19	24	29	34	38
6.00	35	30	24	19	13	8	2	7	12	17	22	26	31	35
6.30	33	28	22	17	12	7	2	7	11	15	20	24	29	33
7.00	31	26	21	16	12	7	2	6	10	14	19	23	27	31
8	27	23	19	15	10	6	2	5	9	13	16	20	24	27
9	24	20	16	13	9	5	2	5	8	11	14	18	21	24
10	22	18	15	12	8	5	1	4	7	10	13	16	19	22
11	20	17	14	11	8	5	1	4	7	9	12	15	18	20
12	18	15	13	10	7	4	1	4	6	9	11	13	16	18
13	17	14	12	9	7	4	1	3	6	8	10	12	15	17
14	16	13	11	8	6	4	1	3	5	7	9	11	14	16
15	15	12	10	8	6	3	1	3	5	7	9	11	13	15
16	14	12	9	7	5	3	1	3	5	6	8	10	12	14
17	13	11	9	7	5	3	1	3	4	6	8	9	11	13
18	12	10	8	6	5	3	1	2	4	6	7	9	10	12
19	11	9	8	6	4	3	1	2	4	5	7	8	10	11
20	11	9	7	6	4	2	1	2	4	5	6	8	9	11
21	10	9	7	5	4	2	1	2	3	5	6	7	9	10
22	10	8	7	5	4	2	1	2	3	5	6	7	8	10
23	9	8	6	5	4	2	1	2	3	4	6	7	8	9
24	9	7	6	5	3	2	1	2	3	4	5	6	8	9
25	8	7	6	5	3	2	1	2	3	4	5	6	7	8
26	8	7	6	4	3	2	1	2	3	4	5	6	7	8
27	8	6	5	4	3	2	1	2	3	4	5	6	7	8
28	7	6	5	4	3	2	0	1	2	3	5	5	6	7
30	7	6	5	4	3	2	0	1	2	3	4	5	6	7
			—	—	—	—	+	+	+	+	+			
			28.26	28.56	28.85	29 15	29.75	30.05	30.35	30.64	30.93			

Hight of the Barometer.

TABLE II.

MEAN PLACES FOR 100 PRINCIPAL FIXED STARS, FOR JAN. 1, 1846.

Star's Name.	Mag.	Right Ascen. h.	m.	s.	Annual Var. s.	Declination. deg.	min.	sec.	Ann. Var. sec.
α ANDROMEDÆ,........	1	0	0	26.257	+ 3.0720	N.28	14	25.40	+20.055
γ PEGASI (*Algenib*),....	2.3	0	5	18.691	3.0784	N.14	19	37.80	20.050
β Hydri,.............	3	0	17	34.168	3.3054*	S.78	7	24.40	19.997
α CASSIOPEÆ,.........	3	0	31	48.294	3.3418	N.55	41	31.08	19.862
β Ceti, ...	2.3	0	35	51.339	+ 2.9995	S.18	49	59.01	+19.810
α URS. MIN. (*Polaris*),.	2.3	1	3	52.226	17.1346*	N.88	29	17.88	19.279
θ¹ Ceti, ...	3	1	16	19.692	3.0015	S. 8	58	45.93	18.952
α Eridani (*Achernar*),.	1	1	31	58.291	2.2339	S.58	1	14.34	18.461
α ARIETIS,............	3	1	58	30.193	+ 3.3475	N.22	43	53.86	+17.432
γ Ceti,..............	3	2	35	19.633	3.1085	N. 2	35	1.17	15.621
α CETI,...............	2.3	2	54	14.072	3.1266	N. 3	28	55 70	14.532
α PERSEI,.............	2.3	3	13	21.403	4.2324	N.49	18	28.20	13.329
ϰ Tauri,.............	3	3	38	20.382	+ 3.5473	N.23	37	27.73	+11.620
γ¹ Eridani,...........	2.3	3	50	50.760	2.7898	S. 13	57	1.50	10.711
α TAURI, (*Aldebaran*),..	1	4	27	5.404	3.4274	N.16	11	41.39	7.097
α AURIGÆ, (*Capella*),...	1	5	5	19.317	4.4082	N.45	50	6.56	4.737
β ORIONIS, (*Rigel*), ...	1	5	7	8.383	+ 2.8787	S. 8	23	3.33	+ 4.583
β TAURI,.............	2	5	16	33.662	3.7827	N.28	28	17.49	3.776
δ ORIONIS,............	2	5	24	8.428	3.0609	S. 0	25	4.86	3.123
α Lepris,.............	3.4	5	25	56.406	2.6425	S. 17	56	12.77	2.968
ε ORIONIS, ...	2.3	5	28	24.062	+ 3.0404	S. 1	18	17.53	+ 2.754
α Columbæ, ...	2	5	34	4 531	2.1691	S.34	9	36.95	2.262
α Orionis,............	1	5	46	50.189	3.2433	N. 7	22	22.32	+ 1.149
μ Geminorum,.........	3	6	13	38.621	3.6257	N.22	35	13.16	— 1.196
α Argus, (*Canopus*),...	1	6	20	32.145	+ 1.3279	S.52	36	49.17	— 1.796
51 (Hev.) Cephei,......	6	6	26	30.287	30.7946	N.87	15	31.20	2.337
α CANIS MAJ., (*Sirius*),	1	6	38	21.883	2.6459*	S.16	30	32.83	4.484*
ε Canis Majoris,......	2.3	6	52	34.440	2.3558	S.28	45	59.38	4.562
δ Geminorum,........	3.4	7	10	55.298	+ 3.5918	N.22	15	37.47	— 6.110
α² GEMINOR. (*Castor*),..	3	7	24	46.065	3.8561	N.32	13	12.93	7.253
α CAN. MIN., (*Procyon*),	1.2	7	31	14.237	3.1445*	N. 5	36	54.95	8.758*
β GEMINOR, (*Pollux*),..	2	7	35	53.153	3.6829*	N.28	23	34.06	8.152
15 Argus,.............	3.4	8	0	59.232	+ 2.5596	S.23	51	50.94	—10.104
ε Hydræ,.............	4	8	38	37.154	3.1966	N. 6	58	48.51	12.800
ι Ursæ Majoris,......	3.4	8	48	38.088	4.1261*	N.48	38	32.35	13.464
ι Argus,.............	2	9	12	58.192	1.6100	S.58	37	49.78	14.961
α HYDRÆ,............	2	9	20	1.170	+ 2.9499	S. 7	59	39.05	—15.366
θ Ursæ Majoris,.......	3	9	22	31.453	4.0504*	N.52	22	31.09	16.108*
ε Leonis,.............	3	9	37	6.098	3.4258	N.24	28	49.46	16.283
α LEONIS, (*Regulus*),...	1	10	0	10.062	+ 3.2211	N.12	43	2.96	—17.377

Star's Name.	Mag.	Right Ascen. h. m. s.	Annual Var. s.	Declination. deg. min. sec.	Ann. Var. s.
η Argus,............	2	10 39 6.223	+ 2.3051	S. 58 52 34.26	—18.33
α Ursæ Majoris,......	1 .2	10 54 10.737	3.8001	N.62 34 51.81	19.24
δ Leonis,............	3	11 5 54.583	3.1928	N.21 21 59.86	19.50
δ Hydræ et Crateris,..	3 .4	11 11 38.718	3.0010	S.13 56 46.85	19.61
β Leonis,............	2 .3	11 41 12.066	+ 3.0654*	N.15 25 58.12	—19.99
γ Ursæ Majoris,......	2	11 45 42.219	3.1874	N 54 33 3.18	20.02
β Chamæleontis, ...	5	12 9 26.893	3.3409	S.78 27 26.15	20.04
α¹ Crucis, ...	1	12 18 4.916	3.2710	S.62 14 39.74	19.99
β Corvi,.............	2 .3	12 26 18.465	+ 3.1342	S.22 32 39.93	—19.92
12 Canum Venaticorum,	2 .3	12 48 49 007	2.8403	N.39 9 4.18	19.60
α Virginis, (*Spica*,)....	1	13 17 5.233	3.1512	S.10 21 20.80	18.94
η Ursæ Majoris,......	2 .3	13 41 27.894	2.3525*	N.50 5 1.45	18.12
η Bootis, ...	3	13 47 21.140	+ 2.8606	N.19 10 21.03	—17.89
β Centauri,...........	1	13 53 0.800	4.1508	S.59 37 33.93	17.67
α Bootis, (*Arcturus*,)..	1	14 8 38.366	2.7336*	N.19 59 12.07	18.94*
α² Centauri, ...	1	14 29 11.925	4.0165*	S.60 11 37.00	15.12*
ε Bootis,.............	3	14 38 15.706	+ 2.6229	N.27 43 35.23	—15.46
α² Libræ,.	3	14 42 22.132	+ 3.3102	S.15 23 53.52	15.23
β Ursæ Minoris,......	3	14 51 13.199	— 0.2692	N.74 47 5.58	14.71
β Libræ,.............	2 .3	15 8 43.595	+ 3.2226	S. 8 48 38.53	13.63
α Coronæ Borealis,...	2	15 28 10.083	+ 2.5279	N.27 14 11.07	—12.33
α Serpentis, ...	2 .3	15 36 41.077	+ 2.9391	N. 6 54 49.88	11.74
ζ Ursæ Minoris,......	4	15 49 41.194	— 2.3520	N.78 15 55.43	10.80
β¹ Scorpii, ...	2	15 56 29.397	+ 3.4742	S.19 22 44.18	10.29
δ Ophiuchi,...........	3	16 6 16.830	+ 3.1382	S. 3 17 35.67	— 9.55
α Scorpii, (*Antares*,)...	1	16 19 58.461	3.6638	S.26 5 4.58	8.48
η Draconis,...........	3	16 21 55.119	0.7960	N.61 51 50.58	8.32
α Trianguli Australis,	2	16 32 25.090	+ 6.2587	S.68 44 4.75	7.48
ε Ursæ Minoris,......	4	17 1 55.988	— 6.5328*	N.82 16 52.30	— 5.03
α Herculis, ...	3 .4	17 7 37.617	+ 2.7320	N.14 34 12.67	4.54
σ Octantis,...........	6	17 22 55.004	106.8627	S.89 16 10.25	3.14
β Draconis, ...	2	17 26 57.473	1.3513	N.52 25 3.28	2.88
α Ophiuchi, ...	2	17 27 47.219	+ 2.7727	N.12 40 37.11	— 2.81
γ Draconis, ...	2	17 53 1.955	1.3900	N.51 30 33.50	— 0.61
μ¹ Sagittarii, ...	3 .4	18 4 33.276	+ 3.5861	S.21 5 36.14	+ 0.40
δ Ursæ Minoris,......	3	18 22 0.703	—19.2683*	N.86 35 42.58	+ 1.91
α Lyræ, (*Vega*,)......	1	18 31 43.386	+ 2.0118	N.38 38 35.33	+ 2.77
β Lyræ,.............	3	18 44 23.696	2.2124	N.33 11 14.80	3.86
ζ Aquilæ, ...	3	18 58 19.965	2.7566	N.13 38 20.49	5.05
δ Aquilæ,............	3 .4	19 17 43.889	+ 3.0086	N. 2 48 43.64	+ 6.67
γ Aquilæ, ...	3	19 38 56.278	+ 2.8511	N.10 14 31.50	+ 8.39
α Aquilæ, (*Altair*,)....	1 .2	19 43 16.128	2.9254*	N. 8 27 54.32	8.74
β Aquilæ,............	3 .4	19 47 44.866	2.9446	N. 6 1 33.90	8.55*
α² Capricorni,.........	3	20 9 30.316	3.3315	S.13 1 4.19	10.74

Star's Name.	Mag.	Right Ascen.	Annual Var.	Declination.	Ann. Var.
		h. m. s.	s.	deg. min. sec.	sec.
α Pavonis,	2	20 13 25.814	+ 4.8046	S. 57 13 19.50	+ 11.03
γ Ursæ Minoris,	5	20 16 31.309	—52.1273	N.88 50 53.54	11.22
α Cygni,	1	20 36 11.005	+ 2.0418	N.44 43 57.43	12.64
61[1] Cygni,	5.6	20 59 59.947	2.6908*	N.37 59 42.08	17.48*
Cygni,	3	21 6 23.073	+ 2.5486	N.29 35 53.03	+ 14.57
α Cephei,	3	21 14 53.940	1.4163	N.61 56 4.55	15.07
β Aquarii,	3	21 23 26.875	3.1628	S. 6 14 44.46	15.56
β Cephei,	3	21 26 39.120	0.8059	N.69 53 7.21	15.73
ε Pegasi,	2 .3	21 36 37.346	+ 2.9441	N. 9 10 17.35	+ 16.26
α Aquarii,	3	21 57 52.326	3.0831	S. 1 3 56.72	17.28
α Gruis,	2	21 58 29.837	3.8134	S. 47 42 12.42	17.30
ζ Pegasi,	3	22 33 46.976	2.9837	N.10 1 44.67	18.65
α Pis. Aus. (*Fomalhaut*),	1	22 49 7.531	+ 3.3095	S. 30 26 12.28	+ 19.11
α Pegasi (*Markab*),	2	22 57 5.584	2.9776	N.14 22 40.12	19.31
ι Piscium,	4 .5	23 32 1.736	3.0569	N. 4 47 30.74	19.36*
γ Cephei,	3	23 33 4.581	+ 2.4042	N.76 46 22.01	+ 19.92

Those Annual Variations which includes proper motion are distinguished by an Asterisk.

SUN'S RIGHT ASCENSION FOR 1846.

Day of Mo.	January.	February.	March.	April.	May.	June.
	h. min. sec.	h. min. sec.	h. min. sec.	h. min. sec.	h. min. sec.	h. min. sec.
1	18 46 52	20 59 11	22 48 17	0 41 52	2 23 6	4 35 48
5	19 4 30	21 15 22	23 3 12	0 56 26	2 48 25	4 52 12
10	19 26 21	21 35 18	23 21 40	1 14 43	3 7 47	5 12 50
15	19 47 57	21 54 54	23 40 0	1 33 6	3 27 24	5 33 34
20	20 9 17	22 14 12	23 58 14	1 51 38	3 47 15	5 54 22
25	20 30 19	22 33 14	0 16 25	2 10 22	4 7 20	6 15 10
30	20 51 0	.	0 34 36	2 29 17	4 27 8	6 35 55

Day of Mo.	July.	August.	September.	October.	November.	December.
	h. min. sec.	h. min. sec.	h. min. sec.	h. min. sec.	h. min. sec.	h. min. sec.
1	6 40 4	8 44 55	10 41 0	12 29 4	14 25 16	16 29 1
5	6 56 34	9 0 23	10 55 29	12 43 36	14 41 2	16 46 23
10	7 17 5	9 19 29	11 13 30	13 1 54	15 1 5	17 8 17
15	7 37 25	9 38 21	11 31 28	13 20 24	15 21 28	17 30 22
20	7 57 33	9 56 60	11 49 25	13 39 8	15 42 14	17 52 33
25	8 17 28	10 15 27	12 7 24	13 58 9	16 3 19	18 14 46
30	8 37 7	10 33 44	12 25 27	14 17 27	16 24 43	18 36 57

The R. A. in this table will answer for corresponding days, in other years, within four minutes; and for periods of four years, the difference is only about seven seconds for each period.

TABULAR VIEW OF THE SOLAR SYSTEM.

Names.	Mean diameters in miles.	Mean distance from the Sun in miles.	Mean dist.; the Earth's dist. unity.	Log. of mean distance.	Time of revolutions round Sun.	Log. of times of revolution
					DAYS.	
Sun.....	883000					
Mercury .	3224	37 million	0.387098	9.587818	87.969258	1.944324
Venus ...	7687	68 "	0.723332	9.859306	224.700787	2.351610
The Earth	7912	95 "	1.000000	0.000000	365.256383	2.562598
Mars	4189	144 "	1.523692	0.182810	686.979646	2.836942
Vesta	238	224,340,000	2.36120	0.373100	1324.289	3.121991
Iris .	Unknown.	226 miilion	2.37880	0.376384	1327.973	3.123190
Hebe *	Unknown.	230 "	2.42190	0.384004	1375. nearly	3.138303
Flora	Unknown.	240 "	2.52630	0.402487	1469.76	3.167300
Astrea .	Unknown.	246 "	2.5895	0.413211	1512.nearly	3.179547
Juno.....	1420	253,600,000	2.66514	0.425710	1594.721	3.202700
Ceres....	Not well known. 160	263,236,000	2.76910	0.442334	1683.064	3.226086
Pallas ...	Not well known. 120	265 million	2.77125	0.442725	1685.162	3.226610
Jupiter...	89170	490 "	5.202776	0.716212	4332.584821	3.636738
Saturn...	79040	900 "	9.538786	0 979476	10759.219817	4.031718
Uranus ..	35000	1800 "	19.182390	1.282853	30686.8208	4.486953
Neptune .	35000	2850 "	29.59	1.477121	60128.14	4.779076

TABLE III.

ELEMENTS OF ORBITS FOR THE EPOCH OF 1850, JANUARY 1, MEAN NOON AT GREENWICH.

Planets.	Inclinati'n of orbits to ecliptic.	Variation in 100 years.	Long. of the ascending nodes.	Variation in 100 years.	Longitude of Perihelion.	Variation in 100 years.	Mean longitude at epoch.
	° ′ ″	″	° ′ ″	′	° ′ ″	′	° ′
Mercury	7 0 18	+18.2	46 34 40		75 9 47	+ 93	327 17 9
Venus..	3 23 26	— 4.6	75 17 40	+51	129 22 53	+ 78	243 58 4
Earth...					100 22 10	103	100 47 1
Mars ...	1 51 6	— 0.2	48 20 24	+42	333 17 57	+110	182 9 30
Vesta...	7 8 29	—12.	103 20 47	+26	254 4 34	157	113 28 12
Juno....	13 2 53	....	170 53 0	....	54 18 32	....	165 17 38
Ceres...	10 37 17	....	80 47 56	....	147 25 41	....	1 3 10
Pallas ..	34 37 44	....	172 42 38	....	121 30 13	....	327 31 24
Jupiter..	1 18 42	—22.	98 55 19	+57	11 56 0	+ 95	160 21 50
Saturn..	2 29 29	—15.	112 22 54	+51	90 7 0	+116	13 58 13
Uranus..	0 46 27	3.	73 12 0	+24	168 14 47	+ 87	28 20 22

* We give the logarithms in the tables, that the data may be at hand to exercise the student on Kepler's third law.

TABLE III.

TABULAR VIEW OF THE SOLAR SYSTEM.

Names.	Mass.	Density.	Gravity.	Siderial. Rotation.			Light and Heat.
				h.	m.	s.	
Mercury..	$\frac{1}{2025810}$	3.244	1.22	24	5	28	6.680
Venus....	$\frac{1}{401211}$	0.994	0.96	23	21	7	1.911
Earth.....	$\frac{1}{355000}$	1.000	1.00	24	0	0	1.000
Mars.....	$\frac{1}{2680337}$	0.973	0.50	24	39	21	.431
Jupiter...	$\frac{1}{1048.7}$	0.232	2.70	9	55	50	.037
Saturn....	$\frac{1}{3500.2}$	0.132	1.25	10	29	17	.011
Uranus...	$\frac{1}{17918}$	0.246	1.06	Unknown.			.003
Sun......	1	0.256	28.19	25d.	12h.	0m.	
Moon.....	$\frac{1}{26620200}$	0.665	0.18	27	7	43	

TABLE III.

Planets.	Eccentricities of orbits.	Variation in 100 years.	Motion in mean long. in 1 year of 365 days.			Mean Daily Motion in longitude.		
			°	′	″	°	′	″
Mercury...	0.20551494	+.000003868	53	43	3.6	4	5	32 6
Venus.....	0.00686074	—.000062711	224	47	29.7	1	36	7 8
Earth......	0.01678357	—.000041630	—0	14	19.5	0	59	8.3
Mars......	0.09330700	+.000090176	191	17	9.1	0	31	26.7
Vesta......	0.08856000	+.000004009	....			0	16	17.9
Juno......	0.25556000	....	....			0	13	33.7
Ceres......	0.07673780	—.000005830	....			0	12	49.4
Pallas.....	0.24199800	....	....			0	12	48.7
Jupiter.....	0.04816210	+.000159350	30	20	31.9	0	4	59.3
Saturn.....	0.05615050	—.000312402	12	13	36.1	0	2	0.6
Uranus.....	0.04661080	—.000025072	4	17	45.1	0	0	42.4

TABLE III.

LUNAR PERIODS.

	d.
Mean sidereal revolution,..........................	27.321661418
Mean synodical revolution,..........................	29.530588715
Mean revolution of nodes (retrograde),............	6793.391080
Mean revolution of perigee (direct),................	3232.575343
Mean inclination of orbit,..........................	5° 8′ 48″
Mean distance, in measure, of the equatorial radius of the earth,....................................	29.98217
Mean distance, in measure, of the mean radius,......	30.20000

SATELLITES OF JUPITER.

Sat.	Mean Distance.	Sidereal Revolution.			Inclination of Orbit to that of Jupiter.			Mass; that of Jupiter being 1000000000.
		d.	h.	m.	°	′	″	
1	6 04853	1	18	28	3	5	30	17328
2	9.62347	3	13	14	Variable.			23235
3	15.35024	7	3	43	Variable.			88497
4	26.99835	16	16	32	2	58	48	42659

SATELLITES OF SATURN.

Sat.	Mean Distance.	Sidereal Revolution.			Eccentricities and Inclinations.
		d.	h.	m.	
1	33.51	0	22	38	The orbits of the six interior satellites are nearly circular, and very nearly in the plane of the ring. That of the seventh is considerably inclined to the rest, and approaches nearer to coincidence with the ecliptic.
2	4.300	1	8	53	
3	5.284	1	21	18	
4	6.819	2	17	45	
5	9.524	4	12	25	
6	22.081	15	22	41	
7	64.359	79	0	55	

SATELLITES OF URANUS.

Sat.	Mean Distance.	Sidereal Period.				Inclination to Ecliptic.
		d.	h.	m.	s.	
1?	13.120	5	21	25	0	Their orbits are inclined about 78° 58′ to the ecliptic, and their motion is retrograde. The periods of the 2d and 4th require a trifling correction. The orbits appear to be nearly circles.
2	17.022	8	16	56	5	
3?	19.845	10	23	4	0	
4	22.752	13	11	8	59	
5?	45.507	38	1	48	0	
6?	91.008	107	16	40	0	