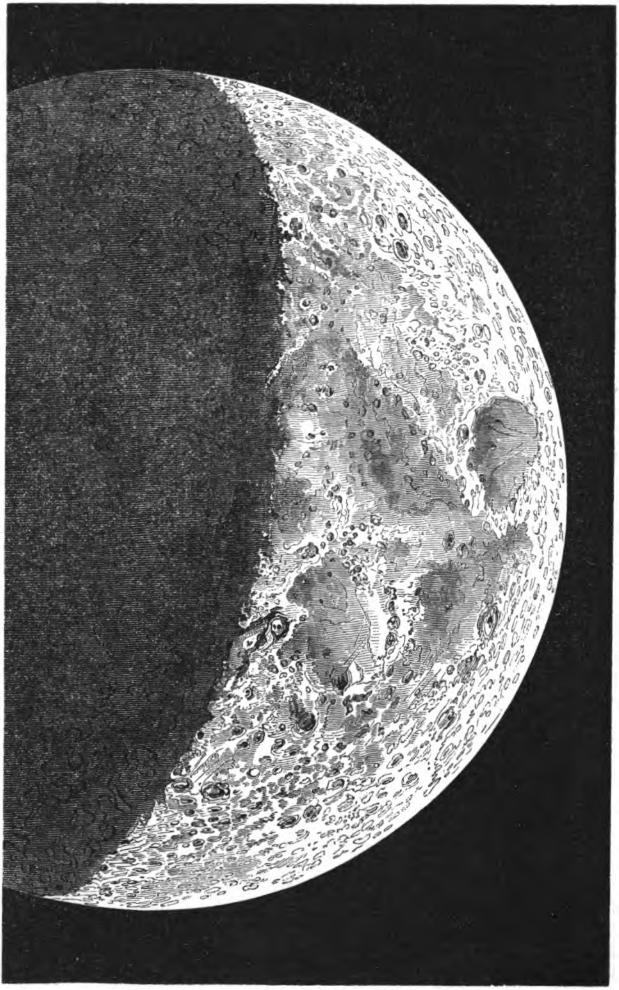
Telescopic appearance of the Moon when nearly five days old.



LONDON

GEORGE BELL, 186 FLEET STREET.

1853.

MANUAL OF ASTRONOMY:

A POPULAR TREATISE

ON

Descriptive, Physical, and Practical Astronomy;

WITH

A FAMILIAR EXPLANATION OF ASTRONOMICAL INSTRUMENTS AND THE BEST METHODS OF USING THEM.

BY

JOHN DREW, F.R.A.S.

DOCTOR IN PHILOSOPHY OF THE UNIVERSITY OF BÂLE;
AUTHOR OF "CHRONOLOGICAL CHARTS ILLUSTRATIVE OF ANCIENT HISTORY AND GEOGRAPHY."

"Of all our pleasures in this world, that resulting from the contemplation of the stupendous phenomena of nature is by far the most exciting and the most intellectual."

Dr. Shuttleworth, late Bishop of Chichester.

Second Edition.

LONDON:
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1853.

LONDON:
PRINTED BY ROBSON, LEVEY, AND FRANKLYN,
Great New Street and Fetter Lane.

TO

SIR JOHN FREDERIC WILLIAM HERSCHEL, BART.

&c. &c. &c.

MY DEAR SIR,

You kindly permitted me to dedicate to you the first edition of this work. I trust you will find the present, in which I have attempted to explain in familiar language the elementary truths of that science with which the name of Herschel must ever be associated, superior to its predecessor; and I would fain hope that, from the perusal of this unpretending volume, not a few may be induced to study your valuable Treatise on the same subject, and be enabled to appreciate your labours in the promotion of astronomical science. With the most profound admiration of your scientific attainments, and respect for your character,

Believe me,

My dear Sir,

Yours very faithfully,

JOHN DREW.

SOUTHAMPTON, *May* 1, 1853.

PREFACE

TO THE SECOND EDITION.

THE object of this Treatise is to supply the student with a manual comprising a clear exposition of the most important truths of the science of Astronomy, and a familiar description of those instruments by whose aid astronomers have arrived at results, the correctness and certainty of which are a source of perpetual admiration.

Having spent the best years of his life in instructing others, the Author trusts that his attempt to simplify the principles of Astronomy has not been unsuccessful, and that his book will meet the wants of many who, without pursuing astronomical science to any great extent, are nevertheless anxious to obtain a general acquaintance with the phenomena of the heavens. In addition to the number of readers of this class from the ranks of well-educated persons, it is his hope that this book will find its way into the hands of intelligent youth, who from its pages may derive a taste for that science which surpasses all others in the sublimity of its disclosures and the certainty of its predictions.

The work consists of three parts:

PART I., on the number, magnitude, and physical constitution of the heavenly bodies, brings down the modern discoveries in Astronomy to the year 1853.*

PART II. is an attempt to simplify the elementary principles of the Newtonian Philosophy.

PART III., on Practical Astronomy, gives an explanation of the manner in which the facts brought forward in the former sections may be verified by the use of astronomical instruments; directs such as may possess telescopes how to use them, what objects to look for in the heavens, and where they are to be found.

* To the list of the minor planets in § 123, two others must now be added, which have been discovered since that part of the work was printed: one by De Gasparis, at Naples, April 5; the other at Marseilles, by M. Chacornac, on April 6, 1853.

The paper on the nicer adjustments of astronomical instruments, read before the Royal Astronomical Society, and printed with the sanction of the Council, with which this part concludes, will, it is anticipated, supply useful hints in the management of the Observatory.

The Author apprehends that the numerous additions to this portion of the work, being the result of his own practical experience, will render it extensively acceptable.

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PART I.

DESCRIPTIVE ASTRONOMY.

SECTION I.

GENERAL VIEW OF THE SOLAR SYSTEM.

1. In no age of the world have the starry heavens failed to call forth the admiration of mankind. The diversified appearance of the spangled hemisphere—the solemn stillness of its unceasing but imperceptible motion—its immutability contrasted with the ever-changing character of things terrestrial,—all unite in creating a feeling of mingled gratification and awe when we contemplate the heavenly vault.

> "Ye stars, which are the poetry of heaven."

Nor, as in many explanations of natural appearances, is this feeling diminished by the increase of scientific knowledge. The poet in some cases might truly say,

> "When science from creation's face
> Enchantment's veil withdraws,
> What lovely visions yield their place
> To cold material laws!"

But his words will not apply to the discoveries of astronomy : these afford ample scope for the imagination to range, and surpass what it could have conceived without their assistance. Knowledge here, so far from diminishing our reverence, will increase it a thousand-fold; and the modern astronomer, acquainted with the heavens through Newton, Herschel, and La Place, will have formed notions of their magnificence far surpassing those of Arab shepherd or of Grecian sage.

2. Let us begin by considering what, in the appearances of the starry heavens, is most likely to strike an observer as yet unacquainted with astronomy. He will not fail to perceive, that by far the greater number of the stars never change their relative position ; that is to say, if any number form to-night the figure of a triangle or a trapezium, they will do so the next night, and will continue to be similarly situated weeks, months, or years hence. These are termed FIXED STARS. A few will be observed constantly to change their position: thus, if one is remarked near any particular fixed star to-night, on the following evening it may have moved considerably to the east or west of such star, and in no long period it will be found to have left that neighbourhood altogether. These are termed PLANETS, from the Greek word πλαναω, *to wander :* only five of these at any time can be seen with the naked eye, and they may in general be distinguished from the fixed stars by the steady light which they emit, whereas the fixed stars incessantly twinkle. Of these bodies it will be sufficient for our present purpose to remark, that they, together with the earth, which is also a planet, and comets, which constitute a distinct class of bodies, revolve round the sun, forming with him the SOLAR

SYSTEM; the fixed stars being infinitely more distant from us than they are.

3. The SOLAR SYSTEM consists of the sun, a self-luminous body, in the centre. If we divide the heavenly bodies into the three classes of fixed stars, planets, and comets, the sun will properly belong to the first class, as it exhibits the characteristic of the fixed stars; such as shining by an inherent light of its own, and retaining unmoved the same position in the heavens.

Round the sun revolve the planets, in orbits not circular, but more or less elliptical. The eight principal planets are, Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune.

Between the orbits of Mars and Jupiter are found several very small planets, termed Asteroids, which were undiscovered till within the last fifty years. Such has been the industry expended on searching the heavens, especially the region of the Zodiac, that during the last seven years, to the end of 1852, as many as nineteen have rewarded the diligence of observers, in addition to Vesta, Ceres, Pallas, and Juno, which were discovered at the beginning of the present century.

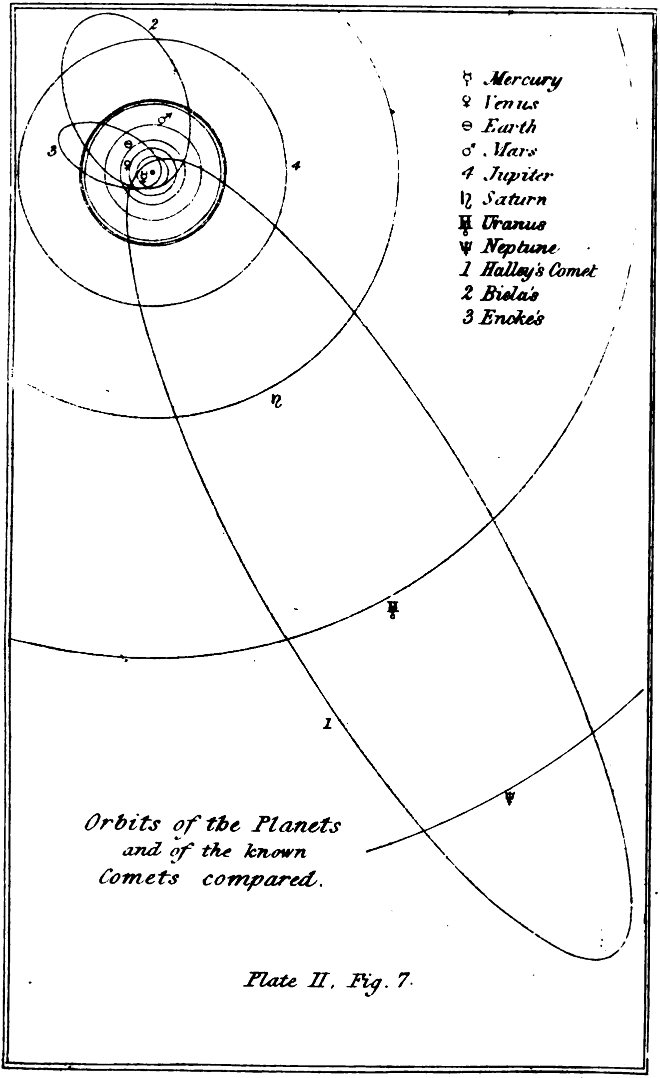
4. Several of the planets are accompanied by moons or satellites, which supply light, during the nightly absence of the sun, to their primaries. The Earth has one moon, Jupiter four, Saturn seven, and Uranus six at least, and probably others which as yet have eluded telescopic observation; Neptune is known to be accompanied by one, and probably two.

In addition to these bodies, comets, in number unknown, form a part of the solar system; these describe extremely elliptical orbits, or orbits of a parabolic form;

as may be seen by reference to fig. 7, Plate II., where the orbits of three of the six known comets out of hundreds which, in the course of ages, have made their appearance, are laid down proportionally. It will be observed that they sometimes approach the sun, and in other parts of their orbits recede from him an immense distance. Some of these singular bodies do not revolve round the sun at all; but, making their first appearance at one part of the system, they sweep towards the sun; then leaving him, they dart across to the opposite quarter, and are seen no more. Either they are lost, or dissolve in the immensity of space; or they visit in the same manner a succession of other systems in remote regions of space.

The planets resemble the earth, as we shall hereafter shew more at length, in various particulars, more especially in their being opaque and solid bodies; but these singular visitants, the comets, appear to have nothing in common with either the planets or the sun, but to consist entirely of the most rare and transparent vapour, far more delicate than the most fleecy cloud that floats in our atmosphere.

5. Instruments called *orreries* are frequently made use of to explain the various movements of the solar system; and it may be allowed that they illustrate some celestial phenomena tolerably well. On other points, however, they convey very incorrect notions, and are calculated to mislead the student in estimating the relative sizes and distances of the sun and planets. The earth, for instance, is usually represented by a globe of an inch and a half in diameter, while the orbit of Uranus is performed at not more than eighteen inches from



Orbits of the Planets and of the known Comets compared.

Plate II. Fig. 7.

the sun. How very little these proportions accord with the true, will be at once seen from the following calculations.

Let the earth be represented by a globe 1½ inches in diameter; the proportionate diameters of the other planets would be as follows:

Mercury . . .	$\frac{6}{10}$ of an inch.
Mars	¾ „ „
Jupiter . . .	16¼ inches.
Saturn . . .	15 „
Uranus	6½ „
Neptune . . .	8 „

While the sun would be represented by a massive globe whose diameter would be fourteen feet.

Preserving the same scale for the distances of the planets from the sun, they would be:

Mercury . . .	193 yards.	
Venus . . .	360 „	
Earth	500 „	
Mars	760 „	
Jupiter . . .	2600 „	
Saturn . . .	4765 „	
Uranus . . .	9590 „	or 5¾ miles.
Neptune . . .	15000 „	or 8½ miles.

The diagram of the solar system (fig. 7, Plate II.) exhibits the orbits of the planets, as well as of three known comets, proportionally delineated.

6. The sun, in his annual motion through the heavens, describes a path among the fixed stars, which has received the name of the ECLIPTIC. The phenomena

of the annual revolution of the earth will be the same, whether we suppose it to be at rest, and the sun to revolve round it, with the ancients; or whether we assume the sun to be the fixed, and the earth the revolving body. The complete revolution of the sun among the stars forms the year, which is equal to 365·2563612 of our natural days, or revolutions of the earth on its axis.

SECTION II.

THE SUN.

THE SUN—THE SOLAR SPOTS—ROTATION OF THE SUN ON HIS AXIS—VARIATION IN HIS DIAMETER, PROVING THE EARTH'S ORBIT TO BE AN ELLIPSE—PROOF THAT THE SUN, AND NOT THE EARTH, IS THE CENTRAL BODY—ABERRATION OF LIGHT—ZODIACAL LIGHT.

7. IN this part of the work will be introduced such particulars respecting the form, physical constitution, or any other peculiarity of the heavenly bodies, as the light of science has disclosed to us: at the same time we shall not hesitate to refer, under the head of Descriptive Astronomy, to any fact relating to their mutual connection with each other through the attraction of gravity, which may, however, be more fully illustrated under the head of Physical Astronomy.

This division of the work will more particularly shew how much the moderns are indebted to the telescope for the revelation of truths which without its aid would have remained unknown.

8. When contemplated with respect to their physical constitution, the heavenly bodies may be divided

into three classes—Fixed Stars, Planets, and Comets. Each of these classes exhibits peculiarities which entitle it to a separate consideration.

The sun may be regarded as belonging to the first class; for, as far as observation has yet gone, the similarity between it and the fixed stars is unquestionable. From our connexion with that luminary and the planets, and from the opportunities we have of examining them through the telescope, we shall treat of the bodies of our system before we proceed to the fixed stars.

To begin with the Sun, the dominant body of the system of which our earth is a member.

The sun is self-luminous—the source of light and heat to the bodies which revolve round him. Though to the naked eye his surface appears equally luminous

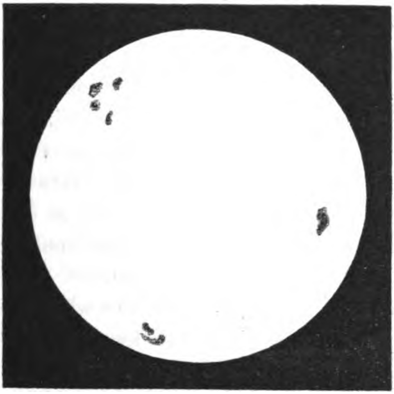


Fig. 1. The Solar Spots.

throughout, yet when examined with a telescope of even small magnifying power, and the splendour of his rays deadened by the interposition of coloured glass, it is frequently observed to be interspersed with dark spots of various forms and magnitudes. If these are repeatedly watched, they will be found not to be stationary on the sun's disc for any long period of time, nor to remain of the same figure; but to vary their position, to contract or enlarge, and, at times, suddenly to disappear; while others break out in places where none existed before: so that plainly these spots are not hollows, or pits, or shadows of mountainous elevations, like those of the moon.

9. The general appearance of these spots is represented in the drawing; they are found, for the most part, to consist of a dark, irregular, central portion, called the nucleus, which is surrounded by a lighter shade, termed the umbra. Even in the course of a few hours they have been observed to change their size, either by enlarging or contracting, or by running into one another. Frequently they appear in clusters, as at the time of the annular eclipse of the sun in 1836, when there were five in the neighbourhood of each other. The size of some of them has been immense: in 1758, one appeared which measured as much as 45,000 miles across: February 20, 1846, the author found the breadth of one by micrometrical measurement to be 10,774 miles: indeed, the least possible spot which can be seen by a very good glass cannot be less than 500 miles in diameter, or must spread over a surface of at least 200,000 square miles.

From the extreme rapidity with which these spots are observed to open and close; from the lighter spots, termed faculæ, which are frequently seen more brilliant than the rest of the sun's disc, and in general on the portion of the sun's surface in which a dark spot is about to appear; and from the wavy, irregular light diffused over the whole surface, as well as from other reasons which have presented themselves to laborious investigators; it has been concluded that the spots arise from variations in the luminous atmosphere of the sun, and that the nuclei are parts of the sun's opaque surface, laid bare by some violent commotion in his aerial regions. Sir William Herschel considered the luminous atmosphere to be sustained far above the level of the solid body by a transparent elastic medium, which, when the luminous atmosphere is partially removed, still reflects a portion of light to the eye, and thus forms the umbra; while the solid body of the sun is the darkest portion of the spot. The temporary removal of both strata, but more of the upper than the lower, he supposed to be effected by powerful upward currents of some kind of gas, which may perhaps issue from spiracles in the body of the sun. This view of the subject has the advantage of accounting perfectly for all the phenomena of the spots, and has been embraced generally, both by British and foreign astronomers.

10. By an attentive observer it will be remarked that such of the spots as remain stationary on the sun's surface for a considerable time, have a gradual motion, apparently across the sun's disc. Making their appearance on the eastern edge of the sun, in about a fortnight (if they continue visible so long), they will move towards the western edge, and disappear behind it; a fortnight after, a spot which may thus have disappeared, may again be seen on the

eastern edge, about to describe the same course as before. Now this motion of the spots can only arise from the rotation of the sun on his axis; and they serve to mark the time of this rotation. This time would be, were the earth stationary, equal to the time elapsed between two consecutive disappearances of the spot on the western edge; but a correction must be introduced into the calculation, in consequence of the earth's motion, which, in the meantime, has been going on in the same direction as the motion of the sun on his axis.

Thus, suppose the earth (fig. 2) to be at E when a spot disappears; if the earth stood still at E, the inhabitants would again see the spot disappear after one

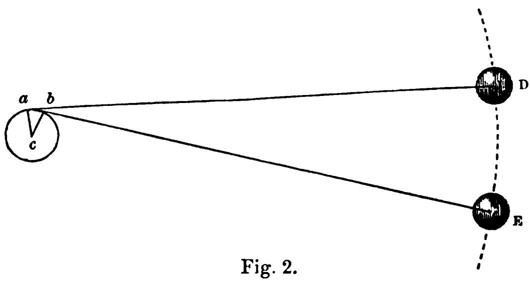


Fig. 2.

revolution of the sun on his axis; that is, when the spot had again arrived at *b*. But in the meantime the earth has advanced to D; the spot has therefore to describe the additional arc *a b* before it will again be lost sight of. Now the arc *b a*, which measures the angle *b c a*, is equal to the arc E D, which measures the angle E *a* D, or the portion of the earth's orbit which she has passed over in that time; hence, As $360° + b\,a$, the whole space described by the spot : the whole time elapsed between the two disappearances :: $360°$: the true time of the revolution of the sun on his axis, as it would have appeared to the earth had it been stationary at E; which time has thus been found to be 25·01154 sidereal days.

These spots prove that the sun is a spherical body; for a spot makes its appearance on the edge of the sun as a fine line, which gradually increases in breadth till it approaches the centre. As it passes on to the western edge, its diameter gradually lessens into a fine line before it entirely vanishes from view. Now such an appearance could take place only in the revolution of a spherical body.

11. The question, whether or not the sun is inhabited, has long been agitated. The opinion of Sir William Herschel, from what he had observed in that luminary, leaned evidently in favour of its being the abode of beings adapted to the peculiar circumstances in which Providence has placed them. If his hypothesis of the two atmospheres holds good, the lower or opaque atmosphere may tend to modify the heat of the upper, and convert it into respirable air. As his opinion ought always to be received with deferential regard, we shall give it in his own words:

"The sun appears to be nothing else than a very eminent, large, and lucid planet, evidently the first, or rather the only primary one of our system, all the rest being truly secondary to it. Its similarity to the other globes of the solar system, with regard to its solidity, its atmosphere, and its diversified surface, leads us to suppose that it is most probably also inhabited, like the rest of the planets, by beings whose organs are adapted to the peculiar circumstances of that vast globe."

12. If the diameter of the sun be accurately measured, as it may be with instruments, termed heliometers, adapted to that purpose, it will be found to subtend a greater angle at some periods of the year than at others: if such observations be continued for several successive years, it will still further appear, that, at the same time in each year, his diameter will be equal to what it was the year before. From these circumstances, we are compelled, then, to come to one of these two conclusions: either that the sun regularly expands or contracts, or that our distance from him is variable. The former supposition is absurd; the latter, then, remains to account for the phenomenon. Now, did the earth remain at the same distance from the sun at every period of the year; that is, were her orbit circular, the sun's diameter would never vary; but as the sun's diameter is different at different times, we are persuaded that its orbit is not a circle; and since the angle under which an object is viewed varies inversely as the distance, the variation in the sun's diameter will enable us to determine what the form of the orbit is.

13. When it is stated that the angle under which an object is viewed (that is strictly, when this angle, as in the case of the sun's diameter, is very small,) varies inversely as the distance, we mean, that if, at a second observation, the diameter is half what it was at the first, the second distance will be double the first distance; if $\frac{1}{3}$, the distance will be treble; and so on. Now, supposing we begin on a particular day to measure the

sun's diameter, and that for every week for a whole year we continue to do the same, and to set off on paper lines radiating from a common centre, proportional to these different measurements, by joining the extremities of those lines we shall represent accurately the form of the earth's orbit.

To illustrate roughly what is meant, refer to fig. 3; and, for the sake of simplicity, imagine the earth fixed at E. Suppose the diameter of the sun at the first observation, December 21, to be $32\frac{1}{2}'$; set off from a convenient scale 65 equal parts towards R (being the number of half minutes in $32\frac{1}{2}$ minutes); when the year has advanced about six weeks, or $\frac{1}{8}$ of the whole,

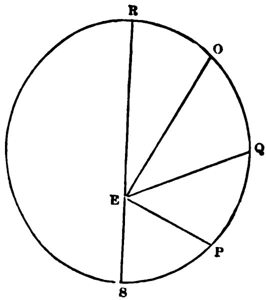


Fig. 3.

let us suppose the diameter of the sun to measure 32′; make E O = 64 equal parts; when a quarter of the year has expired, let the diameter of the sun be measured, and, on the supposition of its being $31\frac{1}{2}$ minutes, make E Q = 63; at P, let the sun's diameter be 31′, and make E P = 62; and when half the year has passed, we shall find his diameter to be the least of all, viz. 30′; make therefore E S = 60 equal parts. By continuing these measurements for the remainder of the year, increasing their number, if we wish for great accuracy, and eventually joining the extremities of the proportional lines thus laid down, we shall have an ellipse (a curve described in § 181), and the sun will be found, not in the centre, but in one of the foci of the ellipse. The more numerous the lines laid down, and the more accurately the diameter is measured, the more correct will be the delineation of the earth's path. We have, for the sake of greater clearness, made use in the diagram of round numbers, which are not absolutely correct; the greatest apparent diameter of the sun is 32′ 36″, and its least 31′ 32″.

14. We have throughout this treatise assumed that the earth revolves round the sun, though the same appearance which has just been described would occur if the sun revolved round the earth, according to the system of Ptolemy. It may not be amiss to shew the reasons by which the motion of the earth is confirmed.

It has already been intimated that the earth is much smaller than the sun, being only three-millionths of his mass. Now, it is contrary to all analogy to suppose that the larger body revolves round the smaller. We see that the moon, the smaller body, circulates round the earth, the larger. Jupiter, Saturn, and Uranus, are the centres of the orbits of their satellites; while the sun is that of the orbits of the planets, his inferiors in size: so that analogy would lead us to conclude—independently of mathematical reasoning—that the sun, and not the earth, is the immovable body.

15. The third law of Kepler, hereafter explained, namely, that the squares of the periodic times of the planets are in proportion to the cubes of their mean distances from the sun, applies to the revolution of the earth, as well as to the revolutions of the other planets. But on the supposition that the sun moves round us,

among other confusions which it would introduce into our system, would be that of overthrowing this fundamental law of the planetary movements.

16. This truth—the revolution of the earth round the sun—has been placed beyond all controversy by the splendid discovery of Mr. Bradley of the aberration of light. Light does not proceed from a luminous body to a distance instantaneously; yet the rapidity with which it travels far exceeds any other motions which come under our notice: the time it takes to reach our earth from the sun is $8\frac{1}{4}$ minutes. It follows, then, that the light which we see at any particular instant is not the light which proceeds at that moment from him, but the light which left him $8\frac{1}{4}$ minutes before. And since objects are seen in the direction of the rays of light which proceed from them, the sun appears in consequence of the earth's advance in her orbit during that time, in the position which, in point of fact, he occupied $8\frac{1}{4}$ minutes before. Now this displacement of the sun from his actual position can only be the result of the earth's motion round him. This displacement is a very minute quantity; and nothing can exhibit in a stronger light the accuracy of modern observations than this splendid discovery. The velocity of the earth in its orbit is 19 miles per second; that of light, 192,000 miles. If a parallelogram, whose sides shall be in this proportion, be constructed, the diagonal of that parallelogram will be the direction of the true position of the sun; one of its longest sides will be the direction in which he will be seen, and the angle contained by these two lines will be the displacement, which will be $20\frac{1}{2}''$. Due allowance for this must be made in each

calculation of the sun's place. Nor is this allowance to be made for the sun only, since the stars and planets are all displaced through the effect of aberration; that is to say, as in the case of the sun, the motion of the earth produces an apparent alteration in their position. If the earth were stationary, no such alteration of position could obtain, but each body would be seen in its true place; this is, therefore, a conclusive proof of the annual revolution of the earth, and of the fixity of the sun in the centre of her orbit.

17. The discovery of this singularly beautiful and important phenomenon shews the manner in which a valuable result may be obtained by closely observing nature, although the immediate object of search may not be accomplished. It was in endeavouring to ascertain the parallax of the fixed stars in the year 1725, that their change of position from the aberration of light was discovered; which result afforded an ample compensation for the labour bestowed on the observations.

18. A singular phenomenon connected with the sun may sometimes be remarked, when the sun is in the equinoxes, a short time before sunrise or after sunset: a streak of light, somewhat resembling the tail of a comet, extends for some distance along the zodiac (whence it is termed the ZODIACAL LIGHT), or rather parallel to the region of the solar equator, which does not quite coincide with the ecliptic. The faintest stars may be seen through it, as they may be through the matter composing a comet. The form of this nebulous appearance is that of a cone, having the diameter of the sun for its base. It does not appear equally bright at

all times when it is seen; indeed, many years it is altogether invisible, especially in our latitude. It would appear to have some connexion with the solar atmosphere; but that this atmosphere should extend beyond the boundary of the orbit of Venus seems unaccountable. Sir John Herschel's opinion is, "that this phenomenon may be no other than the denser part of that medium which, as we have reason to believe, resists the motions of comets, loaded, perhaps, with the actual materials of the tails of millions of these bodies, of which they have been stripped in their perihelion passages, and which may be slowly subsiding into the sun."

19. The following account of the appearance of the zodiacal light within the tropics, from the pen of Captain W. H. Smyth, R.N., whose authority as an observer stands very high, will be gratifying to those who have not had an opportunity of witnessing it under equally favourable circumstances: "At first, it seems a faint, whitish zone of light, less intense than the milky way, with ill-defined borders, scarcely to be distinguished from the twilight, being then but little elevated, and its figure nearly agreeing with that of a spheroid seen in profile. As it rises above the horizon it becomes brighter and larger, till it resembles a lenticular beam of light, somewhat analogous to the tail of a comet, rounded at the vertex, with its base towards the sun, and its axis in the direction of the zodiac."

The zodiacal light may frequently be seen in this country — most advantageously in March and September, when the sun is near the equator.

SECTION III.

ON THE EARTH.

THE EARTH OF A GLOBULAR FORM—DETERMINATION OF THE EARTH'S DIAMETER BY VARIOUS METHODS—DECREASE OF GRAVITY AT THE EQUATOR ARISING FROM ITS SPHEROIDAL FORM—METHODS OF DETERMINING THE RATIO OF THE TWO DIAMETERS—FOUCAULT'S PENDULUM EXPERIMENT—DENSITY OF THE EARTH—CONNEXION OF NAVIGATION WITH ASTRONOMY—THE ATMOSPHERE—REFRACTION—TWILIGHT.

20. As the earth which we inhabit is that particular body of our system with whose form and size we have the most favourable opportunities of becoming acquainted, we shall, before proceeding to describe the other planets, notice those particulars which science has contributed respecting it. Nor shall we, in doing so, be deviating from the particular province of astronomy—seeing that the earth itself is a planet, subject to the same laws as the others, and occupying a definite place in the celestial sphere.

From an intimate acquaintance with her physical constitution, we may hope to be able, by analogical reasoning, to learn somewhat of her sister planets—their condition, size, and form. Moreover, the correct knowledge of the earth's diameter has supplied us with a scale for the measurement of distances throughout our system, as will be clearly shewn in a future section: viewed then in this light, it must be acknowledged that the measurement of the size, and determination of the form of the earth, are most intimately connected with the science of astronomy.

21. The most inattentive observer must have arrived at the conclusion, that the earth is not an undeviating plane or flat surface. Standing on the shore of the ocean, it will be seen that, on the approach of vessels, their masts, sails, or rigging will be in sight long before the hull or body of the vessel is seen; while the first objects which meet the sailor's eye are the summits of lofty buildings or elevated mountains. Now if the earth were an extended plane, when a vessel first came in sight, she would be a mere speck in the horizon; but, as she approached, we should not see one part sooner than another, but the whole of her at once.

The surface of the water, then, which we are apt to think perfectly level, is not so; and hence, in constructing canals, an allowance of eight inches in a mile, below the horizontal plane, is necessary, to compensate for the curvature of water when at rest. Let us suppose, for the sake of illustration, that a tolerably large portion of water were solidified, and had become capable of being cut off; the *slice*, so to speak, which should measure two miles across, would rise eight inches in the middle. This degree of curvature, or nearly this, is found to be the same on every part of the earth, and in every direction: hence we conclude, without further examination, that its form is globular, or nearly so.

22. Still further. If the earth were an extended plane, a ship starting from any point on its surface, and sailing constantly in the same direction, either east or west, would never return to the place from which she started, but continue to increase her distance

from it. But navigators constantly are leaving England, as well as other countries, and following the same course, making only such bends as the obstruction of the land obliges them to do, eventually return to their own country after having circumnavigated the globe.

23. The fact of its sphericity is, however, put beyond a doubt by the last proof which we shall adduce. An eclipse of the moon (§ 63) is caused by her passing through the shadow of the earth; now, whatever part of the shadow she enters, or whatever part of the earth projects this shadow (which at no two consecutive eclipses is exactly the same, nor, indeed, during the entire duration of one eclipse), the shadow thrown on the moon's disc is invariably observed to be a segment of a circle. Now no other form than that of a sphere or globe will, in every direction, cast a circular shadow; the earth therefore must be globular.

24. It may be supposed that the rotundity of our earth is rendered irregular by the elevations and depressions of the mountains and valleys on its surface: this is by no means the case; the greatest elevation of the highest mountains above the level of the sea is not more than five miles, and their mass takes off no more from the earth's rotundity, than particles of dust do from that of a small terrestrial globe.

25. The determination of the size of the earth may appear a problem incapable of solution to those who have not much attended to mathematical pursuits. In order to remove the impression of its impossibility, we shall refer to and explain a few of the methods adopted, premising that all the more minute circumstances will be entirely left out of the consideration; these are nume-

rous, and in practical surveys, are of great importance; so much so, that of late years, since the great improvements in mathematical instruments and methods of measurement, the determination simply of the form of the globe, or of large portions of its surface, has been constituted a distinct science, under the name of *Geodesy;* the province of which extends over all those exceedingly nice corrections, arising, amongst other causes, from the unequal curvature of the earth, the state of the atmosphere causing unequal refractions, the height of stations above the horizontal plane, &c. &c.; the effects of which, though minute individually, would, when accumulated in an extensive survey, produce a serious error in the result. So accurately has the diameter of the earth been measured by the greatest mathematicians of the principal countries in Europe, that, as Sir John Herschel declares, the error, if any does exist in the estimate of the earth's diameter, a space of 7912 miles, cannot be so much as 200 yards.

26. One method of determining the circumference of the globe is by measuring the distance between two towers, or any other high buildings, and taking, at the same time, the angle subtended by a line from the top of either, and a plumb-line directed towards the earth's

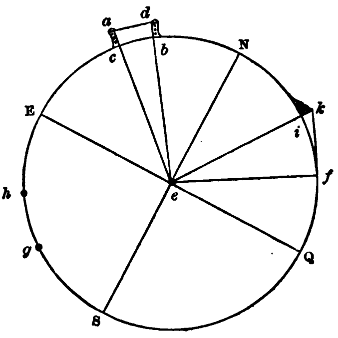


Fig. 4.

centre: thus let *a c* (fig. 4) and *b d* be two high buildings; at the building *d* measure the angle *a d e;* at *a* measure the angle *d a e;* the sum of these two angles subtracted from 180° will give (Euclid, i. 32) the angle *a e d.* Measure also the distance *b c* very accurately—then say, as the number of degrees in the angle *a e d* is to 360° (the whole angular circumference of the globe), so is the distance *b c* to that circumference measured in miles.

27. Another method, which is the one most usually adopted, is to measure the length of a degree of the meridian. Thus, let the latitude of the place *g* (fig. 4) be determined with great accuracy, by repeated observations of the heavenly bodies in a manner hereafter to be explained under the head of Practical Astronomy: determine also the latitude of *h;* for simplifying the process, we will suppose the two places to be exactly north and south of each other. If the distance between them be then measured with great care, a simple proportion will give the approximate circumference of the globe; thus, supposing the latitude of *h* to be 50° 54′ S., and that of *g* to be 56° 24′ S., then, as

5° 30′ the difference of latitude E *g*—E *h*, or *g h*,
: 360°
: : the measured distance, say 390 miles,
: 24,900 the number of miles in the whole circumference of the globe.

28. To those acquainted with trigonometry the following method will be intelligible. Let *i k* (fig. 4) be a high mountain overlooking the sea, whose height is known, *f k* a line touching the horizon in the farthest visible point; measure the angle *e k f;* and from these

data the semi-diameter of the earth may be thus found. Let $i\,k = 2\frac{1}{3}$ miles, which is the height of the Peak of Teneriffe; $e\,k\,f = 88^\circ\ 2'$, let $x =$ the semi-diameter of the earth; the angle $k\,f\,e$ is a right angle (Euclid, iii. 18), then by right-angled trigonometry,

As $k\,e : f\,e :: \text{rad.} : \text{nat. sine of} \angle\, e\,k\,f$, or $88^\circ\ 2'$;
or, as $x + 2\frac{1}{3} : x :: 1 : \cdot 999411$
whence $x = 3959$ miles, which is within a few miles of the truth.

29. It is found, however, by very careful admeasurements, that the length of a degree of latitude, ascertained in the manner described in § 27, near the equator, is different from the length of a degree measured near the poles; on the equator it is at its minimum, increasing in length as the latitude increases. In fact a section of the earth passing through both poles would not be a circle, but, as the admeasurements shew, would be an ellipse; indicating that the earth is flattened at the poles, and that it protrudes in the region of the equator.

The first intimation which astronomers received of this fact arose from the following circumstances. Astronomers sent in the seventeenth century, by the French government, to Cayenne, for the purpose of making observations on the fixed stars, found that their clocks, the pendulums of which had been so regulated as to beat seconds in the latitude of Paris, lost time at the rate of two minutes twenty-eight seconds per day. When this fact became generally known, it deeply interested the leading mathematicians in Europe, who applied themselves diligently to account for this variation: Huygens and Newton simultaneously discovered the cause.

30. Before we enter into this reason, let it be called to mind, that the vibration of a pendulum is caused by the attraction of gravity constantly tending to compel it to rest in a line perpendicular to the earth's surface, while the momentum acquired by falling towards the perpendicular on one side causes it to describe an arc on the other: if the pendulum continue of the same length, the time of vibration, within certain small limits, will be the same, whether the arc described be greater or less. But if the force of gravity were to change, the time of vibration would be altered; for it is plain that if the intensity of attraction increased, the pendulum in every oscillation would be drawn more quickly through the arc towards a perpendicular; in other words, the time of vibration would be shortened. In a given time then (say one diurnal revolution of the earth) the increase or diminution of the force of gravity would cause a pendulum to describe a greater or less number of vibrations. Now, at or near the equator, it is found that pendulums, their length being the same, vibrate more slowly than they do in higher latitudes: we conclude, then, that the force of gravity diminishes as we approach the equator.

31. The mode of reasoning by which this effect is accounted for is the following: it was originally suggested by Sir I. Newton, though later mathematicians have been able to arrive at greater accuracy than he was able to do, from the comparatively defective character of astronomical observations in his time. It will hereafter be demonstrated, that every body revolving in a circle has a tendency to fly off at a tangent to that circle, and that this tendency increases with the rapidity

of revolution. Now, as the earth turns on its axis, those parts nearer to the poles describe smaller circles than those more remote; the equatorial regions describing the largest circle of all. Now, since all the parts of the earth's surface describe each a circle in twenty-four hours, it follows that those at a distance from the poles must move more rapidly than those in the neighbourhood of the poles, and that the greatest rapidity of revolution will be at the equator; here then the centrifugal tendency will be at its maximum; and it will diminish as we approach the poles, at which points it will be at its minimum. This centrifugal force has caused matter to accumulate in the region of the equator, so that the earth's equatorial diameter is greater than its polar by 26·5 miles. And since the attraction of gravity decreases in the inverse proportion of the square of the distance from the centre of the attracting sphere, it is plain that the attraction will be weaker on bodies on the earth's surface near the equator than at or near the poles, in the proportion of the square of half the earth's equatorial diameter to the square of half the polar diameter.

32. The force of gravity at the equator is still further weakened by the direction of the centrifugal force, which is always in the same plane as the circle of revolution.

The direction of gravity is always towards the centre of the earth. Thus, whether a body be at *n*, or at *o*, or at *q* (fig. 5), the direction of the gravitating tendency is towards C, the centrifugal, though sometimes perpendicular to this direction, is not always so.

Take any portion of the earth's surface which is neither at the equator, *e q*, nor at either of the poles, but intermediate between these two positions, as *o*: this portion, by the daily revolution of the earth, describes the circle *o r g*; its tendency will be to fly off in the plane *v g r o t*, while gravity acts in the direction *o* C; here it will be seen that the centrifugal force operates not in direct opposition to that of gravity, but obliquely to it:

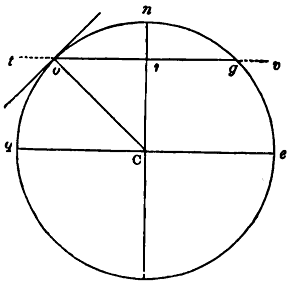


Fig. 5.

whereas if we take a portion of the earth's surface at the equator, the centrifugal tendency will operate in the plane *e* C *q* exactly at right-angles to the attraction of gravity, which will thus be diminished by its whole force.

Sir I. Newton, taking both these causes into account, demonstrated that a revolving fluid mass, of equal density throughout, would assume the form of an ellipsoid (that is, a figure of which every section passing through the poles would be an ellipse), whose diameters would be as 230 : 229. But the earth is not of uniform density; the land in this respect differing from the water, and some portions of the land differing from others: it has been ascertained from measurement, that the difference in the two diameters is not so great as his calculation made it.

33. If it be possible to measure the intensity of gravity at numerous points on the earth's surface, we

should be able from this directly to determine the effect of the combined operation of the two causes; namely, the centrifugal force, and the nearer approach of the poles to the earth's centre than of the equatorial regions.

The pendulum offers to us the means of determining this point with great accuracy; for by marking the number of vibrations in a given time at different points on the surface of the globe, the force of gravity may be detected; it will, in fact, be as the square of the velocity of the vibrations in the several places; or it may be deduced from the length of the seconds pendulum at various distances from the equator. Observations to this effect have been made in various latitudes, and the result agrees with theory, in assigning $\frac{1}{194}$ as the loss of gravity at the equator compared with what it would be at the poles; so that a body weighing 194 lbs. in the latter position would only weigh 193 at the equator; of this quantity, arising from the two causes above assigned, $\frac{1}{590}$ part must be attributed to the spheroidal figure of the earth, $\frac{1}{289}$ to the centrifugal force, and $\frac{1}{590} + \frac{1}{289}$, or about $\frac{1}{194}$ to both causes combined.

The proportion between the earth's polar and equatorial diameter is as 298 : 299; or, more correctly, the polar diameter is 7899·17, the equatorial 7925·648 miles. At the poles, the length of a degree of latitude =69·39 miles,

in latitude	80°=69·36
„	50=69·1
„	20=68·78
„	0=68·7

M. FOUCAULT'S PENDULUM EXPERIMENT DEMONSTRATING THE EARTH'S DIURNAL ROTATION.

34. If a pendulum consisting of a very heavy weight suspended by a fine wire of considerable length be put in motion, it will continue to vibrate in the same plane. Supposing the vibrations to be originally north and south, the plane of vibration will appear by degrees to have an inclination towards the west. Now, if the length of the wire be very great, and the wire itself free from torsion, and the pendulum protected from drafts of air, it ought to advance in latitude 50° 54′, 11° 38′ per hour, which advance would be caused by the earth's turning in an opposite direction. The explanation of this fact is exceedingly complicated, arising from the circumstance of the point of suspension being carried on as well as the divided circle over which the pendulum is supposed to swing; the experiment itself is seldom successful, inasmuch as after a short time, instead of oscillating in a vertical plane, the pendulum acquires an elliptical motion. The following method of delineating graphically the direction the pendulum ought to take, may perhaps render the principle of the experiment evident; which is, that a pendulum vibrating without friction at the point of suspension, unimpeded by the resistance of the air and uninfluenced by torsion, will vibrate in a plane which will not be affected by the earth's rotation on its axis.

This principle is thus expressed by M. Poinsot, in the *Comptes rendus*, Feb. 17, 1851.

"M. Foucault prend le plan d'oscillation d'un pendule libre suspendu par un fil flexible; et en effet il est assez clair que ce pendule étant écarté de sa position d'équilibre doit se mouvoir dans un plan vertical, que ne participe point à la rotation de la terre estimée autour de la vertical. Ce plan par la rotation de la terre estimée autour de l'horizontale peut bien changer de place, mais il ne change point d'orientation sur le globe."

35. Taking this principle for granted, I apprehend true results may be derived from the following considerations.

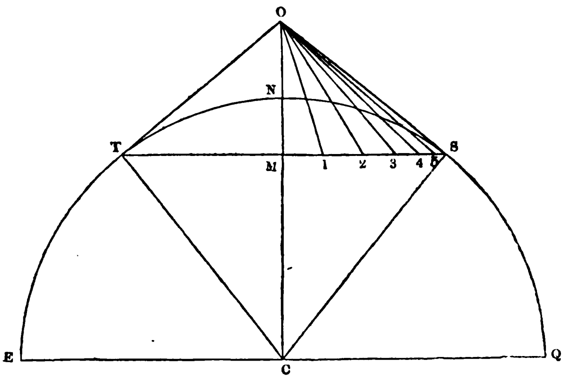


Fig. 6.

Let E N Q represent the northern hemisphere, projected orthographically on the plane of a meridian; N is the north pole, S T the parallel of 50° 54′ north latitude; the angle S C Q = lat.; S C N = colat.; draw S O perpendicular to S C, and O T perpendicular to T C, these will represent cotangents of the latitude; S M will be the cosine of the latitude; O M, O1, O2, O3, O4, O5, O S are cotangents of lat. drawn through the points occupied by the place, in this case Southampton, at periods of one hour of sidereal time distant from each other.

Now MO1 = 1O2 = 2O3 = 3O4 = 4O5 = 5OS.

Let this angle $=\theta$.

Then $\theta : 15^\circ(=\frac{360^\circ}{24}) :: \cos. \text{lat.} : \cot. \text{lat.} :: \sin. \text{lat.} : \text{rad. or } \theta = 11^\circ\ 38'$

Suppose the cone S O T developed into a plane; or let us employ for the purpose of illustration an 18-inch terrestrial globe; then S C or C Q = 9 inches; S O = 9 × cot. lat. = 7.314 inches; with this radius of 7.314 inches describe a circle on a sheet of drawing-paper, which cut round the circumference.

Find the circumference of the parallel of latitude S M T, which will be equal to cos. lat. × 9 × 2 × 3·1416 = 35·664. From the former circle cut off a part of the circumference = 35·664 inches, and divide this portion into 24 equal parts; cut through from the first division to the centre, from which draw lines to each of the 24 divisions. Assuming one of these as a starting-point, we will consider it as the initial plane of vibration of a pendulum moving in the meridian; draw parallel lines to it through each division, and it will be seen by inspection, that (from the alternate angles) each of these lines will form an angle, with each successive radius of the circle = the angle formed by that radius and the one representing the initial plane of vibration. Let n = number of hours from the commencement; the angle at any point will be $\theta n = 11^\circ\ 38 \times n$.

36. Form a cone with the divided portion of the circle. Let this cone be placed on the globe with its apex exactly over the north pole; the circumference of

the base will coincide exactly with the parallel of 50° 54′; it is represented in section by S O T.

The tangents which meet in the point O are in the plane of the horizon of the place. They are in the plane of the meridian of that place at each successive hour of the earth's rotation. The lines originally drawn parallel to each other, will be seen to deviate from the initial plane of vibration, which was originally coincident with a meridian 11° 38′ per hour; $\frac{360°}{11° 38'}$ or 30h. 57m. 16s. must elapse before the pendulum will again vibrate north or south or in the meridian.

Now the angle T O S = twice the latitude. Hence at the pole, lat. 90°, T O is in the same straight line with O S, and the cone becomes a plane; the hourly advance of the horizontal plane beyond the fixed plane of vibration will be $\frac{360}{24} = 15°$.

As the latitude decreases, the angle T O S diminishes, and the lines T O, S O, &c. lengthen as cotangents of latitude. At the equator, tangents at the points E and Q will never meet, and the cone becomes a cylinder, whose axis is infinite; here, therefore, the pendulum will fail to point out the hours.

I apprehend that this method of delineation will not only satisfy the conditions of the problem, but will render the principle as clear as it possibly can be made without recourse to the higher mathematics.

ON MEASURING THE DENSITY OF THE EARTH.

37. Nothing, perhaps, appears to savour more of presumption to the minds of those unacquainted with experimental philosophy in its higher branches, than

the announcement of the possibility of ascertaining the mean density of the entire mass of the earth ; yet this has been accomplished with wonderful precision, considering the difficulties to be encountered in such an undertaking. Indeed, without knowing this density at least approximately, we should remain ignorant of the absolute densities of the planets ; although their relative densities would be known from observations of their perturbations. Sir Isaac Newton, in one of those happy conjectures which, in men of genius, would seem to arise from inspiration, nearly approached the truth, long before any direct experiments had been performed to obtain a result so necessary to the perfection of his theory of gravity. The following are his own words : how nearly his conjecture agrees with the truth will be seen in the sequel : "Since the upper part of the earth in general is twice as heavy as water—and in the depths below it is found to be four or even five times heavier—it is probable that the quantity of matter of the entire earth is five or six times more massive than it would be if it consisted of water alone." *Principia*, iii. 10.

38. As the problem of measuring the density of the earth was performed with more than usual exactness and care in the year 1841, we shall bestow some space in describing, first, the method adopted by Dr. Maskelyne, and next, the method of Cavendish, whose plan was acted upon by the late F. Baily, Esq., with every precaution to insure accuracy.

Referring to the principles laid down in Physical Astronomy, § 158, 159, and especially in § 196, the following train of reasoning will be immediately apprehended. Suppose, from observation, that two planets, A and B, are found to operate on a third by attractions proportionate to the numbers 7 and 2, at distances which are to each other as 4 to 3; let, moreover, their diameters be as 3 to 2.

Let d stand for the density of A, and D for that of B; then the attraction of A and B on the third body will be directly as their masses, and inversely as their distances squared, from the paragraphs above quoted; hence, remembering that similar solids are to each other as the cubes of their diameters if homogeneous, or in the compound ratio of the cubes and their densities if their densities differ, the attraction of A will be $= 3^3 \times d \times 9$, and that of B will be $2^3 \times \text{D} \times 16$.

But by observation the attractions are found to be as 7 is to 2; therefore,

$$3^3 \times d \times 9 : 2^3 \times \text{D} \times 16 :: 7 : 2; \text{ or,}$$

$$486\, d = 896\, \text{D},$$

$$\text{that is, } d : \text{D} :: 896 : 486.$$

Hence then, if we know the density of one planet, we may find that of the other.

In the processes about to be described we are compelled to consider the earth to be the planet whose density is required, and instead of the other planet, we substitute some mass whose density is known (as that of a mountain or a sphere of lead), whose attraction on a third mass (as a small ball of any substance whatever) is then to be measured and compared with that of the earth on the same, making very exact allowance for the proximity of the mountain or leaden sphere, or rather finding what its attraction would amount to if it were situated as far off as the centre of the earth; which, as we shall see, § 159, is the point at which all the attraction of the earth is, so to speak, concentrated. Having then compared these attractions, and knowing the density of the mountain or lead, that of the earth may be ascertained in the manner pointed out in the case of the two planets supposed. In the year 1774, Dr. Maskelyne, the astronomer royal of that period, whose remembrance should always be respected as the originator of the *Nautical Almanac*, was commissioned by the Royal Society to try certain experiments in the neighbourhood of the mountain Schehallien in Scotland, with a view of determining from them the density of the earth. Assuming that the spirit in the levels of his instruments would be attracted towards the mountain, or that the plumb-lines by which the instruments were rectified would deviate from a vertical plane, it is clear that zenith distances of a fixed star, taken on separate sides of the mountain, would differ from each other by double the amount of deviation.

The meridian zenith distances of certain stars were observed by him first on the north and then on the south side of the mountain. The result of all his observations—and he was one of the best practical astronomers of the time—gave a constant error of $11\frac{1}{2}''$ more than could be accounted for by the difference of latitude of his stations; that is, the mountain caused a deflection of the plumb-lines from the perpendicular of $5\frac{3}{4}''$. The mountain was then very accurately measured from the base to the summit, its component parts examined, and its specific gravity determined. These data were put into the hands of Mr. Hutton, who, after a year's labour in reducing them, arrived at the conclusion, by comparing the mass of the mountain with the deflection of the plumb-line from the vertical, that the density of the earth was in proportion to the density of the mountain as 5 to 3, or that it was five times the density of water, or nearly double that of rocks on or near its surface. Hutton only reduced forty of Dr. Maskelyne's observations; but the same result was obtained by Baron Zach, who reduced the whole, amounting to between three and four hundred.

39. The experiments with the torsion rod for determining the mean density of the earth by the late F. Baily, Esq.—an account of which was published, in January 1843, in the Memoirs of the Royal Astronomical Society—surpass all former attempts to solve that problem, in the character of the instruments used, the carefulness of the observations, and the clear account given to the public of the means employed. As this is the most recent attempt to determine the density of our planet, and as it is not likely to be repeated for some time, we shall endeavour to render as clear as possible the method adopted, which was nearly similar to that employed by Mr. Cavendish fifty years before.

In fig. 7, *a* and *b* are two small balls united by a wire, which is supported in the centre of gravity by fibres of untwisted silk; this is called the torsion pendulum. In the case we are now considering, the length of the line *f c* was seventy-six inches; the whole apparatus was made with extreme nicety, and enclosed in a case, one side of which was glazed. When large balls of lead, as *d* and *e*, are brought suddenly towards the smaller balls *a*, *b*, a vibratory motion in these is immediately produced; that is, they move backward and forward through the arc *lm*, till, after some time, they attain a state of rest in the line *i k*, much nearer to the two balls than their original position of rest, which we will sup-

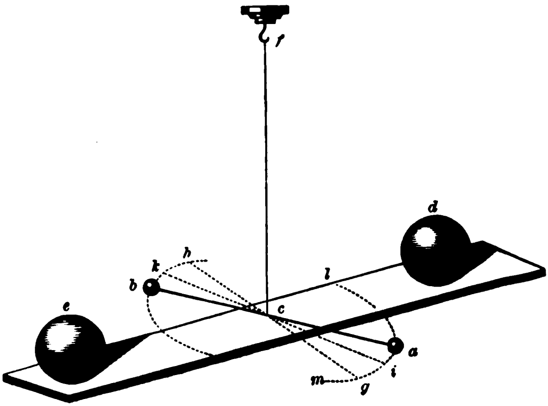


Fig. 7.

pose to be *g h*. This fact clearly proves that gravitating attraction exists in the spheres *d e*, for they are found to attract the smaller balls, and produce in them, previously to their attaining a state of rest, an oscillatory motion exactly similar to that produced in the common pendulum by the attraction of the earth; the only difference being that the attraction of the earth operating vertically, the vibrations of the pendulum are performed on each side of a vertical line. In the experiment before us, the torsion pendulum vibrates horizontally, on each side of a line where the torsion of the wire and the attraction of the spheres balance each other.

40. The resemblance between these two distinct modes of exhibiting the effect of gravity will appear

further from what has been proved respecting the time occupied in these vibrations. As with regard to a pendulum it is known, within small limits, to describe an arc of greater or less length in equal times, so it is found by observation that the torsion pendulum will describe isochronous vibrations. By a series of most elegant analytical operations it has been most clearly proved, that from the time occupied in each vibration may be deduced the force of torsion, or the power the wire exerts to recover its original position; from this, and from the displacement of the line of rest, viz. the angle *i c g*, the power of the attractive force of the two spheres *d* and *e* may be calculated. It would be impossible to offer proofs of these beautiful truths, however, without going deeply into refined mathematical calculations.* The next point to be ascertained was the attractive power of the earth; and here the pendulum comes to our aid most appropriately. From the length of a pendulum vibrating seconds at the place of observation, was deduced the force of gravity at the distance of the position of the observer from the earth's centre.

Let us now retrace our steps, and collect the results of the various experiments.

1. We have the amount of attraction of two spheres of lead, whose density is known, measured by the arc of displacement *i g*, allowance being made for torsion.

2. The amount of the earth's attraction, deduced

* Those who wish to go deeply into the subject will examine the publication already referred to; non-mathematical readers in this case, as in many others, are compelled, from necessity, to take the word of mathematicians in the place of demonstration.

from the length of a pendulum which should vibrate once in a second of time.

3. The distances of the attracting spheres from the balls, and also the distance of the centre of the earth.

4. The diameters of the spheres* and of the earth.

Required, from these data, the density of the earth.

Now this case is exactly analogous to that of the two planets operating on a third, with which we set out: we know the force of attraction of the earth and of a leaden sphere on the suspended balls; the diameters are known—the distances of the attracting bodies; from the considerations, then, before adduced we may calculate the density of the earth compared with that of the leaden sphere. It only remains, by a very simple reduction, to compare this density with that of water, the usual standard, and the problem is solved.

Many, who readily receive that part of the theory of gravity which asserts the attraction of one planet on another, feel a difficulty in allowing the universal diffusion of that attraction through every portion of matter, however small; the experiment just described may convince them of the truth of the principle. In the instance quoted great pains were taken to prevent any agitation from the surrounding air by enclosing the apparatus in a case; the effects of radiation of heat, of electricity, or of magnetism, were guarded against by interposing wood, flannel, and gilding between the balls; yet the attractive power passed through all these media, and produced the phenomena which have been

* Two spheres were used to make the amount of attraction more evident; by halving the amount we may introduce only one into the calculation.

explained. The sensitiveness of the torsion pendulum may be imagined from the fact, that it never was in a state of absolute rest, from, perhaps, the displacement caused by persons or things in motion around it, though not in its immediate neighbourhood. The line of rest was in every single experiment ascertained by taking the mean of its vibrations. The small balls were constantly changed; the materials being, in different trials, ivory, lead, glass, platina, brass, and zinc. Numerous experiments were tried with each, the means of suspension being either a brass or iron wire, or a double silk thread. The whole number of experiments recorded amounts to 2063, the mean density of the earth being deduced from each set separately; the mean of the whole gives 5·6747 for the density of the earth compared with that of water. The result arrived at by Cavendish was 5·48.

We see, then, that by two methods entirely distinct, the attraction of mountains and the torsion pendulum, results differing but slightly from each other have been obtained. We may therefore rest assured that we are now acquainted with the density of the earth to within a very minute fraction; it is, in fact, about the density of silver ore throughout. One conclusion we must immediately assent to from this consideration, namely, that the earth is a solid body, not a hollow sphere. The average specific gravity of rocks on the surface is less than 3; but as the density of the earth is much greater than this, it follows that the internal matter of the earth is more dense than the superficial layers, and that therefore the earth is solid throughout.

How wonderful is that intellect which God has bestowed upon man, who is thus able to weigh, as it were in a balance, "the great globe itself!" The dictum of the ancient philosopher, "Give me where to stand, and I will move the earth," sinks into commonplace when compared with this single triumph of modern analysis united with practical skill.

ON THE CONNEXION BETWEEN ASTRONOMY AND NAVIGATION.

41. The connexion of navigation with astronomy demands a few observations on the subject of that science.

The latitude of a place is its distance from the equator measured in degrees. This circle may be looked upon as a natural division of the earth into two hemispheres, and all nations have agreed in reckoning latitude from it. In computing longitude, however, that is, the distance of any particular meridian from any other meridian, it is evident that no starting-point has been pointed out by nature; and hence different nations commence their longitude from the meridian of different places. The French reckon from the meridian of Paris; we reckon from Greenwich, because there is situated the great national observatory, and there it is that those correct observations have been made on the heavenly bodies, which enable the navigator of the trackless ocean to know the exact point which he at any moment occupies on the surface of the globe. In short, the whole of the scientific part of navigation is included in determining the latitude and longitude of the ship; inasmuch as when these are known, its position may be found on a chart, or map of the ocean. The method of determining these is by correct observation of the heavenly bodies, their altitude, distances from each other at certain times, &c., some notion of which will be conveyed under the head of "Practical Astronomy."

These observations would be of little use without accurately calculated tables of the places of the heavenly bodies. These calculations are given in the *Nautical Almanac*, which is annually published by our government, who, with a laudable anxiety befitting the ruling powers of the first maritime nation in the world, that it might pass into the hands of the greatest possible number of navigators, allow it to be sold at the low charge of half-a-crown, which cannot be more than a small fraction of its cost to government. It is not to be supposed, from its title, that the *Nautical Almanac* is useful only to sea-faring men; no observatory can dispense with its assistance, nor can the amateur perform any problem in practical astronomy without consulting its valuable contents. So correct are the calculations whose results it makes known, that they may be considered, apart from their practical utility, as a standing honour to our nation. Here the labours of the astronomer, in his well-furnished observatory, and of the abstract calculator by his study fireside, unite in assisting the man of enterprise in navigating the boundless ocean.

The *Almanac* is published three or four years in advance, so that ships outward-bound on long voyages may insure the possession of this valuable treasure before they leave the harbours of their native country.

The following extract from an address of Sir John Herschel, in awarding the Astronomical Society's gold medal to Mr. Baily for his *Sidereal Catalogue*, most beautifully and forcibly alludes to the utility of the fixed stars in astronomy and its cognate sciences:

"The stars are the landmarks of the universe; and, amidst the endless and complicated fluctuations of our system, seem placed by its Creator as guides and records, not merely to elevate our minds by the contemplation of what is vast, but to teach us to direct our actions by reference to what is immutable in his works. It is, indeed, hardly possible to over-appreciate their value in this point of view. Every well-determined star, from the moment its place is registered, becomes to the astronomer, the geographer, the navigator, the surveyor, a point of departure which can never deceive or fail him, the same for ever and in all places; of a delicacy so extreme as to be a test for every instrument yet invented by man, yet equally adapted for the most ordinary purposes; as available for regulating a town clock as for conducting a navy to the Indies; as effective for mapping down the intricacies of a petty barony as for adjusting the boundaries of Transatlantic empires. When once its place has been thoroughly ascertained and carefully recorded, the brazen circle with which that useful work was done may moulder, the marble pillar totter on its base, and the astronomer himself only survive in the gratitude of posterity; but the record remains, and transfuses all its own exactness into every determination which takes it for a groundwork, giving to inferior instruments, nay even to temporary contrivances, and to observations of a few weeks or days, all the precision attained originally at the cost of so much time, labour, and expense."

THE ATMOSPHERE—REFRACTION.

42. The earth, as well as several, if not all, of the planets, is surrounded by an atmosphere—a gaseous covering which enwraps the globe and exercises an important influence on astronomical observations.

The atmosphere is capable of admitting light and reflecting it in every direction. Were it not for the latter property, the shadows of objects on our earth would be a deep black; but by the reflection of rays from every particle composing the air, they are mellowed into a sober tint, and by no means entirely deprived of light.

The air possesses weight, as the barometer discloses, and is also compressible; it follows from these two properties that a lower stratum of air, having to bear the pressure of all above it, must be more dense than the superincumbent strata. Experiments with the barometer lead us to the conclusion, that there is a constant proportion between the height we ascend above the level of the sea and the weight of the atmospheric column; this is that, the conditions of the air as regards moisture and heat being the same, the density of the atmospheric column will diminish in geometrical progression, as the heights above the level of the sea increase in arithmetical progression. By calculation founded on this proportion we learn that the atmosphere extends to the height of about forty-five miles above the surface of the earth.

43. As no ray of light can approach us from a star or other celestial body without traversing the atmosphere, it is in relation more particularly to the trans-

mission of light that the atmosphere bespeaks our attention.

When a ray of light passes from a rare medium into a denser, it becomes refracted or bent out of its course towards a perpendicular. Now although we are not at present aware of the nature of the celestial space which extends beyond the atmosphere—whether we suppose it to be a vacuum, or that it is occupied by an extremely subtle ether—this we are quite sure of, that it is incalculably rarer than the air we breathe, or than that which floats many miles above the surface of our globe; even the extremest tenuity of our atmosphere would be dense compared with the medium through which the heavenly bodies move, otherwise their advance would be impeded so perceptibly, that a correction on that account must long since have entered into the calculation of the planets' places: but this allowance it has not been found necessary to make, except in the case of a few comets—bodies of the most extreme rarity. From this medium, then, whatever it may be, a ray of light entering the comparatively dense atmosphere becomes inclined towards a perpendicular; and inasmuch as the density of the atmosphere increases as it approaches the surface of the earth, the course the ray will assume will not be a straight line, but a gradual curve; the refraction becoming greater and greater as each denser stratum of the atmosphere is successively entered. Now inasmuch as all bodies are seen in the direction in which the rays from them enter the eye, a heavenly body will appear in the direction of a tangent to the curve, which the ray proceeding from it described in its passage through the air; hence it is that all the heavenly bodies, except those in the zenith, appear higher than they actually are. The effect of refraction in elevating the object will always be in a vertical plane, that is, in a plane perpendicular to the horizon. The augmentation of the true altitude is, however, much greater on the horizon than at higher altitudes; for the nearer the ray approaches a perpendicular before it enters the atmosphere, the less will be its deflexion; while, in the zenith, the effect of refraction will not be experienced at all, because the rays descend vertically from the heavenly bodies occupying that position. In the mean state of the atmosphere—that is, with the thermometer at 50° Fahrenheit, and the barometer at thirty inches, the allowance for a heavenly body on the horizon is 34′. In every book of astronomical or mathematical tables, the allowance to be made for refraction is given for all altitudes, which is always subtractive from the observed altitudes, in order to obtain the true.

The amount of refraction may be rendered evident by finding, from observation, the greatest and least altitudes of some circumpolar star (see Practical Astronomy) that passes at or near the zenith: then, knowing the latitude of the place, the distance of the star from the pole at each observation will also be known. As the star is not influenced by refraction in the zenith, the differences of these distances will be the refraction at the least altitude.

44. Many rules for determining refraction have been given by various astronomers, who have deduced them from observation, and not from theory, which has not yet been successfully applied to the subject. The sim-

plest appears to be the following, which will give a fair approximation. Refractions deduced by this formula are absolutely correct only in mean states of the barometer and thermometer :

Let $57''\cdot817$ = refraction at alt. of 45°;
z = zenith distance of the object;
r = the refraction required in seconds;
then $r = 57''\cdot817 \times \tan. z$.

When the air is more dense than usual, or the heat greater or less than the mean temperature, a correction must be applied; for which reference may be made to an extensive table of refractions.

45. One beautiful effect of the translucent and refractive properties of the atmosphere is the delightful hour of twilight, without which we should be enveloped in sudden darkness the moment we lose sight of the sun. When the sun sets, however, to a person standing on the earth, his rays still illuminate the upper regions of the atmosphere, and the light supplied from them continues gradually lessening till he is 18° below the horizon. In consequence again of the elevating power of refraction, the sun appears above the horizon before (astronomically speaking) he has arrived at that circle; so that the day, especially in high latitudes, is considerably lengthened, and the night rendered proportionably shorter.

The inhabitants of tropical regions enjoy but little twilight. Refer to fig. 46, § 227, which represents the sphere of the heavens to an inhabitant of the equator. How soon will the sun sink down the 18° from *h* to *p!* after which not a glimpse of his light will appear; and even long before this so little is supplied, that in a very short time after sunset, darkness comes on. In fig. 48, § 229, which represents the latitude of London, the arc F X P is the portion the sun describes in the night of June 21; where, X R being less than 18°, there will be no absolute night, the twilight never failing, even at midnight. This will explain what the almanac means by "perpetual day," beginning or ending at such a date.

SECTION IV.

THE SEASONS.

46. WERE the earth to revolve round the sun with its equator coincident with the plane in which it revolves, or, which is the same thing, with its axis of rotation perpendicular to the ecliptic, there would be no change of seasons; the sun would be ever over the equator; north and south would be equally illuminated by his rays. The inclination of the axis from a perpendicular to the ecliptic, at an angle of 23° 28′,* is the cause of the variety of spring, summer, autumn, and winter.

47. In fig. 37, Plate IV., let A B C D represent the earth's annual path round the sun S, with the earth in four different positions, 90° distant from each other; the earth's axis remaining parallel to itself in all positions, as there represented. Beginning with the position A, the winter quarter of the northern regions, we perceive that the sun is vertical over those places

* The mean obliquity of the ecliptic for the year 1852 is 23° 27′ 29″.

$23\frac{1}{2}$ degrees south of the equator. The circle they describe in the daily revolution of the earth, *t c*, is termed the tropic of Capricorn, so named from the sign the sun enters at that time. The boundary separating the light and dark hemispheres will reach beyond the south pole $23\frac{1}{2}$ degrees. The circle at that distance from the southern pole is termed the antarctic circle, *a′r′*; another at the same distance from the north pole is the arctic circle—viz. *a r*. An inspection of the figure will establish the following particulars:

1. In the position A, it will be summer to the inhabitants of the southern regions; the rays of the sun shining more directly on them, in consequence of the southern pole being turned towards him.

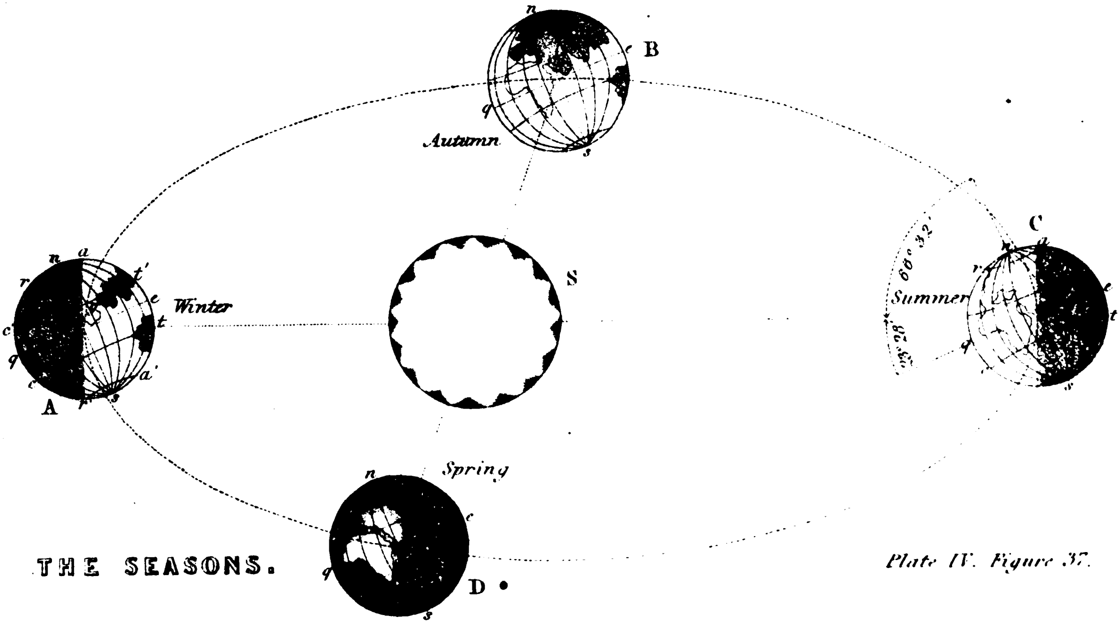
2. The inhabitants of the earth within the antarctic circle will not lose sight of the sun during the daily revolution of the earth, inasmuch as they do not retire within the darkened hemisphere.

3. Those of the arctic circle do not see the sun during the diurnal revolution, inasmuch as they fail to advance within the enlightened portion of the earth.

4. The countries above the equator will have shorter days than those below: the tropic of Cancer, for instance, will describe *t′ y′* in the daylight, while the tropic of Capricorn will describe the much larger arc *t y*. And since the motion of the earth is equable, the days will be shorter in the former position than in the latter.

5. The spaces included within the arctic and antarctic circles are termed the FRIGID ZONES; between the tropics, the TORRID ZONE; those between the tropics and polar circles, the TEMPERATE ZONES.

The position of the earth in the spring quarter is



THE SEASONS.

Plate IV. Figure 37.

represented at D. Here the sun shines over the equator. At this time day and night will be equal; for the boundary of light and darkness passing through the poles, every country on the globe passes through the enlightened portion in the same time as through the darkened half. The same circumstances will recur at B, in the autumnal quarter.

At C, the sun being over the tropic of Cancer, it will be summer to the northern regions; and the circumstances of the inhabitants of the northern and southern hemispheres will be the reverse of those described above.

48. It is a singular circumstance that, in our winter, the earth occupies that part of her orbit which is nearest the sun, as is proved by his disc subtending a greater angle at that period of the year: the difference of the distance, however, falling short, as it does, of that in summer by only $\frac{1}{30}$, can produce but little increase in the sun's heat. The principal causes of the increase of temperature during the summer quarter would seem to be, first: the sun's rays, which fall in a very slanting direction during the winter, give place to those which fall more nearly vertical; and therefore a given portion of the earth's surface will receive many more of them, and thus acquire a higher temperature. Again, the heat acquired by the earth during the long days of summer is not radiated or given out during the short nights of that season, but goes on accumulating from day to day: hence it is that in general our hottest weather is not at midsummer, but in July or August, after the earth has

been under the sun's more vertical rays for some weeks continuously. In the winter, on the contrary, the coldest weather is usually in January or February; in the long and cold nights of winter the heat radiating much more rapidly than the sun, though gradually rising higher above the horizon, can cause it to accumulate during the day.

The seasons, astronomically speaking, commence when the sun is either in the equinoxes—that is, over the equator—or at the two points 90° distant from them, called the SOLSTITIAL POINTS; viz. the first of Cancer and the first of Libra. Let two circles be drawn in the heavens, through the north and south poles, at right angles to each other, passing through these points; they will be the SOLSTITIAL and EQUINOCTIAL COLURES.

The length of the four seasons of the year will be found, from observation, to differ considerably. The following table will shew the duration of each:—

	days.	hrs.	min.
From the vernal equinox to the summer solstice .	92	21	50
From the summer solstice to the autumnal equinox	93	13	44
From the autumnal equinox to the winter solstice	89	16	44
From the winter solstice to the vernal equinox .	89	1	33

49. We ought not to pass by unnoticed a beautiful exemplification of the provident wisdom of the Almighty in the provision made for alleviating the darkness of the polar winters. During the long nights the inhabitants are by no means so destitute of light as we imagine. The sun is never so much as 18° below

the horizon of any of them, but creeps along just underneath, as will be understood by reference to fig. 47, § 228—the Parallel Sphere—which nearly represents the position of the heavens to the inhabitants of the polar regions, where *g b* is the line the sun will describe when at its greatest depression: hence they have twilight every day, more or less brilliant, during the sun's absence. Again, the full moon always happens when she is opposite the sun. When the sun, then, is below the horizon, the moon at full is always above; and when he is depressed, she never sets: hence the inhabitants of the arctic regions have the moon at, before, and after the full, shining for fourteen days in succession; and only lose sight of her during her first and fourth quarters, when she is less than half full, and can give but little light. From the above cause, we may remark, how much more of moonlight we ourselves have during the winter, when it is most required, than during the summer nights; the full moon describing, in the winter, the arc F L P, or one approaching its length (fig. 43), § 229, while the sun describes in the day the small arc G C O. The moon in the icy regions is moreover generally surrounded with halos, or concentric circles of beautifully coloured vapours, which, contrasted with the whiteness of the eternal ice-mountains, produce an appearance surpassing in beauty, according to Capt. Lyon's estimation, even the charms of an Italian sky. So bountifully has the great Author of nature provided for the delight and comfort of every member of the great human family, that even the inhabitants of these remote and desolate shores feel all the patriot's attachment to the land of their birth.

> "See, o'er Greenland, cold and wild,
> Rocks of ice eternal piled;
> — Yet the mother loves her child,—
>
> And the wildernesses drear
> To the native's heart are dear;
> All love's charities dwell here."
>
> MONTGOMERY.

SECTION V.

THE MOON.

APPEARANCE OF THE MOON — THE MOON POSSESSES NO INHERENT BRIGHTNESS—LUNAR MOUNTAINS—METHOD OF MEASURING THEIR HEIGHTS — THE MOON HAS NO ATMOSPHERE — PHASES OF THE MOON—VARIABLE ORBIT OF THE MOON—RETROGRESSION OF HER NODES.

50. THE moon, the inseparable companion and comparatively near neighbour of the earth, has, for the last 300 years, attracted the particular attention of astronomers; nor have her features lost their interest with the present generation. To contemplate these will be one of the first employments of the telescope. Nor is it necessary for the purpose that the telescope be one of extraordinary power; a 3½-feet achromatic will disclose to us her heights, her valleys, her craters, her plains. From the peculiar brightness of the moon, observers have been led to suppose that she must possess some inherent brilliancy, in addition to the power of re-

flecting the sun's rays. Such a supposition does not, however, seem necessary: the solar rays, we must remember, fall upon her without passing through any intervening medium, such as our atmosphere, which might deaden their effect; while the deep azure of the heavenly vault, forming, as it does, a dark background, makes her light appear more dazzling from the contrast. There can be no question but that the earth appears far more brilliant to the moon than our satellite does to us.

51. The phenomenon vulgarly called "the old moon in the new moon's arms," by the French *la lumière cendrée*, or "the ashy light," confirms this opinion. When the moon is from three to five days old we are able distinctly to make out the whole circle of her disc, although a small part only is illuminated by the sun. The reason is, that the light of the sun being reflected by the earth, which is at that time nearly full to the moon, is reflected to us from her surface; and even after this second reflection, it enables us clearly to make out the whole disc. It is usual to account for the red colour of the moon when in the central shadow, during a total eclipse, by supposing it to be a light derived from our atmosphere, which forms a faintly illuminated ring round the dark body of the earth at that time. It must, however, be allowed that this hardly seems a sufficient cause; and we cannot but confess that another is wanted, more satisfactorily to account for this singular phenomenon.

52. With a telescope, then—at least not inferior to a 3½-feet achromatic—let us begin to watch the moon in her first quarter. We shall see her surface covered with

elevations of a most singular character. The shadow which divides her surface when she shines as a crescent is not a definite line, but jagged and broken from passing over mountainous districts. Detached ridges of elevated portions of her surface project into the dark part and catch the sun's rays, while the hollows or valleys are in the deepest shade; as her face becomes more enlightened other ridges come into view, casting their long shadows on the regions beneath. One peculiarity will immediately strike the observer; the singular uniformity preserved in the shapes of these elevated portions of her surface—they have all a tendency to the circular form. Rising abruptly from plains, which themselves have been agitated by a general disturbance, and being unconnected with each other, these crater-like structures indicate the existence of volcanic agency, or at least of a violent upheaving force. There are many perfectly insulated conical peaks springing from the level ground to the height of many thousand feet; nor are there wanting chains of mountains, generally precipitous on one side, which descends abruptly eighteen or twenty thousand feet, while the other is a gradual slope. In the centre of many of the craters single elevations rise to an enormous height, as is shewn by the strong light which falls upon them. In such cases the original basin may have been the product of a volcanic eruption, and these after elevations may have been the result of a second, in which the matter was sent up perpendicularly, and falling back on itself, assumed the form of a conical column. In other parts of her surface long streaks may be seen, all tending to a central crater; and these can leave little doubt of their having arisen from streams of solidified lava, which proceeded in ages past from the neighbouring volcano. Her mountainous districts are without that gradual swell, or gentle ascent from a level plain, by which many on our globe are distinguished. These craters vary in size considerably, the largest measuring about eighty miles across, and the smallest visible perhaps 400 or 500 feet.

The number of the smaller circular caverns is much greater than of the more extensive—indeed it would be hardly possible to represent the whole of them on any map of the moon's surface—two thirds of which are occupied by these crater-like formations.

When first the moon was subjected to telescopic observation, the names of the most celebrated philosophers and astronomers were given to the craters with their surrounding elevated ridges, while the plains were termed seas; hence we have Tycho, Plato, Copernicus, Mare Imbrium, Mare Serenitatis, &c. Many observers have completed maps of the moon's surface; the last and best is by two German astronomers, Beer and Mädler—it is three feet in diameter, and is elaborated with true German accuracy and perseverance.

The fine reflectors of Lord Rosse, Nasmyth, Lassel, and De la Rue, shew portions of the moon's surface diversified with varied colours, indicating a variety in the soil or in the geological character of the superficial strata.

53. The annexed plate represents the moon under her most agreeable aspect, when she is nearly five days old, at which period the *lumière cendrée* is distinctly visible. It is copied from a drawing kindly supplied by Mons. C. Bulard, B.A., of Paris, reduced from one made

with the help of a 5-feet telescope, magnifying power 150; the original, with delineations of several detached portions of the lunar disc, having been presented to the Academy of Sciences by M. Arago, by whom they were highly approved for their correctness and beauty of finish. The two largest spots seen on the edge are Theophilus and Cyrillus. Theophilus, one of the numerous circular valleys which cover the surface of the moon, is surrounded by a ridge or rampart, 18,224 feet above the exterior plain, and 6102 above the valley, or interior of the crater, according to the computations of Mädler from micrometrical measurements of the length of the shadows; the distance between the ridges is 64¾ English miles; the breadth of Alphonso, not shewn in the drawing, is 84¼ miles.

The larger depressions on the edge, commencing with the upper cusp, are Mare Frigoris, Mare Serenitatis, Mare Tranquillitatis: the figure represents the moon at an altitude of 30°; the line joining the cusps will then be inclined to the horizon.

In the *Memoirs* of the Astronomical Society may be found a paper by Mr. Nasmyth, read June 14, 1844, in which he has successfully attempted to account for the peculiarities in the superficial structure of the moon. A model of a portion of her surface, now in the rooms of the Society, constructed on an exact scale by the same gentleman, conveys a most correct idea of her scenery.

54. It is a singular circumstance that the moon invariably presents the same side towards the earth, in consequence of her completing a revolution on her axis in the same time as she takes to revolve round the earth. As, however, her axis is slightly inclined to her

orbit, and preserves its parallelism, and since, moreover, her orbit is inclined to the ecliptic, we are able to look, as it were, somewhat beyond her north and south poles in the course of a month. Her thus presenting, during a revolution, a little more of her surface, north and south, to our view, is termed the moon's LIBRATION IN LATITUDE.

55. LIBRATION IN LONGITUDE is the term given to her presenting somewhat more of one side or the other to us, when her rotation on her axis is either more quickly or slowly performed than her motion in her orbit, which is by no means equable, whereas her revolution on her axis is never more or less rapid at one time than at another.

56. The moon when full, though a brilliant object, is not so agreeable when viewed through a telescope as when she is in her first or fourth quarter, because the solar rays fall then directly on her, and there is an absence of those shadows which so beautifully distinguish her mountains and her plains. If, however, the aperture of the telescope be partially closed, a practised eye will discern many minute beauties, which will amply repay hours spent in contemplating her at that period.

57. The lately-constructed monster telescope of Lord Rosse has sufficient power to bring into view a portion of the moon's surface no larger than an ordinary building; so that if towns or structures at all resembling those of human construction were there, they would have ere this been discovered. The force of probability is on the side of the moon's not being inhabited; at all events, no beings resembling ourselves can exist in her. The absence of an atmosphere—her want of

water, of which no traces have been found—the rugged character of her surface—all tend to confirm this opinion.

58. A very pleasant object for telescopic observation is the occultation of a fixed star by the moon, which is of very common occurrence. Knowing, from the Nautical Almanac, the time of such an occurrence, by carefully watching the moon, we shall observe her, as she advances in her orbit, approach the star, pass over it, and leave it behind. That she has no atmosphere is clear, from the fact that, on such occasions, the star suddenly disappears behind her, and does not fade away in degrees of light: so instantaneous is the disappearance, that the second of its occurrence is noted in astronomical tables; and, from the sudden extinction of the light of the star, we are supplied with a method of calculating the longitude. Again, had the moon an atmosphere,* the shadows of her elevations would not be, as they are, entirely dark; but mellowed off, like shadows of objects on our globe, which are never absolutely without light, through the reflective and refractive properties of the air. In the moon the brightness of direct illumination stands in direct and striking contrast with the profundity of darkness. Where there is no water nor air, there can be no animals with blood or lungs adapted to respiration; no plants which require both; no sound, for it could not be heard in vacuo; no organs of hearing; no smell, no taste: so

* The German astronomers before referred to state that it is possible that the moon may be surrounded with a weak envelope, but that the smallness of her mass incapacitates her from retaining an extended covering of gas.

that if our satellite is inhabited at all, it must be by beings with whom we could have no sympathy, and of whose physical constitution we can form no accurate conception.

59. The explanation of the phases of the moon is exceedingly simple. When, in her progress round the earth, the moon is between the earth and the sun, the whole of her unenlightened side is turned towards us, and she is consequently invisible : as she advances towards the east, which she does at the mean rate of 13·176° daily, about the second or third day she displays a fine crescent on the western limb. The light on her surface gradually increases for the space of a fortnight, until she arrives opposite the sun, at the other side of the earth, when the whole of her disc which is directed towards us is illuminated, and it is full moon. In the other half of her revolution the western side, which was first enlightened, begins to grow dark, until by degrees the darkness covers her entire disc, and she is again obscured for about four, five, or six days, which she occupies in passing between us and the sun, after which time the same appearances will recur in the same order as before.

60. Respecting the time the new moon remains invisible, no certain rule can be given, much depending on the clearness of the atmosphere, and on an individual's power of vision. An instance is on record of a lady noticing the moon near her conjunction with the sun in the morning, exhibiting a wire-like crescent; and the day after, in the evening, she observed the opposite crescent eastward of the sun soon after sunset : the same person thus having seen, on the morning of one

day and the evening of the next, the waning and the waxing moon.

The phases of the moon are illustrated in fig. 41, Plate V.

The diameter of the moon varies from 29′ 22″ to 33′ 32″; its distance, therefore, from the earth must vary very considerably; her orbit, in fact, is an ellipse, whose eccentricity is great, and the position of whose longest diameter is constantly varying. No motions, indeed, can be imagined much more complicated than those of the earth and moon. United as they are by gravitating attraction, they separately perform a revolution, smaller or larger, according as each is respectively distant, around the common centre of gravity. But in no case can either of these curves be completed, or return into itself; because before this can occur, the earth and moon have together advanced in their orbit round the sun, which orbit will be described by the common centre of gravity of the two. Moreover, when the moon is between the sun and the earth, the attractions of these two bodies operate in opposite directions; hence her orbit will be elongated towards the sun, and she will increase her mean distance from the earth: this point is her APOGEE. In the opposite point of her course, when the earth and sun attract her in the same line, her distance from the earth will be a minimum: she is then in her PERIGEE. These two positions are called SYZYGIES: at these the centres of the sun, earth, and moon, will be in a straight line. In other positions, the lines of attraction of the sun and earth form different angles when meeting at the moon, and thus tend to alter the form of her orbit in every revolution round the earth. Now, since the inequality of the attractive forces will alter the rate of the revolving body (see § 185), it follows that for no two consecutive revolutions will either the form of her orbit or her rate of advance be the same. These are a few of the causes which render the problem of calculating the moon's place for any particular time so exceedingly difficult; yet has this been accomplished with great accuracy. A few results of the labours of astronomers in the lunar theory will be given.

61. The mean inclination of her orbit to the ecliptic is 5° 8′ 48″, and therefore it crosses that circle in two points, which are the NODES of the moon : these points, from the combination of the various attractions to which she is subject, are found to have a rapid retrograde motion ; that is, her orbit on any particular month will cross the earth's 1° 28′ westward of the point of section the month before. In the course, therefore, of 18·6 years her nodes will have made an entire revolution of the ecliptic : this period is termed a cycle of the moon. The mean distance of the moon from the earth is 238,361 miles, and her diameter 2160 miles; her time of revolution round the earth, reckoning from her departure till her return to a particular star, that is, her SIDEREAL REVOLUTION, is 27 days 7 hours 43 min. 11·5 sec. ; but in the meantime the earth has advanced ·98565° (nearly one degree) daily in her orbit in the same direction ; about two days more, therefore, will be occupied before the moon will be in the same position with regard to the sun : hence the time elapsing between two successive lunations will be 29 days 12 hours 44 min. 2·87 sec.; this is termed a SYNODIC REVOLUTION.

62. A good idea of the moon's orbit may be obtained by tracing on the celestial globe the moon's place for four or five successive months. It will be found that the lines representing her orbit in no two instances will agree; the nodes will be seen to shift their position westward every lunation: her path among the stars may be traced, and many other peculiarities in her motion will be most satisfactorily elucidated by this simple means. Should it be found that the moon's path crosses the ecliptic at the time that the sun occupies the same point; or, in other words, should the sun's longitude at the time be equal, or nearly so, to that of the moon's ascending or descending node; there will be an eclipse either of the sun or the moon, as the case may be.

SECTION VI.

ON ECLIPSES.

CONICAL SHADOW OF THE EARTH AND MOON—METHOD OF MEASURING ITS LENGTH AND BREADTH AT ANY PARTICULAR POINT—CONE OF SUNLIGHT—PARTIAL, TOTAL, AND ANNULAR ECLIPSES OF THE SUN—WHEN AN ECLIPSE MUST HAPPEN—PENUMBRA—ECLIPSE OF THE MOON—PROJECTION AND CALCULATION OF THE LUNAR ECLIPSE OF MARCH 31, 1847.

63. It is an acknowledged principle in optics that the extreme lines of the shadow of an opaque body will diverge, remain parallel, or converge to a point, according as the luminous body is smaller, equal to, or greater than it in diameter. Now as the sun is much larger

than the earth or moon, and as each of these bodies is spherical, it follows that the shadows of the earth and moon will be conical, or will converge to a point.

64. The distance of the earth from the sun being known, and also the diameters of these two bodies, the length of the earth's shadow, *i.e.* how far it extends into space, and its breadth at any particular part, may be easily ascertained. For, in fig. 9, let A B be the earth, S T the sun, then will *n x p* be the conical shadow of which we wish to find the length *t n*; *s m* will be the radius of the sun, *t x* that of the earth, *s t* the distance of the earth from the sun; all which quantities are

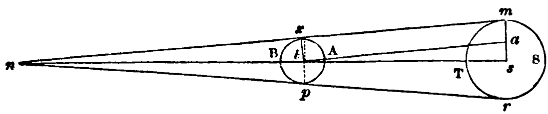


Fig. 9.

known. Draw *t a* parallel to *m x*, *s m* and *t x* being at right angles to *n m*; then, because the triangles *s a t* and *t x n* are similar (Euclid, vi. 2 and 4),

as *s a* : *s t* :: *t x* : *t n*; that is,

as the difference between the semi-diameters of the sun and earth : the distance of those two bodies :: the earth's semi-diameter : the distance of the apex of the conical shadow from the earth; or, taking the earth's radius as unity,

110 : 24096 :: 1 : 220 nearly;

so that at the distance of 220 semi-diameters of the earth the shadow ceases. Now as the moon is distant from the earth only 60 semi-diameters ($4000 \times 60 =$ 240,000 miles), it follows that she is not so far distant as to escape falling into this shadow. No other heavenly body, however, is so near the earth; it follows, therefore, that only the moon will be liable to cross the earth's shadow.

65. To ascertain the breadth of the shadow at the distance of the moon from the earth; in fig. 9 let us suppose S T to be the earth, and $t\,x$ the semi-diameter of her shadow, at a distance from the earth equal to that of the moon; then

$n\,s : n\,t :: s\,m : t\,x$; that is,

220 semi-diameters of the earth : 220—60 :: 1 : $\frac{8}{11}$;

hence, the breadth of the shadow at the mean distance of the moon will be $\frac{8}{11}$ of the earth's diameter, or $\frac{8}{11}$ of 7912 miles, or 5754. As the angles are small, we may find the angle this shadow will subtend by the proportion, as 2160 the moon's diameter in miles : 5754 :: the angular diameter of the moon : the angular diameter of the shadow of the earth at the distance of the moon. But the moon varies its distance from the earth constantly, hence arises a variation in her angular diameter. During one lunation it is found to range between 29′ 21·91″ and 33′ 31·07″; the angular diameter of the shadow will therefore likewise be variable.

66. This, however, is not the usual method of determining the diameter of the earth's shadow, which may be deduced more directly from quantities given in the *Nautical Almanac.* Letting P=the sun's horizontal parallax; p=the moon's; R the sun's semi-diameter; then the semi-diameter of the shadow will be equal to $P+p-R$.

67. The explanation of the phenomena attending an eclipse will now be easily understood. To begin with

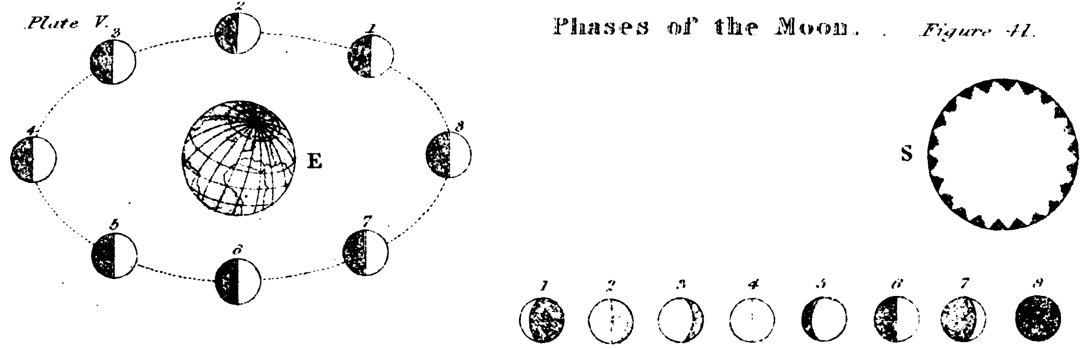
an eclipse of the sun : the rays of light sent out by the sun, and received by the earth, form the frustum of a cone of light, of which the earth's shadow is a continuation. Thus, in fig. 44, Plate V., *s n o r* will be the conical frustum of the sun's rays intercepted by the earth at *n o*, the completion of which is the conical shadow cast behind the earth into space. Now, whenever the moon passes into any portion of this cone of sunlight, there will be an eclipse of the sun to at least some portion of the earth, caused by the interposition of the opaque body of the moon between that part of the earth and the luminous body of the sun. If the moon only skims the edge of the cone, it will be a PARTIAL eclipse; but if she dips into it entirely, the eclipse will be TOTAL to all those parts of the earth over which the centre of the shadow of the moon passes, and partial only to those somewhat removed from the centre; and not visible at all to those parts of the earth on which the moon's shadow does not fall. If the centres of the sun and moon coincide at a time when it so chances that the moon's diameter subtends a less angle than that of the sun, the eclipse will be ANNULAR, a rim of light appearing round the moon's disc; a most beautiful phenomenon, witnessed in perfection in Scotland in the year 1836—evanescent, however, in its duration; for as the greatest apparent diameter of the sun can exceed the least of the moon only by 3′ 13″, which distance the moon, in passing by the sun, will accomplish in about 6 or 7 minutes, the duration of an annular eclipse, under the most favourable circumstances, can never be longer than that space of time, and generally it will be much less. The duration of the annular eclipse of May 15, 1836, was 4 minutes 12 seconds.

68. The cone of sunlight into which it is necessary that the moon should enter to cause an eclipse, can never have a greater diameter, at the distance of the moon, viz. at *a b* (fig. 44, Plate V.), than 3° 8′ 56″, or a less than 2° 48′: its centre will always be in the ecliptic. It follows, then, that if the moon's latitude, at the time of new moon, is greater than half that diameter, or 1° 34′ 28″, she will not dip into the cone of sunlight at all; or, in other words, there will be no eclipse of the sun. Now, her latitude is equal to this quantity when she is 18° 36′ from her node; if, then, at the time of conjunction with the sun, the moon be more than 18° 36′ from the node, there will be no eclipse of the sun. Again, in order that her latitude be 1° 24′, she must be 13° 42′ from the node. If, at the time of conjunction, her latitude be less than this quantity, there must of necessity be an eclipse. If her distance from the node range between 13° 42′ and 18° 36′, an eclipse of the sun may or may not occur, according to circumstances.

69. On each side of the main shadow of the moon and earth there will be a space which is partially deprived of the light of the sun, some portion of his rays being intercepted by these opaque bodies before his disc is entirely hidden: to determine its limits, we must draw lines, *s p*, *r m* (fig. 44, Plate V.) from the extremity of a diameter of the sun, crossing each other at *q*, and touching the earth's disc at *n* and *o*; these lines will form a conical shade diverging from the sun beyond the earth, the partial shadow within which is

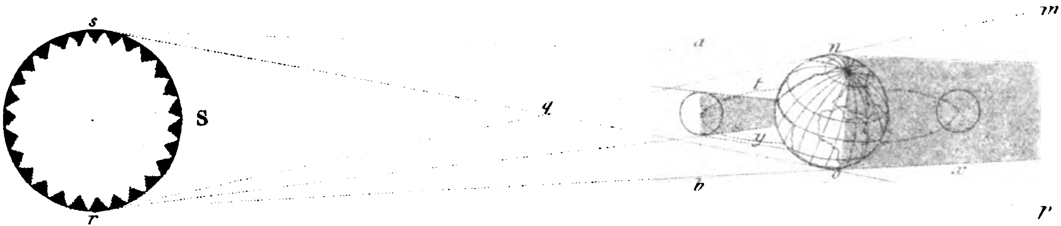
Plate V.

Phases of the Moon. *Figure 41.*



Appearances of the moon in the several positions.

Eclipses. *Figure 44.*



termed the PENUMBRA. The penumbra of the moon may be delineated in the same manner; the lines *t*, *y* will be its boundary.

70. An ECLIPSE OF THE MOON occurs when she enters the shadow of the earth. Unlike an eclipse of the sun, which is only visible to the inhabitants of that portion of the earth over whom the small shadow of the moon passes, an eclipse of the moon will be visible from all places that have the moon above the horizon, and to them all will appear of the same extent, but will occur at different local times; it thus furnishes a means of determining approximately the difference of longitude of any two places from which the lunar eclipse may be seen. Now, since the position of the moon's nodes varies, as we have seen, every month (see § 61), on no two consecutive months will they be similarly situated, at the time the moon is in opposition. If the moon's latitude be so great at that time that she does not enter the earth's shadow, there will be no eclipse; and, by a process of reasoning similar to that just adduced in the case of solar eclipses, it might be shewn that the least angular distance of the moon, at the time of opposition, beyond which an eclipse may be avoided, is 12° 24′: at every opposition, when the moon is nearer than this quantity to the line of nodes, an eclipse must occur—total, if she plunges entirely into the earth's shadow; partial, when only a portion of the shadow impinges on her disc. If her orbit coincided with the ecliptic, or if the nodes completed the circuit of the ecliptic in the same time as the earth, viz. once in a year, eclipses to the same extent would take place every month. As the case stands, after a lapse of a lunar cycle, 18·6 years,

eclipses, the same as regards extent, will again occur in the same order of time.

71. To give a general idea of the projection of an eclipse of the moon, we will take as an example that which occurred March 31, 1847, which will illustrate most of the principles laid down, and enable the student to project any other from the data of the *Nautical Almanac.* It will be necessary to refer to a future page for the explanation of several astronomical terms, such as 'parallax,' and 'celestial latitude' and 'longitude,' which will be found in the last part of this work.

72. The projection of a solar eclipse for the earth generally, is similar in principle; but the problem of determining to what part of the earth it may be visible is one of much greater difficulty, arising from the effect of parallax, which alters in a great degree the position of the moon viewed from differents parts of the earth's surface. The shadow of the moon covers a space on the earth about 180 miles in diameter; it is projected in an ellipse. The eclipse will be total or annular to those places over which the centre passes, partial to those beyond the centre, and invisible to those over which it does not pass.

CONSTRUCTION AND CALCULATION OF THE ECLIPSE OF THE MOON, MARCH 31, 1847.

73. Take from the *Nautical Almanac* the elements given in page 71.

As the earth is moving in the same direction as the moon, the inclination of her apparent or *relative orbit* will not be the same as that of her true orbit, or that which she would appear to describe viewed from a stationary position. The motion of the earth will alter her longitude, but not her latitude. Thus, while the moon is increasing her longitude from *c* to *a*, fig. 10, suppose the earth to move from *c* to *b*; the relative orbit will be *d a*, whereas the true orbit will be *e a*; the inclination of the former will be the angle *c a d*, of the latter *c a e*. Let l=the moon's horary motion in longitude, L the earth's, or, as it is termed in the *Almanac*, the sun's; i=the angle *c a d*; n=the moon's horary motion in latitude; then tan. $i=\frac{n}{l-L}$; the horary motion of the moon in this orbit will be less than her true in the proportion of *a d* to *a e*, $=\frac{l-L}{\cos. i}$.

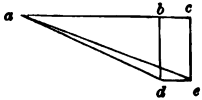


Fig. 10.

Draw the line X Z (fig. 11), representing the ecliptic, the path of the earth or sun. Take any point S as a centre, and from a scale of equal parts take a radius equal to the number of minutes in the semi-diameter of the earth's shadow, with which describe the circle *n* P R; draw S D perpendicular to X Z, making S D= the moon's latitude (in minutes) at the time of opposition; make the angle Y D K=the inclination of the relative orbit (D Y having been drawn parallel to S Z); from S let fall S M perpendicular to D K, produced if necessary; with the centre M, and radius M O = the moon's semi-diameter (in minutes), describe the circle O *q*; with the same radius describe circles touching externally the circle *n* P R, whose centres will be G and K; join S G, S K: M will be the position of the moon's centre at the time of the greatest obscuration, K and G the position of the moon's centre at the beginning and end of the eclipse; D her position when in opposition; M D

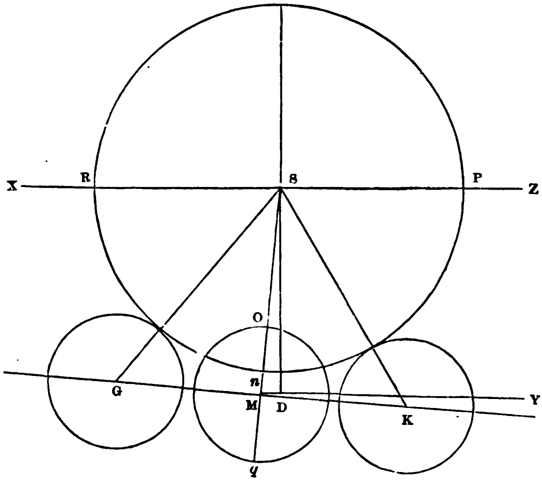


Fig. 11.

(measured on the scale of minutes) the distance between her places at the time of opposition and at the central time of the eclipse, which, compared with her horary motion in the relative orbit, may be changed into time: M K = M G, the distances between her position at the central time and at the commencement and end of the eclipse. These measurements may also be turned into time, her horary motion being known.

O n, compared with the moon's diameter, will shew the portion of the moon eclipsed, which will be $\frac{O\,n}{O\,q}$.

The degree of correctness which may be attained by this method is very considerable, but not absolute; for it assumes that the moon's distance from the earth and her horary motion continue the same throughout.

The calculation of all these quantities separately will be found in the following pages.

ELEMENTS OF THE ECLIPSE OF THE MOON, MARCH 31, 1847.

Mean time of opposition in longitude :

March 31 d. 9 h. 16·8 m.

Moon's latitude south	45′ 21″	or 45′·35 = N.
Moon's horary motion in latitude north	2 44	„ 2·73 = n.
Moon's „ „ in longitude .	29 44	„ 29·73 = l.
Sun's „ „ „ „ .	2 28	„ 2·46 = L.
Sun's equatorial horizontal parallax .	9	„ 0·15 = P.
Moon's „ „ „ .	54 9	„ 54.15 = p.
Sun's semi-diameter . . .	16 1	„ 16·01 = R.
Moon's „ . . .	14 45	„ 14·75 = r.

I. For the inclination of the relative orbit i:

$$\tan. i = \frac{n}{l - L} = 5° \; 43' \; 30''$$

II. Moon's horary motion in relative orbit :

$$\frac{l - L}{\cos. i} = 27'·397$$

III. To find DM and SM :

$$DM = \sin. i \, N = 4'·524$$
$$SM = \cos. i \, N = 45'·13$$

IV. Time of describing DM :

27·397 : 4·524 :: 60 m. : 9·9 m.

Middle of the eclipse :

9 h. 16·8 m. + 9·9 m., or 9 h. 26·7 m.

Reduction of mean equatorial horizontal parallax to a mean latitude of 45°:

$$(9\;99929) \; p = 54·06 = p'$$

Semi-diameter of shadow :

$$\frac{61}{60}(P + p' - R) = 38'{\cdot}836$$

$$SK = 38{\cdot}836 + 14{\cdot}75 = 53{\cdot}58$$

$$SM = 45{\cdot}13$$

$$MK = \sqrt{53{\cdot}58^2 - 45{\cdot}13^2} = 28'{\cdot}88$$

As 27·4 : 28·88 :: 60 m. : 1 h. 3·2 m. time of describing MK and MG ; 9 h. 26·7 m. – 1 h. 3·28 m. = 8 h. 23·5 m. time of first contact with the earth's shadow ; and 9 h. 26·7 m. + 1 h. 3·28 m. = 10 h. 30 m. last contact with the shadow.

For the magnitude of the eclipse :

$$SM - Sn = 6{\cdot}37 = nM$$

$$14{\cdot}75 - nM = no = 8{\cdot}42$$

In the *Nautical Almanac* there was an error in the calculation of the times of commencement, centre, and end of this eclipse, which was corrected in the *Nautical Almanac* for 1849, as follows :

First contact, 8 h. 23·6 m. ; middle, 9 h. 26·7m. ; last contact, 10 h. 29·8 m. The author communicated the error to the Royal Astronomical Society, but it had previously been detected by M. Franck of Lubeck.

SECTION VII.

PRECESSION AND NUTATION.

74. THE combined operation of the sun and moon on the earth, or rather on the redundant matter accumulated at the equatorial regions, produces the phenomena of Precession and Nutation.

The pole of the heavens is the stationary point immediately over the pole of the earth, round which the diurnal rotation of the heavenly bodies is performed. Now although, for general purposes, this point may be considered fixed in its position among the stars, yet more minute examinations, continued for a long period, and compared with those made ages before, indicate clearly, that the pole itself varies its position, slowly but decidedly, from time to time. The problem of finding the stationary point, and mapping it down, is not a difficult one: this has been done, and the pole of the heavens has been found to describe a wavy curve round the pole of the ecliptic, at the distance of 23° 28′ from it, in a direction from east to west, contrary to the motion of the earth in its orbit. Now, since the position of the equator is always at right angles to the line joining the poles, it follows, that as the pole moves, the equator must move with it; and as the pole of the heavens moves round the pole of the ecliptic, so the equator will be, from time to time, differently situated as regards that circle. The effect of such motion will be found to be a retrograde movement of the points where these two circles intersect each other; hence, on referring to the celestial globe, it will be seen that the first point of Aries is very far from the constellation bearing that name; because, since the first formation of the constellations of the sphere, the equinoctial points have departed as much as 30° from the position they then occupied; but as we reckon right ascension and celestial longitude from the first of Aries, which, at each annual revolution of the earth, assumes a position in antecedentia, or precedes its last, this phenomenon has been termed the PRECESSION OF THE EQUINOXES.

75. This is caused by the attractions which the sun, moon, and planets, exercise on the protuberant parts of the earth about the equator, which draw those parts towards the plane of the ecliptic; the force of those attractions, combined with the force by which the earth revolves on its polar axis, causes the equinoctial points to retrograde with a variable motion on the ecliptic, and the obliquity of the equator to the ecliptic to change continually.

If the variations in the motion of the equinoctial points and in the obliquity of the ecliptic be abstracted for a moment in idea, the poles of the equator would describe circles about the poles of the ecliptic, and the first point of Aries would retrograde uniformly. This uniform retrogradation is what is understood by the precession of the equinoxes.

76. The variations in the attractions exercised by the moon and sun on the earth, which render the movement of the first point of Aries sometimes direct and sometimes retrograde to a small extent, and the obliquity of the equator to the ecliptic sometimes greater and sometimes less than its mean state, cause the poles of the earth to describe waving lines about the pole of the ecliptic, and this effect is what is called NUTATION. The part which is produced by the moon alone is called the Lunar Nutation, and that which is produced by the sun the Solar Nutation. The former is the more considerable of the two. Now as the moon's nodes make the circuit of the ecliptic in about nineteen years, after which time she will be similarly situated with regard to that circle, and also the equator as she was before, the small elliptic curve of nutation will be completed in that period.

77. The attractions of the sun and moon tending to produce these disturbances are on the redundant matter at the equator only; but as this is attached to the inert mass of the earth, it cannot move without carrying the earth with it; and thus its motion is amazingly retarded: so slowly, indeed, is the pole of the earth carried round that of the ecliptic, that it would require 25,868 years to complete the circle. The corresponding motion of the equinoctial points is at the rate of 1° in 72 years, or 50·1″ per annum. Now since nutation completes its curve in 18·6 years, 25,868 divided by 18·6, or 1380, will be the number of smaller curves described about the circular curve of precession; each one displacing the pole not mere than 17″.

78. A tolerably correct notion of the conical motion of the earth's axis may be obtained from marking the spinning of a teetotum. The axis may be supposed to represent the axis of the earth; the flat circle at right angles to it, the equator; the plane on which it revolves may be supposed parallel to the plane of the ecliptic. Just before its motion ceases, the axis will incline from a perpendicular, and will describe a curve round the perpendicular, in the act of balancing itself, similar to that described by the earth's axis round a perpendicular to the ecliptic.

79. The effect of the precession and nutation combined will be to alter the longitude of objects, and consequently their right ascension and declination, which depend on this quantity and the latitude. To illustrate the effect of precession, tie a string tightly round the celestial globe, in the region of the equinoctial line: so arrange it that it shall cut the ecliptic at two points, say 10°

westward of the present equinoctial points, and equidistant between these let it be 23½° from the ecliptic. This will represent the position of the equator 720 years hence. Or, draw a line with colour on the globe in the direction indicated: observe, its effect in reckoning right ascension and longitude will be to increase both of them, since the starting-point, the intersection of the equator and ecliptic, is removed backward: the latitude of the stars will remain the same, but their distance from the equator in its new position will require correction. To begin with the first quadrant: a northern star, as Menkar, will have its declination increased; a southern star, as Rigel in Orion, will have approached nearer to the equator, or have diminished its declination. In the second quadrant, the stars above the equator will have a less declination, as Procyon; while Sirius, and other stars south of the equator, will have acquired additional declination. The third quadrant will require the same corrections as the second, and the fourth quadrant as the first. These corrections will be at a maximum at the equinoctial points, and at a minimum 90° distant from them. In tables of the right ascensions and declinations of the fixed stars, these corrections are stated; without them they would only be correct for the year they were published. By comparing these tables with the position of the stars with respect to the fictitious equator on the globe, a good idea will be obtained of the rate and reason of the alterations each year requires. One effect of precession is, that Polaris, the star now near the north pole, will not always hold that position; the pole will approach it still nearer yet, until its distance be only half a degree; it will then leave it, and from year to year increase its distance. In about 12,000 years, α Lyræ, one of the brightest stars in the heavens, will be the pole star, inasmuch as the pole will approach it within about 5°.

80. The observations made, then, in the most careful manner, in the best-regulated observatories, with the best of instruments, are of no practical use till they have been reduced. Observations of the places of the sun, the moon, and the planets, require corrections for parallax, refraction, aberration, precession, and nutation; the stars for all these, with the exception of parallax, to which they are not subject (see § 215). From this fact, some idea may be formed of the labour of tabulating thousands of stars, even after their apparent right ascensions and declinations have been registered from the best observatorial instruments. The following table of the time of observed meridian passage of several stars, taken at random, compared with the predictions of the *Nautical Almanac*, will tend to give confidence in the results of the labours of astronomers in this department of science. The hours and minutes are the same; the seconds and fractions of seconds of the time the stars passed the meridian of the places mentioned are subjoined, together with the time predicted in the *Nautical Almanac* for the year;

		Observations at			Prediction
1835.	Star.	Greenwich.	Cambridge.	Edinburgh.	of Nautical Almanac.
Nov. 1.	n Piscium .	30^s·05	30^s·17	30^s·12	29^s·65
	μ Ceti . .	5 ·04	5 ·33	4 ·86	4 ·92
	π Arietis .	9 ·09	9 ·02	8 ·55	8 ·18
	f Tauri . .	49 ·64	49 ·82	49 ·61	49 ·81

SECTION VIII.

THE TIDES.

81. ONE more effect arising from the connexion between the three bodies—the sun, moon, and earth—remains to be treated of before we dismiss them from our consideration.

The TIDES are certain movements produced in the waters, which in part surround the earth, by the attraction of the sun and moon on them.

In fig. 45, Plate VI., let Z represent the moon, R the earth. Now the moon attracts every particle of the earth; and the water, being free to move, will tend towards her at *o*: it will be high tide, therefore, to those places situated at *o* and its neighbourhood, which have the moon on the meridian: but since the quantity of water remains the same, the places at *n* and *s*, 90° distant from *o*, will supply the rise at *p*; with them therefore, and down the line *n* R *s*, it will be low water.

As the earth turns round with her diurnal motion, other places will advance towards the moon, or will have her in the meridian; it will therefore be high tide to them at that time. So far the matter is clear; but the peculiarity is, that when it is high tide at *o*, it will also be high at *q*, diametrically opposite, or with those places on whose inferior meridian the moon is situated.

82. To render our explanation of this fact more lucid, let us investigate the operation of attraction on three bodies, at different distances from the attractive body. (Fig. 12.)

The effect of a body, Y, operating on three others, *r*, *z*, *x*, in the same line, would be to increase their mutual distances; for *r* would be drawn to *w*, through the

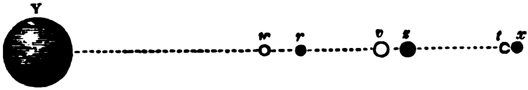


Fig. 12.

space *r w*; *z* being further off from Y, would be drawn through a less space, in the proportion of $Yr^2 : Yz^2$ (§ 158)—viz. to *v*, *z v* being less than *r w*; *x* would be still less operated upon, and would pass through a less space towards the attracting body, viz. *x t*. The result will be, that the distances of the two bodies *r* and *x* from *z* will be increased; *v w* and *v t*, their new distances, being greater than *z r* and *z x*, their original distances.

83. Let the waters on either side of the earth R, in fig. 45, Pl. VI., be considered in the same circumstances as the two bodies *x* and *r* with respect to *z* in fig 12. The operation of the attraction of the moon Z upon them and the earth will be to raise the waters at *p*, and to draw the earth, as it were, away from the waters at *r*, causing a simultaneous rising of the tides at *o* and *q*.

84. Not only is the moon an agent in producing tides, but the sun also: in consequence, however, of his greater distance, his attraction is not so much felt; the whole force of attraction being in compound proportion of the mass directly, and the distance squared inversely (§ 158). The force of attraction thus deduced will give the sun's attraction : the moon's : : 2 : 5.

85. The operation, then, of the sun and the moon will produce two sets of tides every twenty-four hours,

as each body arrives at the superior and inferior meridian of any place; in other words, as the earth revolves, every part of the earth in succession, as it comes under these bodies, or has them in the meridian, or diametrically opposite, that is, both at *o* and *q*, will have high tide; while those down the line *n* R *s*, and on the other side of the earth opposite, will have low water. It is found, however, that those two separate tides appear as one in general; when, however, these bodies are in conjunction or opposition to each other, certain phenomena occur, which are called spring and neap tides.

86. Let E in fig. 48, Plate VI., be the earth, M the moon in one of her quadratures, 90° distance from the sun, that is, when she is half full. In this case the moon will cause the waters to rise at *z* and *y*, while the sun will produce the same effect at *r* and *q*; but in a less degree; the quantity of water being always the same, the rise at *z*, under the moon's influence, will only be as much as her attraction exceeds that of the sun, that is, $5-2$, or 3.

At new and at full moon, however, when the moon is at P, in opposition, or at Q, in conjunction with the sun, their attractions will both combine to cause the waters to rise at *z* and *y*; or the force exerted by the joint attractions will be $5+2$, or 7. In the former case neap tides occur, when the water is neither very high nor very low at any place; in the latter, spring tides, when they rise much above the mean height at *z* and *y*, and sink proportionally low down the line *r* G *q*.

87. The largest diameter of the spheroid formed by the elevation of the water, *z y*, will follow the moon in her motion round the earth. Now, as the moon ad-

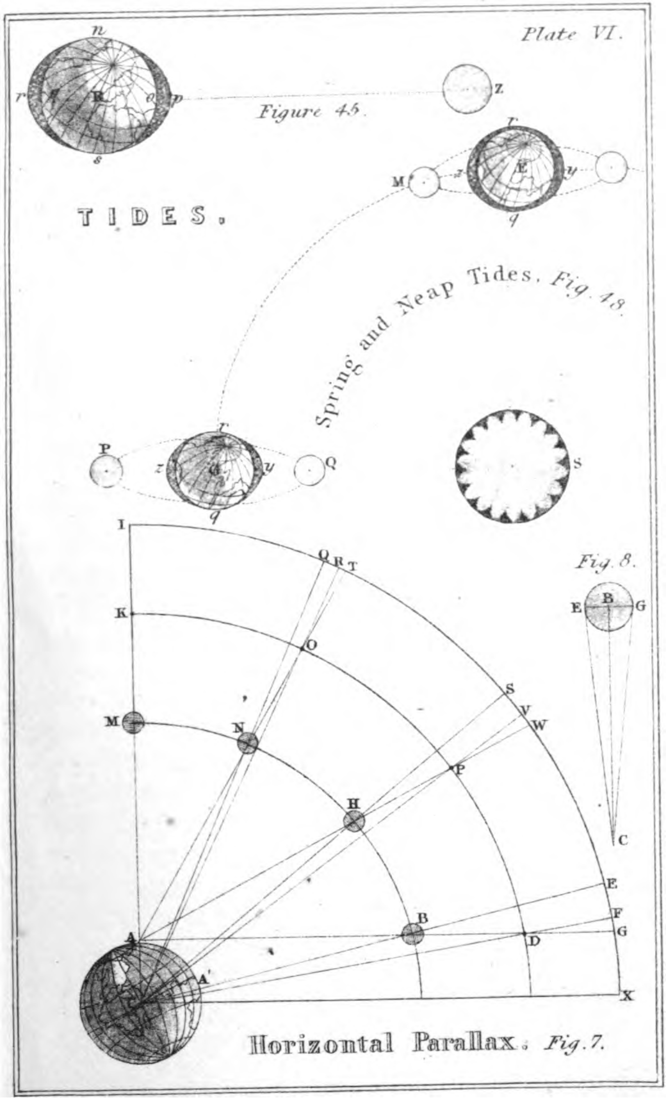


Plate VI.
Figure 45.
TIDES.
Spring and Neap Tides. Fig. 48.
Fig. 8.
Horizontal Parallax. Fig. 7.

vances about 13° daily in her orbit, the earth has to make not only a diurnal revolution, but to describe an arc equal to that described by the moon, before the place on whose meridian the moon was the day before will again overtake the moon: to accomplish this takes about fifty minutes. The mean duration of the ebb and flow will be, therefore, half of 24 hours 50 minutes; or after the lapse of 12 hours 25 minutes, a second high or low tide will occur at any particular place—the one from the direct attraction of the moon when on the meridian, the other occurring when she is on the inferior meridian, that is, on the meridian of a place diametrically opposite to the one in question.

88. In point of fact, however, the maximum height of the tide is not in general when the moon is on the meridian, but in some places as much as three hours afterwards. In consequence of the impulse given to the waters by her attraction, which indeed continues in a less degree after her meridian passage, they continue to flow; and thus accumulate for some time, till they have lost the inertia in the direction of the moon's course. In like manner, the highest spring tides do not occur at the instant of the sun and moon's acting on the waters in conjunction or opposition, but some time after.

89. Such is the general view of the theory of the tides. Various circumstances tend to modify the operation of the causes described; sometimes the declinations of the sun and moon differ very considerably, so that the tendency of the one body will be to cause a high tide above the equator, that of the other, to elevate the waters in the southern oceans. In March and Sep-

tember the flood-tides are higher, and the ebb-tides lower, than at any other period of the year; because the sun being near the equinoctial, the new and the full moon will happen at or near the equinoctial also; and thus the two bodies unite to produce their most powerful effect in the equatorial regions.

90. The tropical regions will in general be subject to the highest tides; for within the tropics the sun and moon are at all times nearer the zenith than at places further from the equator, and thus operate more directly upon the water. Within the polar circles, on the contrary, the ebb and flow of the tides are scarcely perceptible.

91. The principles thus laid down will hold good only with regard to the unobstructed ocean: where the sea is land-locked, or the extent confined, as is the case with the Mediterranean and Baltic, there will be no tides. In short, there will occur circumstances from the accident of position, from projecting headlands or opposing currents, to modify the tides at each particular place on the globe. The utmost we can accomplish in the present treatise is to present general views of the effect of this phenomenon, leaving particular cases to be studied in distinct treatises on the subject.

92. The result of what we have stated regarding the tides may be thus summed up: the sea flows about six hours, the tide during this time rising by degrees; it is then slack water, the sea remaining stationary for about a quarter of an hour, more or less; it then retires for six hours, and after another period of repose for fifteen or twenty minutes, the tide again rises, and the same course is gone over again. At the mouths of

rivers, or in straits between an island and the mainland, even this result must be modified: the course of the river will accelerate the ebb and retard the flow in a very considerable degree.

93. The tides afford a remarkable proof of the Newtonian theory of gravitation. We are not able to predict, with any thing like certainty, the exact moment of high tide at any particular port; nor is this to be wondered at, when we consider the varied operation of terrestrial obstructions or of the winds on the waters of the ocean. Yet, if the Newtonian theory be correct, there ought to be two high tides in a lunar day, each at a certain period after the moon has passed the superior and inferior meridian. Now, although the real time of high tide may, on any particular day, differ from that predicted by a few minutes, yet in the long-run it has ever been found to be high water within a certain time after the moon's meridian passage. Now, had the tides lagged only one-tenth of a second daily, in the course of the centuries during which the rising of the tides has been remarked, we should have found it on record that the highest tide had occurred at some place or places at varying periods after the moon's meridian passage; whereas, according to the Newtonian theory, the time of high water can never differ more than a certain quantity—termed the *establishment* of the port—from the time of the moon's meridian passage; and since this is found to be the case in a long succession of observations on the tides, we may with confidence account for the rise and fall of the ocean on the principles of the Newtonian philosophy.

SECTION IX.

THE INFERIOR PLANETS—MERCURY AND VENUS.

94. In consequence of the proximity of the planet Mercury to the sun, he is seldom visible to the naked eye;* indeed he can be seen only at the time of his greatest elongation, either just before sunrise or after sunset. His nearness to the horizon at that time is a great drawback to our obtaining any knowledge of his physical constitution; the vapours and clouds which float about at low altitudes being most unfavourable for telescopic observation.

The apparent diameter of the planet varies with his position, being greatest at his inferior conjunction, least at his superior (*a* and *z* in fig. 16, Plate III.). His revolution round the sun is completed in 87 days 23 hours 15 minutes 43·9 seconds. By remarking the time certain spots take to pass across his surface and reappear, his diurnal revolution has been found to be of nearly equal duration with that of the earth, being performed in 24 hours 5 minutes 28 seconds. The sun will appear to Mercury three times as large as he does to us, and the heat received will be about seven times that of our tropical regions.

95. The planet Venus is much more favourably circumstanced for observation, and hence our acquaintance with her is more extended. Her distance, like that of

* D'Alembert has left on record that he never saw Mercury with the naked eye but twice in his life. Copernicus died without having seen him at all.

Mercury, is very variable, her angular diameter ranging between 9″ and 1′ 1″. The best period for watching her is at the time of her greatest elongation from the sun, at which time she subtends an angle of about half a minute. She is the brightest of the planets, and may not unfrequently be seen at noonday with the naked eye. Her year is equal to 224 days 16 hours 49 minutes of our reckoning.

96. Venus would appear to be the sister globe of our earth; her diameter differs only by 200 miles from that of our planet; her day only by a few minutes; she is surrounded, like the earth, with an atmosphere, through which clouds and vapours float, variable as those which traverse our aërial regions, indicating the existence of water underneath, from which they derive their origin. The line separating the enlightened from the unilluminated portion of the planet, when viewed as a crescent or half full (see § 258), is not definite, like that distinguishing the light and dark portions of the

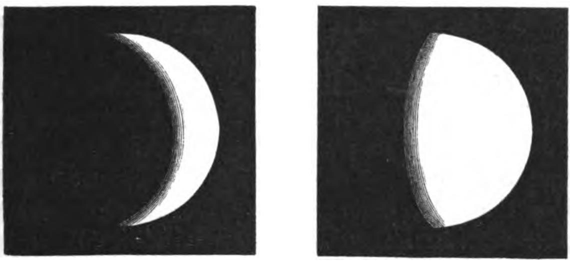


Fig. 13.—Phases of Venus.

moon, but shaded off into a gradual twilight—an appearance exactly similar to that which the earth would present to the inhabitants of the planet Mars, to whom she exhibits phases, as Venus and Mercury do to us.

When viewed as a crescent, the cusps of the planet extend far beyond the perpendicular diameter, being elongated through the effect of the planet's atmosphere: from the same cause the illuminated portion is always larger than calculation would make it.

97. The transits of Mercury and Venus may be calculated very much on the same principle as a solar eclipse; it is clear that they can only happen when the sun is in or near the ascending or descending node, at which time only the planet will cross the ecliptic. The position of Mercury's nodes is in that part of the sun's path which he occupies in May and November; hence a transit of that planet occurs in these months (see § 265). Venus's nodes are passed by the sun in December and June. With the exception of the transits, Venus goes through her changes, as regards oppositions, conjunctions, elongations, phases, &c. with remarkable regularity every eight years.

98. Mountains at least as lofty as any on our globe* diversify her landscapes. These have been discovered by the irregularity in the dark line of shadow separating her disc, which is caused by the shadows of the mountainous ridges; while single illuminated points have been observed abutting into the darkened half. Near the middle of the planet, towards the highest part, there must be a ridge of considerable elevation, as its shadow is observed to give a blunted form to the upper

* Some astronomers have considered the mountains of Venus not less than 20 miles in height.

horn of her crescent (see the drawing). These appearances being regular and fixed have enabled us to determine the length of her day, which is 38 minutes 53 seconds less than our own.

The inclination of her axis from a perpendicular to her orbit is 75°. Her equator, therefore, forms that angle with her orbit. The alternations of heat and cold in that planet must be much more powerfully felt than with us: her heat and light, derived from the sun, is about double that which we experience. There may be, however, some provision in the atmosphere both of Venus and Mercury to moderate this excessive heat: without such provision, fluids which are liquid on our globe would there become aëriform; water would exist as steam, mercury would volatilize, and resinous substances assume a liquid form.

SECTION X.

THE SUPERIOR PLANETS.

MARS: HIS ATMOSPHERE—OUTLINES OF SEAS AND CONTINENTS OBSERVABLE ON HIS DISC—ICE IN THE REGION OF HIS NORTHERN POLE—JUPITER: HIS BELTS AND SATELLITES—VELOCITY OF LIGHT DISCOVERED FROM THEIR ECLIPSES—SATURN: HIS RINGS, BELT, AND MOONS—URANUS: MOTION OF HIS SATELLITES—DISCOVERY OF NEPTUNE IN 1846.

99. PASSING to the planet Mars, which, in respect to distance from the sun, immediately follows the earth, the same points of resemblance which characterised

Venus may again be traced. He presents a gibbous appearance when at his greatest elongation; but the line which divides the darkened crescent from the illuminated portion of his disc is clear and definite, indicating the absence of asperities of any magnitude on his surface; hence, through a telescope, Mars appears either quite circular, or presents an oval disc, of which the vertical diameter is the longer. His day differs little in length from ours, being 24 hours 39 minutes 21 seconds; while the same cause which has produced an accumulation of matter in our equatorial regions has operated in the same manner on the planet Mars; his polar and equatorial diameters, when measured with the micrometer, exhibiting a difference in the proportion of 189 to 194.

100. The atmosphere of Mars would appear to be very dense and of considerable extent; when that planet passes over a fixed star its light is observed to faint away gradually before it is obscured by the body of the planet, from the atmosphere meeting it first. Such, at least, was the opinion of the earlier observers. Their conclusion, however, Sir W. Herschel felt inclined to doubt; while Sir J. South's observations in 1831 have induced many to deny the existence of a very extensive atmosphere to this planet. Sir W. Herschel allows it, nevertheless, a considerable portion; "for," says he, "besides the permanent spots on its surface, I have often noticed occasional changes of partial bright belts, and also once a darkish one in a pretty high latitude: and these alterations we can hardly ascribe to any other cause than the variable disposition of clouds and vapours floating in the atmosphere of the planet." From the

nature of his atmosphere arises in part, perhaps, the red colour which distinguishes the planet; though this may be caused by the ochry tinge of the soil underneath. Clear indications of continents and seas are disclosed by the telescope; the latter presenting a greenish hue, similar to what we may suppose our oceans would present to his inhabitants: a brilliant white spot is from time to time observed in the neighbourhood of his north pole, which decreases in size when it is turned towards the sun. With no great stretch of imagination, we can conceive this to be snow and ice, accumulated in these regions during his long polar winters of twelve months' duration, which melt before the sun as the summer season returns. The axis of Mars is inclined to the ecliptic about 30° 18′, and his diameter is 4100 miles. The length of his year is 686 days 23 hours 30 minutes 41 seconds.

101. The planet Mars varies its distance from the earth very considerably, its nearest point being when in opposition to the sun, as at x, when the earth is at *y* (fig. 16, Plate III.), when its apparent diameter is about 18″; at other times its distance is so increased that its angular diameter is not more than 6·4″; that is, when near *m*, the earth being still supposed to be at *y*.

The two German astronomers, to whose labours we are indebted for the elaborate map of the moon we have before alluded to, have produced two beautiful maps—the northern and southern hemispheres of the planet Mars. These maps are projected from various accurate drawings made during successive years from 1830 to 1839. The features of the planet are, no doubt, equal in correctness to those of the moon, and exhibit most wonderful varieties of continents, islands, peninsulas, seas, and icy regions, round the northern pole. The telescopic appearance of this planet is shewn in the drawing.

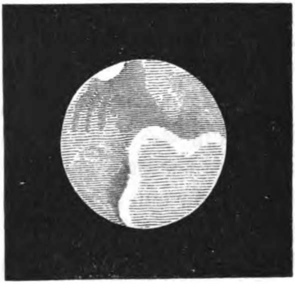


Fig. 14.—Mars.

102. We now come to the planet Jupiter, which, next to the sun, is the most magnificent body of our system. His great size, being 1280 times the volume of the earth, the clearness of his light, and his accompaniment of moons, renders him a most agreeable object for telescopic observation. He revolves on his axis in the comparatively short period of 9 hours 55 minutes 50 seconds; so that his equatorial regions move with great velocity. This has caused so remarkable a difference in the two diameters, that their inequality is visible to the eye without measurement; the polar diameter is to the equatorial as 100 to 107.

103. The belts of Jupiter are certain streaks across his disc, running parallel to his equator; they are not fixed or regular, either in size or number, but are found to vary by contraction or dilation, to run into each other, and sometimes suddenly to disappear.

They are supposed to be clouds floating about in the atmosphere of the planet; or rather, perhaps, the darker body of the planet appearing through the atmosphere. Their parallelism to Jupiter's equator may arise from currents of air, somewhat analogous to our trade-winds, setting either east or west, but with much greater constancy and regularity.

Fig. 15.—Jupiter and his four Moons.

104. The distinguishing feature of the planet Jupiter is his being accompanied by four moons, which revolve round him in periods of time varying from 1 day 18 hours to 16 days.

As the planet casts a shadow behind it, these moons are constantly suffering eclipses, and not only do they disappear by immersion into the shadow, but by passing behind the planet, and even when between us and Jupiter they are invisible, except with a superior telescope. In the latter case, the shadow of the satellite may be seen, under favourable circumstances and with a good glass, projected on the planet as a dark round spot. The times of these very interesting occurrences are given every month in the *Nautical Almanac.*

The moons of Jupiter form, with the planet as a central body, a planetary system in miniature; subject to all the laws and obedient to the same forces as those which regulate the connexion of the sun and planets, and which will be explained under the head of Physical Astronomy. Their orbits are ellipses slightly eccentric, having the planet in one of the foci; they describe equal areas in equal times (§§ 201-203), and the cubes of their mean distances are in the proportion of the squares of their periodic times.

The third and fourth are thought to be about the size of Mercury; the first and second about as large as our moon. From the proportion which has been discovered by comparing the periodic times of the first three satellites, a most singular and beautiful result has been obtained. The mean sidereal revolution of the first is about half the time of the second; which latter is about half that of the revolution of the third. Again, the mean longitude of the first, minus three times that of the second, plus twice that of the third, is always equal to 180°: hence it results, that when the first satellite is eclipsed, the other two will always dispense their light; and *vice versâ.*

105. Jupiter's equator is but very slightly inclined to his orbit, and the paths of his satellites are nearly in the plane of his equator. All the satellites except the fourth eclipse the sun at every revolution; while, from the bulk of their primary, they are themselves eclipsed at every revolution by entering his shadow. In the course of a Jovian year there will occur no less than 4500 eclipses of the moons, and about the same number of eclipses of the sun. When Jupiter is about 90° from the sun, or comes to the meridian at or

near six o'clock, his shadow is projected laterally, in a direction opposite to that of the sun: in this case the immersions of the satellites take place at a considerable distance from the body of the planet; and in the case of the third and fourth satellites they often vanish and re-appear on the same side of the planet. The orbit of the fourth is so much inclined, that he escapes, at regular periods, being eclipsed at all. The mean duration of an eclipse

Of the first satellite, is	$2\frac{1}{4}$ hours.
Of the second	$2\frac{3}{4}$,,
Of the third	$3\frac{1}{2}$,,
Of the fourth	$4\frac{1}{2}$,,

By accurate micrometrical measurements of the distances of the satellites, compared with their periodic times, the Astronomer Royal has determined the mass of Jupiter, as compared with that of the sun, to be as 1 to 1046·77. The density of Jupiter is not more than one-quarter of that of the earth; so that the force of gravity on his surface is not so great as we should conclude, from taking into consideration only his immense volume.

106. The beautiful discovery of the velocity of light arose from the observation of the eclipses of Jupiter's satellites. When Jupiter is in opposition (viz. at x, fig. 16, Plate III.), it was discovered by a Danish astronomer, Romer, in 1675, after a series of observations extending through many years, that the eclipses happened much sooner than the calculated time; on the contrary, when the earth was at its greatest distance from Jupiter, the eclipses were always later than he expected. The explanation given by him, and con-

firmed by the subsequent discovery of the aberration of light, was, that the time in the latter instance was lost by the last ray sent out by the satellite before its immersion into the shadow of Jupiter, having to pass through a distance greater than in the former case by the whole diameter of the earth's orbit, before the eclipse could be announced to the inhabitants of the earth. The time occupied by a ray of light in traversing this space of 190,000,000 miles has been found to be 16 minutes 26 seconds; so that, since the time of this discovery, when the eclipses of Jupiter's satellites are calculated, allowance is made for the distance of the planet from the earth, before the occurrence is tabulated. These eclipses are so nicely calculated, that the instant of ingress or egress of a satellite is known to a second; and hence they are made use of to determine the longitude of any place on the globe, as will be shewn more at large under the head of Practical Astronomy.

107. The planet Saturn exhibits a phenomenon which never would have entered into the mind of man to conceive, had not the telescope revealed it to us: it is surrounded by a ring, or rather by several concentric rings, somewhat similar to the horizon around a globe, but at a greater comparative distance. That these rings are opaque is proved by the shadow cast by them on the body of the planet; at the same time the shadow of the planet on the rings may be distinctly seen. The attention of astronomers has lately been directed to this planet in consequence of its favourable situation for observation, while most powerful telescopes have assisted their investigations. Mr. Lassell of Liverpool has

discovered an eighth satellite; Mr. Bond of Cambridge, Massachusetts, and the Rev. W. R. Dawes, independently of each other, have remarked a dark ring between the well-known ring and the body of the planet. It is, however, transparent; for the portion which crosses the planet is of a lighter shade than the rest, as shewn in the drawing. What was originally considered as the ring of Saturn is now found to consist of certainly two, and probably several, distinct rings, though the divisions in the outermost ring are made out only occasionally and with difficulty. These rings are found to revolve round the planet in a period equivalent to that of a satellite at the mean distance of the rings from the planet. Through this revolution they are able to maintain themselves in *stable equilibrium*, and there will consequently be no fear of their falling upon the planet, from which they are preserved by centrifugal force, in the same manner as the moon is kept at a distance from the earth. Were the rings stationary, the slightest disturbance from attraction of a body beyond would cause them to fall upon the planet, and not recover their position.

108. Saturn also exhibits belts like Jupiter; and thus we may suppose him also to have an atmospheric envelope, like the other members of the planetary system.

109. The figure of Saturn is the flattest of all the planets at the poles; for, in addition to the centrifugal force, which is very considerable, seeing that he revolves in 10 hours 19 minutes 17 seconds, the attraction of the ring over his equator has aided the accumulation of matter in that region: hence, from these two causes arises the remarkable difference in the polar and equa-

torial diameters of the planet, they being in the proportion of 10 to 11. The diameter of Saturn is 78,730 miles : his periodic time 29 years 174 days 1 hour 51 minutes 11 seconds.

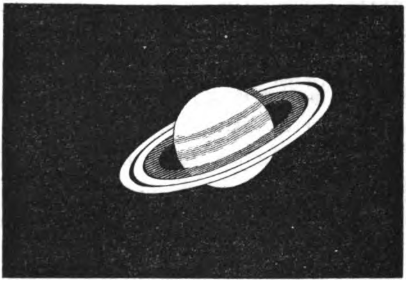


Fig. 16.—Saturn.

110. Of Saturn's satellites, eight in number, little is known : the largest, which is termed the Huygenian satellite (from Huygens, its discoverer), and may generally be reached by a 3½-feet achromatic, or any superior telescope, is the most distant; the next nearer to the planet may often be seen; the next three require very powerful telescopes to reach them; and the two which just skirt the ring, and the last discovered, require the most powerful assistance of optical instruments, and that too under very favourable circumstances.

111. Saturn is next in size to Jupiter, being about 995 times the volume of the earth. His orbit is but little inclined to the ecliptic; but the rings form an angle of 28° 40′ with the plane of the earth's orbit; hence they are, for the most part, presented to us in an elliptical form. In certain positions, however, of the Earth and Saturn, the edge of the rings is presented to

us: they then disappear, except to telescopes of the most extraordinary power, by which the edge may be perceived as an infinitely fine line. Dr. Herschel thus remarked it in 1789, and had the pleasure of watching the two nearer satellites threading it like beads, as they revolved in their orbits in its immediate neighbourhood. Again, on April 29, 1833, the rings entirely disappeared, so as not to be discoverable in Sir J. Herschel's twenty-feet reflector, with an aperture of eighteen inches.

112. In 1848 the Rev. W. R. Dawes and Mr. Lassell watched the disappearance of the ring with great care; and from their observations it is concluded that the edge of the ring disappears, not from its thinness, but from its incapacity of reflecting light; that it is probable, moreover, that an atmosphere surrounds the rings, which, during the time that the edge is presented to the earth, refracts a certain amount of copper-coloured light, which seems to border the rings at that time.

113. Of the planet Uranus its illustrious discoverer communicated to the world all that has hitherto been known: only six satellites have been actually disclosed, and even of the existence of four of these some doubt had been expressed till the re-discovery by Mr. Lassell of two of them; so difficult is it for the telescope to penetrate the remoteness of the space which that distant body occupies. Travelling his remote career, he consumes eighty-four years in completing his revolution, perhaps accompanied by more satellites than even the planet Saturn. The time may, indeed, come when still more powerful glasses, directed to the heavens, will disclose particulars respecting this distant body infinitely

surpassing our present conceptions. As it is, we seem to obtain a glimpse of another order of things in the revolution of his satellites, whose motions are performed contrary to the general movements of our planetary system, from east to west; while the inclination of their orbits to the ecliptic, 78° 58′, differing not much from a right angle, is another deviation from what would seem to be the arrangement subsisting with regard to all the other bodies, whether primaries or satellites.

114. Nor, if due attention be paid to the subject, will it appear surprising that so little has been added to the original remarks of Sir W. Herschel. This planet has not till lately been favourably situated for observation; while the number of telescopes able to bring his moons to light is very small; for they may be reckoned among the faintest objects in the heavens.

Sir William (at that time Dr. Herschel), in compliment to George III., named his newly-discovered planet Georgium Sidus: Uranus is the name by which it is now known.

DISCOVERY OF THE PLANET NEPTUNE.

115. The latter part of the year 1846 was rendered remarkable in the annals of astronomy by the discovery of a new planet, under circumstances which tended to elevate the character of scientific pursuits in the eyes of those who judge of their merit only by the result.

The problem of determining the disturbing effect upon one planet by another, when their masses and positions are given, has long been known; and, indeed, is the basis of the calculation of the places of the planets given for every day in the *Nautical Almanac*.

The place of Uranus, thus ascertained, after due allowance had been made for the disturbing effect of Jupiter and Saturn, was still found to be wide of his true place as determined by observation; a residuum still remained to be accounted for, and this had increased to a large amount in the year 1846. Entirely independent of each other, two mathematicians, M. Le Verrier of Paris, and Mr. J. C. Adams of St. John's College, Cambridge, undertook to solve the reverse of the problem stated above, namely, given the disturbance of the planet in its orbit, required the position and mass of the disturbing body; and both of them effected the solution with astonishing precision, bringing to bear upon the subject an amount of mathematical knowledge which excited the admiration of all who were competent to judge of their labours, and the astonishment of those who were not.

116. M. Le Verrier was the first to make known his results to the public. No sooner had he completed the determination of the position of the unknown planet, on September 23, 1846, than he wrote to Dr. Galle of Berlin, requesting him to turn his telescope about 5° east of δ Capricorni, and that there the planet would be found. Dr. Galle, acting in obedience to this direction, detected the planet the same evening near the spot indicated.

117. Dr. Galle's search was much facilitated by his having just received the 21st hour of the Berlin maps of the stars from Dr. Bremiker, in which all the stars in the neighbourhood of the ecliptic, down to the tenth magnitude, are inserted. Had this map reached this country a short time previously, the honour of prior

discovery would have indisputably fallen to the lot of an Englishman. It appears that Mr. Adams, having completed his calculation in 1845, had laid it before Mr. Challis and the Astronomer Royal at the latter part of that year. At the suggestion of the Astronomer Royal, Professor Challis instituted a search for the planet, with the Northumberland equatorial, at Cambridge. Not being provided with the 21st hour of the Berlin maps, he began mapping down all the stars near where the planet was expected, and on August 4th recorded the place of the planet, and again on August 12th. "I did not," says Professor Challis, "make the comparison till after the detection of it at Berlin, partly because I had an impression that a much more extensive search was required to give any probability of discovery, and partly from the press of other occupation. The planet, however, was *secured*, and two positions of it recorded six weeks earlier here than in any other observatory, and in a systematic search expressly undertaken for that purpose."

118. Some little irritation was felt and expressed by our neighbours at the time, in consequence of our claiming for Mr. Adams an equal participation in the honour of the discovery with M. Le Verrier, which did not, however, extend to the principals, who associated on the best terms at the Oxford meeting of the British Association, which was distinguished for the number of astronomers, native and foreign, there assembled, who testified their admiration of the labours of these two eminent men.

119. The next step was to calculate backward the place occupied by Neptune, which was the name agreed

upon for the stranger planet, in past years, and to ascertain whether it had been seen at any former period. It was found that Lalande had marked it in his catalogue of stars on May 8th, 1795, and again on May 10th; but finding that the places given by the two observations did not agree, he rejected one, which accordingly was not printed in the *Histoire Céleste*, but was found on examination of the original manuscript; and the difference of the places corresponded exactly with the planet's motion in the interval.

These observations have done good service in enabling calculators to determine the elements of the planet more accurately, which must otherwise have depended on a few observations, and those not far apart.

120. M. Le Verrier gave the following elements of the planet before its actual discovery:

Mean longitude . . .	318° 47′, Jan. 1, 1847.
Perihelion	284° 45′
Semi-axis major . .	36·154
Eccentricity	0·10761

Mass $\frac{1}{3900}$ Periodic time, 217·387 sidereal years.

The predicted longitude for the day of its discovery was 324° 58′, the observed longitude 325° 52′ 45″; the agreement between the predicted and true place is most wonderful, when the nature of the problem is considered.

The following are the true elements of the planet deduced from the later observations by Mr. Adams:

Mean longitude, Jan. 1, 1847 (G. M. T.) . .	328°	13′	54″
Longitude of perihelion on the orbit . . .	11	13	41
„ ascending node	130	5	39

Inclination to the ecliptic	1° 47′ 1″
Mean daily motion	21.″3774
Semi-axis major	30·2026
Eccentricity of orbit	0·0083835

Time of revolution, 165·96 years.

Mr. Adams's elements of the planet calculated before the discovery, September 1845, were,

Mean distance (assumed nearly in accordance with Bode's law)	38·4
Mean longitude, Oct. 1, 1845	323° 34′
Mean daily motion	14.″932
Longitude of perihelion	315·55
Eccentricity	0·161
Mass, that of the sun being unity	·00016563

121. Mr. Adams, considering the eccentricity resulting from his first calculations to be far too large to be probable, went through a new set, in which he assumed a distance less than the former by about $\frac{1}{30}$ of the whole, and thus wrote to the Astronomer Royal, Sept. 2, 1846: "The result is very satisfactory, and appears to shew that by still further diminishing the distance, the agreement between the theory and the later observations may be rendered complete." By this later calculation the mass was reduced to 0·00015003, and the eccentricity to 0·12062.

The true distance, it will be observed, is less than either calculated. Both Adams and Le Verrier took the result of Bode's law (*Physical Astronomy*, § 204), as a first approximation to be corrected by ascertaining the agreement between the calculated places of the planet and its observed. Mr. Adams was gradually approximating the truth when the planet was discovered, as the above extract from his note to Mr. Airy will shew. Bode's law in this case entirely fails; when, however, it is taken into consideration that nearly the same effect may be produced during part of one synodic period by the attraction of a smaller body, if its distance be less, as by a larger body at a greater distance, the discrepancy is easily accounted for; and this splendid discovery, differing as it does from any other on record, will ever illustrate the names of Le Verrier and Adams, and remain a monument of the triumph of theoretical astronomy.

From the time of the discovery of Neptune, Mr. Lassell of Liverpool has watched it carefully, and has discovered one satellite, of which the orbit has been determined with considerable precision. At one time he entertained strong suspicions of the existence of a ring similar to that of Saturn, and of another satellite; these suspicions have not been confirmed by his observations at Malta, where he is now, Dec. 1852, busily engaged in studying the peculiarities of Saturn, Uranus, and Neptune, through an atmosphere far more transparent than that of England. The probability is, that if other satellites exist, they are much smaller than the one which has rewarded Mr. Lassell's labours.

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122. The question must long since have suggested itself to the reader's mind—"Are these planets inhabited; and if so, by what kind of beings?"

Setting aside all imaginative views, and confining ourselves simply to acknowledge facts, let us see whether sound philosophy does not enable us to supply an answer to this inquiry. To suppose that the all-wise Creator has placed those mighty orbs in the heavens merely to be viewed by us, the inhabitants of one small world, would derogate from the perfections of Him who maketh nothing in vain. As far as investigations into nature have extended, we find the whole material world teeming with life; a drop of water may contain its hundreds—the air, the verdant fields, their thousands of living creatures delighting in existence; can we, then, suppose that the planetary globes are "cities of the dead;" that there the voice of joy, the piercing vision, the brightness of intelligence, are things unknown?

The discoveries of science are opposed to this conclusion. The nature of light—whether derived from our sun, the planets, or the fixed stars—is found to be precisely the same—resolvable, by the prism, into the primary colours. The organs of vision, then, of the inhabitants of the planets must, to a certain extent, we should imagine, be, like ours, adapted to the reception of this light. They feel, too, the sun's absence; and hence the all-bountiful Creator has provided those more remote from his influence with attendant satellites, to cheer the darkness of their night. Let the imagination picture the beautiful night of the planet Saturn: the dark sky illumined by several moons; some rising, others setting, some full, others crescent-like, appear amidst the starry firmament; his rings, arching the heavens as girdles of light, reflecting the sun's rays, and indicating, by the varied appearance of their surface, their own revolution. Contemplating this scene, say whether that planet is the habitation of beings who, like ourselves, are formed to admire the Creator's works, and to adore Him through them; or whether it is the gloomy retreat of silence and desolation.

Regard, again, the atmospheres of the planets. Reasoning from analogy, we should conclude that the inhabitants of those distant worlds possess powers which, like our own, require renovation by breathing a vital air; that they have the faculty of admiring their landscapes, varied by mountains and valleys in some cases, by the flow of the ocean in others, by the succession of day and night in all. With these discovered points of resemblance to the circumstances in which we are placed, there are, no doubt, others still, and perhaps for ever, hidden from mortal view, which, if known, would confirm the similarity between them and our abode, and demonstrate the existence of a beautiful congruity in every portion of the created universe.

Much absurd speculation has been employed on the character and physical peculiarities of the inhabitants of the planets, which has tended to render the public mind generally less open to the legitimate deductions of science with regard to them. The severest reasoner must, however, we should think, join in the conclusion, that all the planetary bodies are the abodes of intelligent beings—alive to physical sensations, capable of locomotion, and doubtless gifted with faculties which enable them to contemplate the great Architect of nature through the medium of His works.

SECTION XI.

THE ASTEROIDS.

123. Between the orbits of Mars and Jupiter there have been discovered within the present century no less than twenty-three planetary bodies of extremely small size, of which the accompanying table exhibits certain particulars:

Name.	Date of discovery.	Name of discoverer.
Ceres	1801	Piazzi of Palermo.
Pallas	1802	Olbers of Bremen.
Juno	1804	Harding of Lelienthal.
Vesta	1807	Olbers.
Astræa	1845	Hencke of Dresden.
Hebe	1847	Ditto.
Iris	1847	Hind of London.
Flora	1847	Ditto.
Metis	1848	Graham of Markree.
Hygeia	1849	De Gasparis of Naples.
Parthenope	1850	Ditto.
Victoria	1850	Hind.
Egeria	1850	De Gasparis.
Irene	1851	Hind.
Eunomia	1851	De Gasparis.
Psyche	1852	Ditto.
Thetis	1852	Luther of Bilk, Prussia.
Melpomene	1852	Hind.
Fortuna	1852	Ditto.
Massilia	1852	De Gasparis of Naples and Chacornac of Marseilles.
Lutetia	1852	Goldschmidt of Paris.
Calliope	1852	Hind.
Thalia	1852	Ditto.

The whole of these members of our system complete their revolution round the sun in periods varying from 1200 to 1600 days: the orbits of several of them are much inclined to the ecliptic, in which they differ from the old planets; thus—that of Hebe has an inclination of 15°, of Vesta 70°, of Pallas 34°; of Iris, however, only 5°.

124. It will be observed that of these twenty-three, nineteen have been discovered within the last seven years: they indicate the investigating spirit of the age and the improvement of instrumental appliances. Nor let it be supposed that chance has had any thing to do with these discoveries. Mr. Hind, the skilful conductor of Mr. Bishop's Observatory in the Regent's Park, has for some time been employed in the accurate construction of a series of charts of that portion of the heavens extending 3° on each side the ecliptic, in which is inserted every star from the 1st to the 11th magnitude. The Berlin charts are on the same plan; and Mr. Cooper of Markree Castle, county Sligo, with the assistance of his astronomer Mr. Graham, is following in the same track. Now, if in the progress of mapping down these minute objects from actual admeasurement, one of them is suspected of having changed its place, it is carefully scrutinised, its distance from its neighbours taken, and at short intervals repeated: if the lately-measured distance is found to differ from the former, such object is immediately claimed as a planet, and its discovery announced to the world; observers persecute it, calculation founded on observation lays down its orbit, declares its periodic time and its distance from the sun, and it is forthwith enrolled as a member of the great solar family. The astronomer, encouraged by success, renews his patient

and laborious search. Mr. Hind's announcement of the discovery of Irene shews the promptness and decision with which these small stars are seized upon when suspicion is excited. "On May 19th, 16^h 39^m, the new star followed a known star by $8^s{\cdot}3$, and at 16^h 52^m the difference of right ascension was $7^s{\cdot}7$; quite sufficient," says he, "to establish motion in one object. At 17^h 15^m the difference of right ascension was $6^s{\cdot}6$. The planetary nature of the stranger was therefore satisfactorily proved from 36^m interval." The next morning's *Times* announced the discovery to the world. Such promptitude is necessary to establish the claim of priority, for the same planet was detected by De Gasparis four days later; while Psyche, De Gasparis' planet, discovered on the 17th by him, was searched for as a planet by Hind on the 18th of March, 1852; Mr. Hind having missed it from the place which it had occupied a short time previously.

The immense and disproportionate space between the orbits of Mars and Jupiter was remarked by Kepler; and the existence of these insignificant planets has given rise to a magnificent conjecture—namely, that between the orbits of Mars and Jupiter there once revolved a planet, which, by some sudden convulsion, burst asunder, and that these are the fragments of that exploded globe. An opinion (considered by Mr. Adams unfounded,) was held, that the positions and intersections of their orbits are such as would be required by the laws of mechanics, were a massive globe to explode in the manner supposed. Sir John Herschel's observations must be subjoined, although the French astronomers would seem to receive the conjecture as an established truth: "This may serve as a specimen of the dreams in which astronomers, like other speculators, occasionally and harmlessly indulge." The application of Bode's law of the planetary distances would, nevertheless, seem to favour the conclusion.

125. The asteroids form a group by themselves. With our powers of artificial vision—supposing the optical organs of the inhabitants, if any exist in them, to resemble those of human beings—it is probable that when one of these small bodies passes by another, the mode of being of its inmates might be disclosed, their towns and fields traced out, and their artificial erections examined, as on a plan or map.

Great discrepancies exist among writers as to the diameters of the asteroids: the probability seems to be, that the largest is the size of the moon; the smallest about 300 miles in circumference. One of them at least has an extensive atmosphere.

SECTION XII.

ON COMETS.

FORM OF THEIR ORBITS—HOW MAY THE IDENTITY OF A COMET BE PROVED?—THE THREE KNOWN COMETS—PHYSICAL CONSTITUTION—DO THEY MOVE THROUGH AN EXTREMELY SUBTLE MEDIUM, OR THROUGH EMPTY SPACE?

126. Comets form an entirely distinct class of bodies from either the planets or the fixed stars, whether we regard the character of their movements or their physical constitution.

The word *comet* is derived from the Latin and Greek word "coma," *hair*, these bodies being usually distinguished by a train or tail, which was supposed to bear some resemblance to a tuft or lock of hair. They revolve round the sun in orbits either of an elliptical or parabolic form. Sir Isaac Newton supplied us with a proof that any body revolving round another, and kept in its orbit by gravity, would describe in its revolution one of the conic sections; either an ellipse, a parabola, or an hyperbola. It has not yet been determined whether or not the orbit of any comet is an hyperbola; indeed, the great difficulty of calculating the orbits of comets arises from their being seen only when in the immediate neighbourhood of the sun; and during the small space of time they are, for the most part, visible, the three curves differ so little from each other, that the nicest observations are necessary to determine to which the orbit of a given comet belongs.

127. The properties of the ellipse will be pointed out under the head of physical astronomy; those of the parabola will be understood from what follows. Let S, fig. 17, be the place of the sun in the focus, R the place of the comet in its perihelion, and let R Q be taken equal to S R; draw N N perpendicular to S Q. If a comet, P, move in such a manner that its distance, P S, from the sun is always equal to P N, its perpendicular distance from the line N N N, it will describe a parabola of which S is one focus, while the other is at an infinite distance. If such be the nature of its orbit, the orbit will not return into itself, but the comet, after one appearance, will not be seen again.

Now, most of the comets are only visible to us during the time they describe a very small portion of their orbit, near their perihelion; in which situation the difference between a very lengthened ellipse and a parabola is so slight, that for a time these two curves nearly coincide. Hence it is that, from one curve being mistaken for the other, some comets, whose return has been calculated for a particular time, have disappointed the expectations of astronomers.

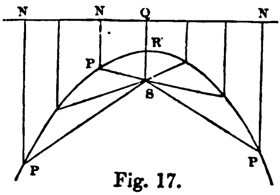


Fig. 17.

128. The comet of 1843 appears to have described an orbit of an hyperbolic form. Approaching the sun as near as 3500 miles, it rushed by him with inconceivable velocity, equal to one-third of that of light; then, branching off, it was lost in distant space. On its course it must have passed between the sun and the earth, and must, to a certain extent, have deprived us of somewhat of the sun's light and heat. This occurred during the time that the sun was shining upon our antipodes, and therefore was not observed in Europe. Had the earth been fourteen days in advance of her position at the time of the tail of the comet reaching across the ecliptic, we should probably have experienced sensations entirely new, from the admixture of its substance with that of our atmosphere. It is not our province to speculate on what would probably have resulted from such a union.

129. We are not to imagine that the orbit of a comet will be invariable. Whenever a comet arrives within the sphere of attraction of a planet, it is drawn considerably

out of its usual track; and in some instances comets, by such means, have been made to describe orbits differing materially from their original paths. A comet was observed in the year 1767, which previously had moved in an orbit of fifty years' duration. Entering our system near the planet Jupiter, his attraction threw it into an entirely new orbit, which was found by calculation to be an ellipse, in which, had it continued to move, its period would have been 5½ years. This was the character of its motion while passing round the sun; but on its return, again approaching so near Jupiter, in 1779, that his attraction became 200 times more powerful than the sun's, its orbit underwent another change into one of twenty years' duration. Throughout no part of this orbit has it come under the observation of astronomers.

130. It may not be out of place here to answer the question which may have suggested itself, "In what manner can the identity of a comet be proved?"

In the first place, we must entirely discard the point of exterior resemblance, inasmuch as this varies with the state of the atmosphere, the time of the day and of the year, and the country in which the comet is observed; so that even were the accounts on record of the appearances of comets free from exaggeration, and in the main correct, still the fact of the same comet being subject to external change would render them of no avail.

131. Long before any thing was known with certainty of the nature of the cometary orbits, observers who were not even provided with very accurate instruments, were fully competent to note, and to the great

advantage of science did note, various particulars respecting them; such as, first, the point in the heavens where the comet most nearly approximated the sun, or its perihelion—also its distance from the sun at the time of its perihelion passage; secondly, the inclination of its orbit to the ecliptic; thirdly, the precise point where its orbit crossed that of the earth; fourthly, whether its motion were direct or retrograde, that is, whether to the east or west. It will be apparent, that whenever a comet appears which in all these particulars agrees, or nearly so, with observations made at a former time, the presumption is that the same comet has returned; which presumption gains strength if, at an equal period of time further back, an agreement has been recorded; and arrives almost to a certainty if the agreement has been noticed for a series of successive periods, each separated by spaces of time equal, or nearly so, to each other. By this means Halley, the friend of Newton, was enabled to predict the return of a comet in 1758, which has twice appeared since his time—on the last occasion in the year 1835, when the gratification of the public was unbounded. Rushing as it did, in the month of October in that year, distinctly visible to the naked eye, by the seven stars of the Great Bear, it was an object of interest and delight to unscientific observers, as well as to those who, guided by unerring principles, had long expected its return. This comet is one of the few whose periods of revolution are known; for, although between 400 and 500 have been from time to time remarked in the heavens, astronomers can boast of having ascertained the orbits and periodic times of only six; they are all known by the names of those who have succeeded in calculating their orbits. The periodic time of Halley's comet is between 75 and 76 years; its orbit is a lengthened ellipse extending far beyond that of the planet Neptune, inclined to the ecliptic at an angle of between 17 and 18 degrees. The next is the comet of Encke, so called from Professor Encke of Berlin; its revolution is completed in 1207 days. The third is a comet whose return has been proved by M. Biela, an Austrian officer, to take place in 6 years and 8 months, and which has been recognised as a member of the solar system under the name of Biela's comet. Each of these revolves in an ellipse, the orbit of Biela's comet extending somewhat beyond the planet Jupiter; at its perihelion, however, it approaches the sun nearer than the earth. The other, at its perihelion, is about as distant from the sun as Mercury; at its aphelion, not quite so far as Jupiter. The perihelion of Halley's comet is about the distance of Venus from the sun. The orbits of Halley's, Encke's, and Biela's comets are represented proportionally in Plate II., fig. 7. The other known comets are Faye's, De Vico's, and Brorsen's; and some others whose orbits have been calculated, but have not yet been verified by their return.

THE PHYSICAL CHARACTER OF COMETS.

132. In a former section of this work, the grounds of our concluding that between the various planets and the earth there existed striking points of similarity, were laid before the reader: that mountains and valleys diversify the face of the moon; that oceans and continents may be seen in the planet Mars; that probably all the

planets are invested with an atmosphere similar to our own. But the comets would seem to possess nothing in common with the other bodies of our system; they are, it is true, masses of matter, but that matter is not dense, like that of the earth and moon.

133. For the proof of this assertion we may refer to the principle laid down in § 161, viz. that if two bodies mutually attract each other, the lighter would move through a space to meet the heavier greater than the heavier would move to meet it, in the inverse ratio of their masses; so that if a body were a thousand times lighter than another, it would move over a thousand times the space that the more weighty would advance to meet it. Now that the comets suffer immense disturbance in their course from the attraction of the planets is well known from the great allowance which must be made for such perturbations whenever they are in the neighbourhood of one of those bodies, without which it would be impossible to predict the time of their reappearance. Yet it has never been found that any *perceptible* influence has been exerted by the comet on the attracting planet; theoretically the planet must have been disturbed (see § 176), but so slightly as to have escaped the most careful observations. When the comet of 1767 got entangled, so to speak, among the satellites of Jupiter, their movements did not suffer derangement in the slightest perceptible degree; so that the proportion of the mass of the comet to that of the least of Jupiter's satellites must have been infinitely small.

134. Viewed through a good telescope, comets are found to consist of a large indefinite mass of cloudy

light, increasing in brilliancy towards the centre. This is the nucleus of the comet; from the nucleus, away from the sun, diverges a stream of light which decreases in brilliancy as it expands; this is the tail of the comet. The tail is deficient in some which have appeared, while others have exhibited even as many as six. The nucleus itself of the comet, at least in most instances, can be nothing more than attenuated matter by no means dense. It was with much difficulty that Sir John Herschel could discover Biela's comet on its return some years since, with a twenty-feet reflecting telescope—an instrument concentrating an immense quantity of light. While making his observations on it, he saw a cluster of telescopic stars of the sixteenth and seventeenth magnitude, which the most trifling fog or haziness would have effaced; and yet their light passed through 50,000 miles of the body of the comet without being obscured.

135. The length of the tails of comets has sometimes been enormous; that which attended the comet of B.C. 43 occupied 90°, as did that of the comet of 1680.

The diameter of the nucleus of the comet of 1843 exceeded 100,000 miles; the breadth of the tail, in some places, 800,000; while the extent could not be less than 170 millions of miles, or nearly equal to the diameter of the earth's orbit.

136. In consequence of comets not presenting different phases, it has been supposed that they shine by their own light. More probably, however, they reflect light in the same manner as thin airy clouds, which, from their tenuity, are observed to be equally luminous through their whole extent. Certain it is, that the density of a comet can be little more than their's.

137. Biela's comet has been regularly observed since 1772. On its appearance in 1846, a most remarkable phenomenon presented itself. Professor Challis actually saw it double—the comet having separated into two parts—so unusual an occurrence could hardly have been conceived; but its duplicity was afterwards placed beyond all doubt by other observers in different parts of the world. In 1826 this comet crossed the sun's disc, and was seen on it, so that the matter composing it must have been opaque.

138. In Sir John Herschel's valuable "Results of Astronomical Observations at the Cape of Good Hope" may be found remarks on Halley's comet during the time of its perihelion passage, which tend more to elucidate the nature of these bodies than the shrewdest conjectures. As the comet approached the sun, it contracted in size, and its tail appeared to have evaporated; still, however, it must, though invisible, have been retained by the attraction of the nucleus. On its reappearance, after having passed the sun, the tail seemed to undergo the process of condensation, and that so rapidly that the mass increased in the proportion of 6 to 5 in 2 hours; the whole settling down in a parabolic form, agreeably to mathematical laws. Deducing certain results from observations of its increase for several days, Sir John, reckoning backward, arrived at the conclusion, "that on the 21st of January, 1836, the envelope had no magnitude; that in short, at that moment, a most important physical change commenced in the comet's state. Previous to that instant it must have consisted of a mere nucleus, a stellar point more or less bright, and a coma more or less dense and ex-

tensive; at that instant the formation of the envelope commenced and continued in the manner and at the rate above described." This conclusion was corroborated by a singular coincidence. M. Boguslawski, professor of astronomy at Breslau, actually observed the comet as a star of the sixth magnitude, a bright concentrated point, on the night of January 22d, with no accompaniment or trace of a tail visible.

As aqueous vapour will settle down and become visible when the temperature of the air reaches the dew-point, so we may suppose that, at this instant, the comet on its receding from the sun arrived at that point where, in obedience to certain laws, its envelope settled around the nucleus forming the parabolic accompaniment; the permanence of its parabolic form during its increase indicated tranquillity and obedience to fixed laws; but who shall say what these are? not gravity certainly; for why should the tail point *from* the sun? May not the matter of the tail, like light and electricity, be subject to unknown laws, which cause it to be attracted by the nucleus, and repelled by the sun?

When this repulsion becomes too powerful, a portion of the tail may fly off, and the comet, relieved in part of repulsion, may accelerate its course; under peculiar circumstances a portion of this matter may revolt and form an independent comet, which shall journey on with its parent, side by side. The former supposition will account for the depreciation in the brightness of comets in later times; the latter for the duplicity of Biela's comet in 1846, and on its last return, 1852.

139. It has been a question long agitated among philosophers, whether the space through which the pla-

nets perform their motion is filled by an extremely subtle medium, or whether it is a perfect vacuum. One would imagine, if the former were the case, that the planets would have their times of revolution altered in a slight degree, which alteration, though not perceptible in one or two revolutions, in process of time would become appreciable. Now, as will hereafter be shewn (§ 194), no period is so constant as that of the revolution of a planet round the sun. Each one completes its revolution, and has done so for hundreds of years, in precisely the same time to the fraction of a second. It is plain, however, that a medium which would impress no delay on the solid and weighty mass of a planet may produce a very perceptible difference in the time of the revolution of a comet; inasmuch as its composition being far less dense, it would be more likely to be impeded in its course. Now it was found by Professor Encke, that the comet which bears his name had been constantly anticipating the calculated time of its arrival at its perihelion: in some instances two days, in others one day. One may, at first sight, suppose, that if the comet moved through a resisting medium, the very reverse would be the fact, and that it would be a longer instead of a shorter time in performing its revolution. But the effect of such a medium would be to retard the centrifugal tendency of the comet, leaving the sun the power of attracting it more powerfully, and, consequently, drawing it nearer and nearer to him, lessening its orbit at each revolution.

The opinion of Professor Encke and of the Astronomer Royal, who translated his dissertation on this subject, is, that there cannot henceforth be a doubt but that the motions of the bodies composing the solar system are performed through a resisting medium; or, at all events, that a correction must be applied to the orbits of comets exactly equivalent in effect to what such medium would produce.

A splendid comet unexpectedly made its appearance near the bright star Capella, on the 8th of June, 1845, and for some time afforded high gratification to the

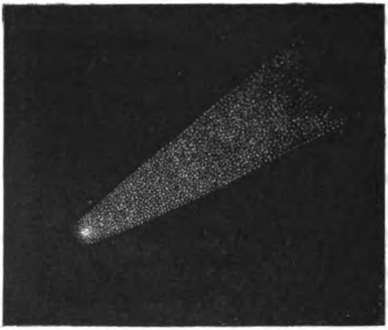


Fig. 18.

lovers of astronomy. At that time it had passed its perihelion, and was receding from the sun. Its telescopic appearance is represented in the above drawing, fig. 18.

SECTION XIII.

SIDEREAL ASTRONOMY.

NEW STARS—VARIABLE STARS—DOUBLE STARS—COLOURED STARS—TRIPLE AND MULTIPLE STARS—THE MILKY WAY—GROUPS AND CLUSTERS OF STARS—DIFFERENT CLASSES OF NEBULÆ.

140. THE bodies composing our system we have seen to be, in many respects, similar to our earth; some of them exceeding it, while others fall below it in magnitude. The distances of these bodies the mind can scarcely comprehend; yet those are as nothing when compared with that of the least remote of the fixed stars. When we are informed that each of the thousands of the stars may be equal in magnitude and brilliancy to our sun, and is probably accompanied by attendant planets, the grandeur of the universe thus disclosed overwhelms the mind, and its powers fail to comprehend the immensity of space filled with system after system in apparently endless succession. Without entering upon any disputed point, or alluding to hypotheses, which, however brilliant and ingenious, are hardly founded upon severe philosophical reasoning, it will be our endeavour, in this part of the work, to exhibit such facts respecting the fixed stars as have been firmly established by repeated and laborious observations. To the immortal Sir William Herschel, whose labours have been followed up by his no less illustrious son, Sir John F. W. Herschel, this branch of astronomy is under the deepest obligations. The information communicated by these renowned astronomers in the form of memoirs,

may be found scattered throughout the *Philosophical Transactions* of the last seventy years. Sir J. F. W. Herschel's observations at the Cape complete the survey of the entire heavens by one individual. From these sources two writers have of late presented popular views of sidereal astronomy: Dr. Nichol in *The Architecture of the Heavens,* and Dr. Dick in his *Sidereal Heavens.* Both of these works will repay perusal, and will exhibit the nature of the labours of the Herschels—especially with respect to nebulæ and double stars. "Others," says the Rev. R. Sheepshanks, "may have measured and noted very laudably, but philosophical views and practical details are almost wholly due to them."

The book which, above all others, ought to be in the hands of the amateur astronomer is *The Celestial Cycle* of Captain W. H. Smyth, R.N. In the second volume, the "Bedford Catalogue" contains a full and particular account of 850 remarkable objects—double stars, multiple stars, clusters, and nebulæ: of each object are given, 1st, the designation and synonyme, with its apparent place; 2d, the position and distance of the components of the double or multiple star; these are followed by a general description of each individual, telescopic views of the most remarkable, and the most authentic details of the history of all.

141. The distance of the fixed stars is immeasurable; observed even with the best telescopes they present no apparent diameter, but only appear as lucid points. Though preserving the same relative distance from each other, it is supposed, and that not without reason, that the stars have a proper motion, exceedingly slow, and only to be appreciated by the most delicate observations

continued through a series of ages. Hence the advantage of extensive and elaborate catalogues, by which the position of the stars at any distant period may be compared with that which they occupied at the time of the formation of the catalogue, and any alteration may be perceived and registered.

NEW STARS.

142. The disappearance of a star in the time of Hipparchus induced him to form the first catalogue. Since that period other stars then known have ceased to shine; while others, not before visible, have been called into existence. In the year 389 a new star appeared in the constellation of the Eagle, and disappeared after having shone with a brilliant lustre for three weeks.

In 1572 a brilliant star made its appearance in the space between the constellations Cepheus and Cassiopeia, which excited the attention of the Danish astronomer Tycho Brahe, who carefully watched it till the month of March 1574, when it disappeared, after having exhibited varied colours in the light it sent forth, and attained a brilliancy surpassing that of the planet Venus. At a more recent date, 1670, a star of the third magnitude, which had appeared in the head of the Swan, could not be seen; it then re-appeared, and after exhibiting singular fluctuations of light for two years, became extinct, and has not since been observed. There is reason to suppose that many other stars found in old catalogues have shared the same fate.

Sir John Herschel concludes, that the star designated 42 Virginis in the Astronomical Society's catalogue has disappeared since May 9th, 1828.

143. One of the most remarkable instances of the appearance of a new star in modern times occurs in the history of the nebula surrounding the star θ Orionis. This was the first object to which Sir W. Herschel directed his famous forty-feet reflector in February 1787. The star was then pronounced to be quadruple. The star has now become decidedly sextuple, even to instruments of very much inferior power; and the legitimate conclusion to which astronomers have arrived is, that the two additional members are of late creation, having made their appearance since the year 1826.

On April 28th, 1848, Mr. Hind discovered, at Mr. Bishop's observatory in the Regent's Park, a star of between the fourth and fifth magnitude, in a line joining η and 20 Ophiuchi, where none was noticed on April 5th: its light in the telescope was remarkably vivid, but it became extinct before the end of the year.

VARIABLE STARS.

144. Variable stars offer phenomena well deserving of the closest attention; they exhibit a periodical increase and diminution of light, and some even disappear altogether for a time.

One of the most remarkable of these is *o* Ceti, R. A. 2 hours 8 minutes 33 seconds, dec. 3° 57′ 25″ s., which has been the subject of observation since the year 1596. This star passes through all the gradations of light and magnitude, from the second to the sixth or seventh magnitude, until it becomes invisible to the naked eye, and can only be traced with the telescope. It remains at its greatest brightness for a fortnight, decreases in brilliancy for three months, remains invisible for five months, when it again becomes visible, and for the remaining three months of its period gradually increases in brilliancy, attaining not always, however, the same degree. Sir W. Herschel makes its period 331 days 10 hours 19 minutes, during which it goes through all its gradations.

145. Another remarkable variable star is Algol, in Caput Medusæ. Its changes are gone through in 2 days 20 hours 49 minutes. During four hours it gradually diminishes in lustre; during the next four its brightness is recovered, and for the remainder of its period it retains its maximum of brilliancy.

The explanations given of these changes have been various: some suppose that an opaque body revolves round the star, and intercepts its light; others, that large spots may exist on the surface, on that part which appears the least brilliant, and that these are presented to us as the star revolves on its axis; others, that the variable star may describe an orbit very elliptical, and that the variation in brilliancy may arise from the distance between us and the star increasing or decreasing.

The following table gives the periods of the more remarkable of the variable stars:

Name of Star.	Period.
δ Cephei	5 days 8½ hours.
β Lyræ	6 „ 9 „
η Antinoi	7 „ 4¼ „
α Herculis	60 „ 6 „
χ Cygni	396 „
γ Hydræ	494 „

DOUBLE, OR BINARY STARS.

146. Many of the stars which appear single to the naked eye, or when viewed through an inferior telescope, appear double through a telescope of greater power; that is to say, the single star is separated into two, which appear very near each other.

This singular fact cannot be accounted for by supposing one star situated behind the other at an immense distance, inasmuch as the number of double stars, which amounts to some thousands, precludes the idea of their being merely optically double; while other circumstances remarked by observers, which we are about to explain, clearly prove that these stars are physically double—united to each other, that is to say, by gravity, the cause which unites the planets and the sun.

Castor is one of the most remarkable double stars. In the year 1759, Dr. Bradley communicated to his friend Dr. Maskelyne the following memorandum respecting the position of the two stars of which it consists: "No change of position in the two stars; the line joining them at all times of the year parallel to the line joining Castor and Pollux in the heavens, seen by the naked eye." Sir William Herschel watched these stars for many years preceding 1803, and found that during that period of time, from 1759 to 1803, the small star, so far from retaining the position indicated by Dr. Bradley in the above memorandum, had a gradual motion round the other. Since the year 1803 other observers, including Sir John Herschel, have attentively measured the increasing angle of position, and found it still progressing. From a comparison of all the observations on this double star, it may be concluded that, in a period of somewhat more than 250 years, the smaller will have completely circulated round the larger; so that about the year 2000, the two stars will be situated just as they were when Bradley made his observations.

Fig. 19.

Double Star, Castor.

Most wonderful are the truths which double stars, similar to the one now described, open to our view: here we see, not a sun with its attendant planets, but two suns, self-luminous and massive, revolving round their common centre of gravity. Whether or not they have an accompaniment of attendant bodies it is impossible to say: certain it is, that the distance of the two stars from each other must be far greater than the distance between any two bodies of our system; so that a retinue of planets might attend each sun, and yet neither system would interfere with the movements of the other.

The labours of Sir J. Herschel, Sir James South, Professor Struve of Dorpat, Dawes, Smyth, and others, have brought to our knowledge at least 4000 of these binary systems. Although, in the present state of the science, observations are yet wanting to prove that each and all these revolve round the centre of gravity, like the two composing the star Castor, yet many others have been marked with accuracy, and their periods calculated. The following table will shew a few of the results of observations in this department of the science:

η Coronæ	revolves in	43 years.
ζ Cancri	„	57 „

ξ Ursæ Majoris	. . revolves in	61	years;
p Ophiuchi	„	80	„
σ Coronæ	„	200	„
γ Virginis	„	513	„

147. Many of these double stars present the beautiful phenomenon of contrast in the colours of the two stars composing the system. ι Cancri is one of these: the larger star is of a yellow colour; the smaller is blue. The larger of the two composing γ Andromedæ is crimson; the other a beautiful green. η Cassiopeiæ discloses a combination of a large white star, and a small one of a purple colour. In α Leonis, β Orionis, and α Serpentis, the large star is white and the small bluish. In 59 Andromedæ, the two stars are of a bluish colour, and equal in size: the same occurs in the star δ Serpentis.

TRIPLE AND MULTIPLE STARS.

148. In studying the starry heavens wonders multiply upon us at every turn. What can be more unlike any combination we could have conceived, from the contemplation of our own system, than a complicated arrangement of three or more suns revolving round the centre of gravity of the whole? Yet instances of these remarkable combinations are scattered throughout the heavens, and indicate a complexity and diversity unknown in that portion of the universe which has been appointed as our abode, as well as the wonderful intelligence of that Almighty Being who has summoned into existence so great a variety in the material universe, and who has imposed upon the whole such laws as insure the utmost regularity amidst seeming complexity. The

star ζ Cancri is a triple star, which, under favourable circumstances, may be seen with a good telescope magnifying 300 or 400 times.

149. ε Lyræ is a double double star; it may be found 2° N.E. of Vega, and clearly seen through a good $3\frac{1}{2}$-feet achromatic; it consists of two pairs of stars, each pair revolving apparently round the centre of gravity of the two, and both pairs revolving round the centre of the whole system.

The annexed cut represents the double star Polaris, the quadruple star ε Lyræ, and the triple star ξ Libræ.

Fig. 20.

Polaris. ε Lyræ. ξ Libræ.

ε or 4 or 5 Libræ is a double double star. The first pair consists of stars considerably unequal; the larger is very white, the other reddish. The second pair is white, and equal in size.

σ or 48 Orionis, a little below the three stars which form the belt, is a double triple star, or two sets of triple stars, almost similarly situated. R.A. 5 hours 30 min., dec. 2° 40′ S.

θ Orionis, in the centre of the sword of Orion, is a quadruple (or rather sextuple) star, forming a trapezium in the middle of the nebula.

44 Orionis, 5° E. by N. from the bright star Rigel,

is another double triple star. ξ or 51 Libra appears generally double; but the larger, through a superior telescope, may be again divided, and found to consist of two stars, as represented in the drawing. Between ζ and β Delphini, but nearer β, may be found a triple star.

In the Unicorn's Head is a multiple star, consisting of one star with about twelve round it. It may be found 16° west of Procyon.

THE MILKY WAY.

150. During the autumnal and winter months we cannot fail to remark a bluish-white zone stretching all across the heavens from one side to the other; this is the Milky Way. It may be traced through the constellations Cepheus, Cassiopeia, Perseus, Auriga, part of Orion and Gemini, and through the southern groups, the Cross, the Altar, Scorpio, Sagittarius, Ophiuchus; here it separates into two branches, which again unite in the neck of the Swan.

151. The conjecture of the ancients that this milk-white zone was an assemblage of stars, was confirmed on the invention of the telescope; for no sooner was it directed to the Milky Way than thousands of stars became visible; and as, in the progress of time, the telescope has undergone improvement, so many more have been brought to light, that it would be utterly impossible to enumerate or classify the myriads which compose it. Direct the telescope at random to any part of this luminous zone, and its field will be filled with scores of stars, some shining brightly, and others fading away in every degree of faintness. It is almost impossible to

withhold expressions of amazement when we contemplate the unnumbered systems which must be scattered throughout this portion of the heavens: perhaps the best idea of the numbers of stars composing this zone may be gained from a simple fact stated by Sir W. Herschel. Suppose his telescope fixed in one position, and that by the diurnal motion of the earth the stars were brought into and carried across the field of view; and imagine also the field of vision to take in about one-fourth the space occupied by the disc of the moon: "In the most crowded parts of the Milky Way," says he, "I have had fields of view that contained no fewer than 588 stars, and these were continued for many minutes; so that, in one quarter of an hour's time, there passed no less than 116,000 stars through the field of view of my telescope." The remark of Sir J. Herschel on the Milky Way conveys a more exalted idea to the mind than could be derived from pages of declamation: "This remarkable belt, when examined through powerful telescopes, is found to consist entirely of stars scattered by millions, like glittering dust, on the black ground of the general heavens."

Can any contemplation more exalt our ideas of the Creator and of the extent of the universe, or teach more humbling lessons to us the inhabitants of a comparatively minute globe, whose existence is unknown perhaps beyond the boundary of the system of which she forms an insignificant member?

"When I consider the heavens, the work of thy hands, the moon and the stars, which thou hast ordained; what is man, that thou art mindful of him—the son of man, that thou visitest him!"

GROUPS AND CLUSTERS.

152. The stars would seem to an unpractised eye to be scattered over the heavens at random, without order or connexion, but this is not universally the case; certain companies of stars are so manifestly associated together, that we are led to conclude that their juxtaposition is not the effect of casual distribution, but of manifest design. The Pleiades, a well-known group, to the naked eye consists of six stars, but as many as fifty or sixty are counted with the aid of the telescope, crowded together in a lonely part of the heavens in a very moderate space.

Coma Berenices is another group, more diffused than the Pleiades and formed of larger stars.

Præsepe, or the Beehive, in Cancer, and the Sword-handle of Perseus, are instances of groups or clusters which may be resolved into stars with glasses of a very moderate power.

STELLAR NEBULÆ.

153. If we imagine a cluster consisting of a much greater number than either of the foregoing, and so far removed that it presents a bluish-white appearance like that of the Milky Way, we shall be able to form a good notion of a stellar nebula. One similar to this which we have supposed may be found in the constellation Hercules; it is almost globular in form, and consists of thousands of stars, so arranged that, when viewed directly, those crowding about the centre unite their rays and form a brilliant light; while near the edges the

component stars may be distinctly seen separately by a 5-feet achromatic glass.

"It would be a vain task," says Sir John Herschel, "to attempt to count the stars in one of the *globular clusters;* they are not to be reckoned by hundreds; and on a rough calculation, grounded on the apparent intervals between them at the borders, where they are seen not projected on each other, and the angular diameter of the whole group, it would appear that many clusters of this description must contain at least five thousand stars, compacted and wedged together in a round space whose angular diameter does not exceed eight or ten minutes."

Fig. 21.

Nebulous Cluster in Hercules.

NEBULÆ IN GENERAL.

154. Sir W. Herschel analysed and arranged the various classes of nebulæ, or those very faint and delicate cloudy objects which meet the eye of the observer as he sweeps the heavens with his telescope, and which may indeed, in some cases, be discerned without its aid. As it would be quite impossible to enter fully into the subject in a treatise like the present, we shall simply lay before the reader the classification of that illustrious astronomer, with the telescopic view of a few of these remarkable objects :—

1. Clusters of stars similar to that already described in the constellation Hercules.

2. Resolvable nebulæ, or those which any increase of optical power in the telescope may be expected to resolve into distinct stars.

3. Nebulæ properly so called, in which there is no appearance whatever of stars.

4. Planetary nebulæ, or those which exhibit a defined disc of circular light.

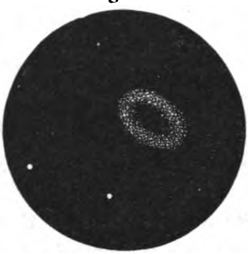
5. Stellar nebulæ.

6. Nebulous stars, or stars surrounded by a halo of nebulous light.

Of the third class a beautiful specimen may be found surrounding the sextuple star in Orion's Sword; and may be contemplated with delight by means of a very moderate-sized telescope. From drawings taken of this nebula at various times, it would appear to vary its form; it is a long irregular mass of light spreading from star to star, enveloping some in its vicinity with a nebulous atmosphere of considerable extent.

Near ν in Andromeda is a large nebula of a long oval form, brilliant in the centre, the light decreasing towards the edges; it may be seen with the naked eye, and has often been mistaken for a comet.

Fig. 22.



Annular Nebula in Lyra.

One of the most remarkable objects of this class is the Annular Nebula in Lyra, between β and γ of that constellation; it is visible through a $3\frac{1}{2}$-feet achromatic, and presents the appearance of a ring seen obliquely, the two diameters of the oval being in the proportion of 4 to 5.

Near γ Andromedæ, about 4° to the east, may be found another, somewhat similar in shape, but much longer in proportion to its breadth.

The Dumb-bell or Hour-glass Nebula, so called from its appearance, is situated in Vulpecula et Anser, and may be seen with a 5-feet achromatic.

Fig. 23.

Dumb-bell Nebula.

Fig. 24.

Planetary Nebula in Ursa Major.

Planetary nebulæ must be of enormous size; one in the neighbourhood of the star ν Aquarii has an apparent diameter of 20″, and would fill with its mass the whole orbit of the planet Herschel.

Nebulous stars are not rare: 55 Andromedæ and ε and ι Orionis are specimens of this class.

At the conclusion of Part III., "Practical Astronomy," will be found the right ascension and declination of these and some other nebulæ, by which they may be found in the heavens according to the directions there given.

155. The leviathan telescope of Lord Rosse having

been brought fully to bear upon these remarkable objects, has made disclosures which will give an entirely new turn to the speculations respecting them. Already it has resolved many which were before thought irresolvable, or only diffusive matter—the elements, as was supposed, of future worlds. It has extended our knowledge of the universe, and disclosed thousands of stars whose existence had been previously unknown. To give even an abstract of the discoveries for which we are indebted to Lord Rosse would far surpass the limits of a work like the present. He is still occupied with investigations, which will tend to immortalize his name.

PART II.

PHYSICAL ASTRONOMY.

ATTRACTION OF GRAVITY—DIFFUSED THROUGHOUT ALL MATTER—LAW OF INCREASE OR DECREASE—ATWOOD'S MACHINE—THE PENDULUM—GRAVITY EXTENDS TO THE MOON—ALSO TO THE PLANETS—PROOF—SIX LAWS OF MATTER AND MOTION—ORBICULAR MOTION IN A CIRCLE—CONIC SECTIONS—MEAN AND TRUE ANOMALY—MOTION IN AN ELLIPSE—CENTRE OF GRAVITY OF THE SYSTEM—PERTURBATIONS AND VARIATIONS—MASSES OF THE SUN AND PLANETS—KEPLER'S LAWS—BODE'S LAW OF PLANETARY DISTANCES.

156. HAVING given a general view of the bodies of the solar system, we proceed to notice the physical laws by which their movements are regulated, and also to explain a few of those disturbances or perturbations which interfere with the regularity of their motions in space.

In this elementary treatise it cannot be expected that we should enter deeply into the subject of physical astronomy, to understand which requires a preliminary mathematical knowledge of an extensive and refined character. Our efforts will be directed to such an exposition of those wonderful secrets of nature which Sir Isaac Newton was the first to unfold, as will enable the student to appreciate the labours of that profound philosopher, and to estimate justly the benefits which science has derived from him.

157. The grand means by which the planetary system is held together is the attraction of gravitation, or that disposition in every particle of matter to attract or draw any other particle towards itself.

The most common illustration which we can give of this attraction is the descent of bodies, when left unsupported, to the surface of the earth. The great merit of Sir Isaac Newton arose from the discovery that the mutual attraction of the bodies of the solar system was subject to the same laws, and was, in fact, identical with terrestrial gravity. The philosophers of antiquity viewed the movements of the heavenly bodies as subject to other laws than those of motions on the earth: to account for them they introduced various singular and absurd principles, which served to render astronomy ridiculous. But the philosophy of Newton has led us to refer the motion of the most distant planet to the same general law which guides the fall of the dew-drop; and to shew that the devious and eccentric comet is united to the central orb of the sun by the same bond which confines us to the surface of the earth; while later astronomers have led us to the conclusion that, even in the immensity of space, the fixed stars, with which our system would appear to have no connexion, are subject equally with ourselves to the law of universal gravitation.

158. The leading points which have been established respecting gravitation are, that every particle of matter attracts every other; and that, in the case of any two bodies attracting a third, their separate attractions will

be in direct proportion as the mass of those bodies, and in the inverse proportion of the squares of their distances.

Fig. 25.

Let D and G (fig. 25) be equidistant from S, but let the mass of D be double that of G; then will its attraction on S be double that of G on S, the proportion of the two attractions being directly as the masses.

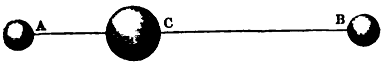


Fig. 26.

Again, let B (fig. 26) be twice as distant from C as is A; then A's attraction on C will be to B's attraction on C as BC^2 to AC^2, or as $2^2 : 1^2$, or as 4 to 1 (the masses of A and B being the same), inversely as the distances squared.

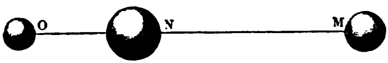


Fig. 27.

If the masses of the attracting bodies be different, and also their distances unequal, the whole amount of attraction will be compounded of that of the masses directly, and of the distances squared, inversely: thus, let M (fig. 27) be treble the mass of O, and M N = twice N O, then

The attraction of O on N : that of M on N : : 4 : 1, inversely as the squares of the distances; but,

The attraction of O on N : that of M on N : : 1 : 3, directly as the masses; therefore the whole amount of the attraction of O on M : that of M on N : : 4 : 3.

159. The character of the operation of gravity on the earth is seen in its causing every unsupported body to fall to the surface of the earth in the direction of its centre: not that the centre of the earth has any peculiar attractive virtue; but, as Sir Isaac Newton has shewn (lib. i. prop. 74 of the *Principia*), the amount of the attractions of all the particles of which any sphere is composed on any body extraneous to itself will be the same as if all the attractive force was united in the centre.

Now since all planetary bodies are of a spherical form—for their slight deviation from a sphere need not generally be taken into account—it is plain that the labours of astronomers are much shortened by the simplicity which is thus introduced into their calculations. Suppose for a moment that the point to which all the attractions exercised by the sun on the planetary system tended not to the centre of the sun, but to some other point, there would be a necessity, in every instance in which a calculation was made, to reduce it to what it would be if the lines of attraction were directed to the centre; whereas in consequence of this truth, we need only consider the situation of the centre of the sun, and the direction of any line of attraction will then be known. The like is true of the attractions exercised by the planets on one another and on their satellites.

A beautiful proof of the fact that the attraction of gravity is diffused through every part of the earth, is the discovery which was first made by the French astronomers Condamine and Bouguer. When making observations in Peru, near the mountain Chimborazo, they found that the mass of the mountain very sensibly drew aside their plumb-lines out of the vertical position in which they would otherwise have hung. Dr. Maskelyne experienced the same effect from the mountain Schehallien in Scotland: to satisfy himself he made the experiment on opposite sides of the mountain, and found in each case that the plumb-line inclined towards it. This experiment and the following have already been treated of more at large in Part I., under the head of "The Earth," § 38.

Another instance on record of the effect of the attraction of mountains is one worked out by Baron Zach, in rather a different manner. For the purpose of a trigonometrical survey near Marseilles, he had erected three small observatories near Mount Mimet, in the neighbourhood of that town. He first obtained the latitude of these by measurement from distant stations whose latitudes were known, and then by astronomical observations. A slight difference in these two results was proved by him to be due to the attraction of the mountain. In the trigonometrical survey of the Isle of Wight a similar effect was found to be produced by the promontory of Dunnose.

160. In general the force exerted by the earth itself upon bodies on its surface is so overwhelming, that their mutual attraction is not apparent. Mr. Cavendish's experiment has, however, shewn the universality

of gravitating attraction. Let two small balls, nicely balanced, be united by a fine wire, and allowed to turn round upon the point of suspension; let two large masses of lead be so placed that their effect will be to turn the balls in the same direction: it will be found that the balls will gravitate towards these masses. (§ 39.)

161. The means adopted to measure the force of attraction are, first, pressure; thus, a cubic foot of lead will be attracted to the earth with a pressure equivalent to 11,325 ounces; whereas a cubic foot of oak will be attracted with a pressure of only 925 ounces; which numbers represent what we understand by the specific gravity of those bodies. Secondly, by marking the number of feet, inches, &c., through which a body is drawn in a second of time. "Thus, suppose the Sun and Jupiter are at equal distances from Saturn: the Sun is about a thousand times as big as Jupiter; then, whatever be the number of inches through which Jupiter draws Saturn in one second of time, the Sun draws Saturn in a second through a thousand times that number of inches."*

162. Now it is found that if no resisting medium intervene, the force of attraction is the same on all bodies situated at the same distance from the attracting body. Thus, in a vacuum, where the force of the fall is not deadened by the air, a feather or any light substance will descend to the earth with the same velocity as a piece of stone or metal let fall at the same instant. This distance in the latitude of London will be $16\frac{1}{12}$ feet in a second of time, which is the measure of the force of terrestrial gravity in that latitude.

* Airy on Gravitation.

163. Gravity increasing in inverse proportion to the square of the distance may be thus illustrated.

Let a body attract another with such force as to draw it through 36 inches in a second, at any given distance ; if the distance be increased to twice that quantity, the attracted body will be drawn through nine inches only, or one quarter of the original distance in the second ; if the distance be still further increased to three times that quantity, the body will be drawn through one ninth of 36 inches in a second, or four inches ; and so on for any distance.

Now suppose the moon, at one part of her orbit, to be twice as near the earth as at another ; it follows, from what has been stated above, that the mutual attraction of the earth and moon in the first position will be four times what it is in the second.

Or suppose the sun to be 400 times further off from the earth than the moon is (which is very near the truth), then will the force of the earth's attraction on the moon be to the earth's attraction on the sun in the proportion of $400^2 : 1^2$; that is, 160,000 to 1 ; or if this be measured by the spaces through which these bodies would move to meet the earth, the moon would move through 160,000 inches in the same time that the sun would move through one.

164. On the surface of the earth, or any distance from it at which it is possible for any body which comes under our notice to commence a descent, the force of gravitating attraction may be considered as invariable ; for, even supposing any body to commence its fall at the distance of a quarter of a mile from the earth's surface, the attraction of gravity at its com-

mencement would be to the force of gravity when it met the earth in the proportion of 4000^2 to $4000\frac{1}{4}^2$, in round numbers; that is, as 16,000,000 to 16,002,000; a difference so slight as to be inappreciable. Hence, in inquiring into the laws regulating falling bodies, we may consider the operation of gravity equable during the time of descent.

165. Gravity, as we have stated, will cause an unsupported body to fall through $16\frac{1}{12}$ feet in a second, in the latitude of London. Suppose, for the sake of illustration, that the operation of gravity ceased altogether at the end of the first second; the body would then reach the earth with a uniform velocity. But this is not the case; the attraction of gravity operates at every instant of the descent of the body, causing its velocity constantly to increase; and thus the rate of descent will be greater in each successive second.

166. Atwood's machine will shew the rate of descent of falling bodies very satisfactorily: many niceties and complexities are introduced into its structure when great accuracy is required. The instrument we are about to describe may be made without much trouble and expense, and will roughly answer the same purpose as the more perfect one.

Let *a*, fig. 28, be a wheel turning freely on its axis; *d* a pendulum beating seconds; *b* and *c* two weights united by a cord carried over the wheel, and differing a little, the heavier being so adjusted that it will fall through one inch in the first second of its descent; that is, supposing the motion to commence at *e*, and that at the same instant the pendulum begins to describe the arc *d m*, by the time it has arrived at *m* let the weight have fallen to *f*; it will be found in the next vibration to have reached *g*, and to have described the space *e g*, four times the distance from the starting-point *e* that *f* is; in the next second it will be found at *h*, nine times the distance; and in the fourth second of its descent, at *i*, sixteen times further off from *e* than is *f*, where it had arrived at the end of the first second.

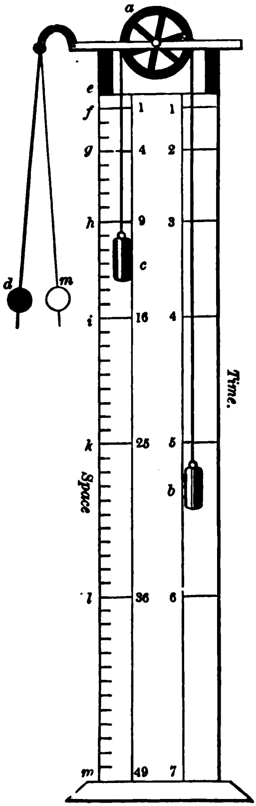


Fig. 28.

By inspecting the figure it will be seen that these spaces are in exact próportion to the squares of the times in which they are described. Thus it may be shewn that, in uniformly accelerated motions, as in those produced by the attraction of gravity, the spaces described are in proportion to the squares of the times of description; provided, let it be remembered, the variation in the attraction of gravity during the time of descent is not appreciable.

167. We have in the preceding paragraph alluded to the pendulum; an instrument of great utility, not

only as a measurer of time, but in the nicer investigations of science. As the laws which regulate the vibrations of a pendulum arise from the action of terrestrial gravity, and as we shall in another part of the work have to shew the application of the pendulum in many scientific inquiries, at the present stage it will be appropriate to inquire somewhat into the nature of these laws.

A pendulum is a weight suspended either by a line, or, as in the time-keeper, by a bar of wood or metal. If the weight were to be drawn aside from the vertical line, in which direction it would naturally be at rest, and were afterwards set free, the attraction of gravity would draw it towards the vertical, while the inertia acquired in the descent would carry it just as far beyond on the other side of the vertical line. Now, were there no friction at the point of suspension, and no resistance of the air, it would thus continue to oscillate; but since these two causes combine to lessen the arc at each vibration, it follows that, after a certain time, the vibrations will cease. It is found that, if the arc of vibration be small, the times of vibration will be very nearly equal as long as motion continues: this property is termed isochronism.

A merely superficial observer will at once perceive that a longer pendulum will vibrate more slowly than one of less length. More accurate investigation will shew that there is a constant relation between the lengths and the times: nor need the weight of the suspended mass be taken into account; for in vacuo, small pieces of lead, brass, or ivory, suspended by fine threads, will be found to vibrate in the same time as large masses of the same or other substances, provided the centre of oscillation be at the same distance from the point of suspension. To ascertain the law regulating the lengths and times, suspend three weights by strings, the lengths of which are in the proportion of 1, 4, and 9. Allow the weights to swing, and mark the time taken by each in a vibration: these times will be found to be in the proportion of $\sqrt{1}$, $\sqrt{4}$, and $\sqrt{9}$; or as 1, 2, and 3; the longest occupying treble the time in a vibration which the shortest does. It will be thus seen that the squares of the times of vibration will be in proportion to the lengths of the threads. A resemblance will be immediately perceived between this proportion and the rate of falling bodies; for if the columns of space in the last figure be supposed to represent the lengths of the strings, the column of times will shew the corresponding proportion between the periods of vibration.

To ascertain the time which will be occupied by a pendulum in one vibration, its length being known, we must remark, by comparison with a good time-keeper, the number of vibrations in a certain number of hours; the time divided by the number of oscillations will give the duration of one oscillation. If, then, we wish to know the length of a pendulum which shall vibrate in a given time, the following proportion, derived from what was said above, will give it. As the time of the vibration of the known pendulum is to the time in which the required pendulum is to vibrate, so is the square root of the length of the known pendulum to the square root of the length of the required pendulum.

The pendulum serves as an excellent measurer of the force of gravity, for by it may be ascertained the distance through which a body unsupported would fall in a second of time. The following process, deduced from mathematical reasoning, will always give that space :

"Since the length of a pendulum, beating seconds in the latitude of London, is 39·126 inches, or 3·2605 feet, half the product of this last number multiplied by the square of 3·1416 * gives 16·09 feet, the space through which a body would fall vertically in one second of time in that latitude."

168. As we have already remarked, we owe to the penetrating genius of Sir Isaac Newton the proof of the identity of terrestrial gravity with the cause of the motion of the bodies which compose the solar system.† Revolving in his mind the fact that the force of gravity continued without perceptible diminution on the tops of the highest mountains, and as high as we could ascend in the atmosphere, the question presented itself to his mind, Why should it cease there? What prevents it from reaching into space? At what point does it break off abruptly? Why should it not affect the moon?

169. Proceeding on these suggestions, he set about calculating the force of gravity (assuming that to be the power operating on the moon) as it would affect a body at the same distance from the earth as is the

* The rule is deduced from the usual formula, $t=\pi\sqrt{\frac{l}{g}}$; in which *t the time*=1 second, *l*=the length of the seconds pendulum, π=3·1416, the circumference of a circle whose diameter is unity, and *g*=twice the required space.

† See *Principia*, 38 Prop. and Phenomena IV., concerning centripetal forces.

moon. The following is an exposition of his line of reasoning.

Assuming, as the measurements of astronomers justify us in doing, that the moon is distant 240,000 miles from the earth, we can easily calculate the space through which she would fall, if left to herself, in the time of a minute. This space would be, as Newton has demonstrated in the 38th Proposition of the *Principia*, the versed sine of the arc described in that time; thus, suppose the arc C *d* (fig. 29) to be that described in a

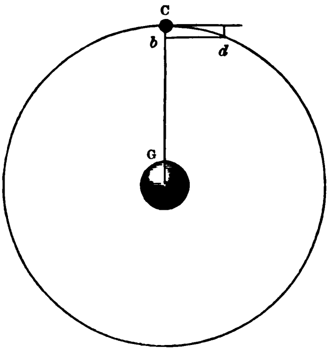


Fig. 29.

minute by the moon C; join C to E, the centre of the earth; draw *b d* perpendicular to C E; then will C *b*, the versed sine of the arc, be the space through which the moon would fall if unsupported, that is, if the centrifugal force should cease. Now the arc C *d* is easily found; for as the moon takes 27 days 7 hours 43 minutes to describe her whole orbit, the following proportion will give it:

As 27 days 7 hours 43 minutes : 1 min. :: 360° : 33″ nearly, = c *d*; of this arc, the versed sine *c b* may be easily computed; it is, in fact, $16\frac{1}{12}$ feet, taking the moon's distance to be 240,000 miles.

Now, on the supposition that the force retaining the moon in its orbit be identical with terrestrial gravity, it ought to have decreased in proportion to the square of the distance; that is to say, assuming the moon to be sixty times further from the earth's centre than a body on the earth's surface, or distant one semidiameter (that is, $EC = 60 \times EG$), which is about the truth; the space described by the moon should be to the space described by a falling body near the earth's surface as 60^2 to 1^2, the time being the same. Now a body would fall through 59,400 feet in one minute near the earth's surface: hence,

As $60^2 : 1^2$ or as 3600 : 1 :: 59,400 feet : $16\frac{1}{2}$ feet, which is the space through which a body would fall in a minute at the distance of the moon. Now this exactly agrees, making allowance for our using round numbers, with the actual distance through which the moon would fall were the centrifugal force to cease. The moon, therefore, is retained in her orbit by gravity, and gravity only, for it would be unphilosophical to assign two causes to account for effects precisely similar.

170. By similar calculations and the like train of reasoning, it might be made to appear that the force of gravity extends throughout the solar system, connecting the planets with the central orb of the sun; and that the same cause which unites the moon to the earth connects with their primaries the satellites of Jupiter, Saturn, Uranus, and Neptune.

On comparing moreover the force of gravity exerted on the separate planets by the sun, which may be ascertained by noting, as in the case of the moon just explained, the space through which each would fall in a given time, it will be found that, agreeably to the proportion originally laid down, this force will be inversely as the squares of their respective distances from him; that is, "the forces with which they are severally attracted by the sun are great exactly in the same proportion as the squares of the several numbers expressing their distances are small."*

171. The following quotation from the Astronomer Royal's treatise on gravitation, published in the *Penny Cyclopædia*, will be appropriate to the subject now under discussion:—

"The reader may ask, How is all this known to be true? The best answer is perhaps the following: We find that the force which the earth exerts upon the moon bears the same proportion to gravity on the earth's surface which it ought to bear in conformity with the rule just given. For the motions of the planets, calculations are made which are founded upon these laws, and which will enable us to predict their places with considerable accuracy if the laws are true, but which would be much in error if the laws are false. The accuracy of astronomical observations is carried to a degree that can scarcely be imagined; and by means of these we can every day compare the observed place of a planet with the place that was calculated beforehand according to the law of gravitation. It is found that they agree so nearly as to leave no doubt of the truth of the law. The

* Cabinet Cy., art. Mechanics, p. 81.

motion of Jupiter, for instance, is so perfectly calculated, that astronomers have computed ten years beforehand the time at which it will pass the meridian of different places; and we find the predicted time correct within half a second of time."

172. Before proceeding to apply more fully the laws of gravitation to the planetary motions, it will be necessary to explain a few elementary mechanical laws.

I. All matter possesses a property called *inertia;* that is, it has a disposition to continue in its existing state, either of motion or of rest.

Of the disposition of matter to continue in a state of rest, we have ample proof in every thing around us. We know very well that nothing near us will move from the position which it now occupies unless it is displaced by some motive force. But the fact that any body, when once moved, will continue in motion till force be applied to stop it, does not so immediately receive our assent. Indeed, so lately as the time of Kepler, the beginning of the seventeenth century, it was a generally received maxim among philosophers that matter was more inclined to rest than to motion. But is it not just as rational to suppose that a body could spontaneously commence motion, as that it has the power of discontinuing that motion? Whenever, then, motion ceases, we must look for some cause of its discontinuance. Of such causes we may mention, as those which are the most obvious, friction, the resistance of the air, and the attraction of gravitation.

If a ball be rolled along the ground, its motion soon ceases from the friction against the surface. A pendulum made to vibrate will, after no long time, cease, being impeded by the resistance of the air, and the friction at the point of suspension; in a vacuum the latter obstacle only has to be overcome, and there it will continue to vibrate for days.

If a ball be projected into the air, the force of gravity will begin to draw it downward the moment its motion commences, and will at last cause it to fall to the ground; the more powerful the projectile force, the longer time elapses before it reaches the earth, or describes the arc *a g b*.

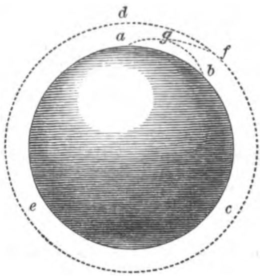


Fig. 30.

The greatest length of the arc *a b* which a cannon-ball describes when projected most powerfully, is about three miles; but were it not for the resistance of the air, it would be impelled ten times as far.

Now it is not difficult to imagine that a body might be projected beyond the atmosphere with such a force as would bring it once round the earth before gravity had drawn it to the surface: it would then continue to describe for ever the circle *f c e d*, inasmuch as it would move free from all obstruction. This case would be of the same kind as that of the revolution of the moon round the earth; or of the satellites of Jupiter, Saturn, and Herschel round those planets.

In the revolution of the planets round the sun we have a still more sublime verification of the truth of the law now under consideration. Unceasingly and unchangingly do they traverse their courses, retaining with undiminished speed all that motion which they received from the hand of the Eternal when first he launched them into space.

173. II. All motion is naturally in a straight line. A bullet shot vertically into the air will descend to the spot from whence it was projected; hence we may conclude, whenever we observe a curvilinear motion, that more than one force is concerned in producing it.

174. III. If a body be acted upon by two forces impelling it in different directions, the body will obey neither, but will take a direction compounded of both, or between the two.

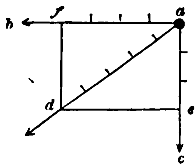


Fig. 31.

Thus if a body *a* be acted on by a force urging it in the direction *a b*, at the same moment that another force impels it towards *c*, the body will take a direction between the two. In order to find that direction, set off on the lines *a b* and *a c* (which represent the direction of the two forces), from a scale of equal parts, a number of divisions proportional to the spaces through which these forces would respectively urge the body in equal times. Thus, if *a* were impelled towards *b* at the rate of four feet in a second of time, while the force in the direction of *a c* would urge it three feet, let four divisions be set off on *a b*, and three on *a c;* draw *e d* parallel to *a f*, and *d f* parallel to *a e;* join *a d*; then will *a d*, the diagonal of the parallelogram *a e d f*, represent both the magnitude and direction of the compound force, in this case five feet—which line will be described in the same time as, with either of the other forces separately, the body would have moved through *a e* or *a f*.

175. IV. If one of these forces be uniform, while the other is accelerated, as in the case of a body falling to the earth, before described, the body will describe a curve.

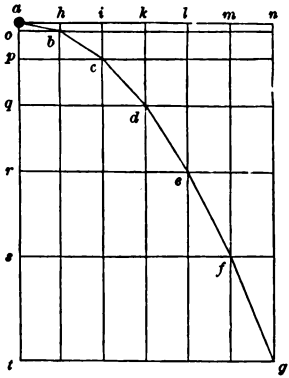


Fig. 32.

Let the body *a*, fig. 32, be urged by a uniform motion in the direction *a n*, in such a manner that it will describe the equal spaces *a h*, *h i*, *i k*, *k l*, *l m*, *m n*, in equal times, say in a second; at the same instant let it be urged in the direction *a t* by an accelerative force, inducing it to describe, in successive seconds, *a o*, *o p*, *p q*, *q r*, *r s*, *s t*, each one greater than the last, as in the case of a body drawn to the earth by gravity; at the end of the first second it will have described *a b*, at the end of the second *a c*, at the end of the third it will have arrived at *d*, of the fourth at *e*, and of the sixth at *g*, by the third law. By inspecting the figure in which the parallelograms are completed and the diagonals drawn, it will be seen that the line *a b c d e f g* approximates a curve; and inasmuch as the accelerative force does not act by fits and starts, we have only to imagine these parallelograms indefinitely diminished, we should then entirely get rid of the angles, and the curve would be perfect. Thus the truth of the law will be shewn.

Now we may suppose *a* to be a ball impelled horizontally from a cannon; at the moment of its leaving the mouth of the gun, gravity, which we have seen to be an accelerative force, will begin to operate, and will cause the ball to reach the ground in precisely the same time that another would do let fall immediately from the mouth of the gun.

176. Law V. Action and reaction are equal.

If the earth and moon were allowed to approach each other, the moon would attract the earth as well as the earth the moon; the larger space, however, would be passed through by the moon, for the attraction of the earth would draw the moon through eighty inches, while the moon's would draw the earth through one inch, for their masses are in the proportion of one to eighty. Thus also it is a fact, true in theory but not evident to our senses, that every body falling to the earth, or projected from it, attracts or repels the earth to or from itself: when the difference in the mass of the earth and that of any body which can be projected from it is taken into account, it will be easily understood why this motion is inappreciable.

177. Law VI. Every body revolving in a circle has, from the natural tendency of motion to be in straight lines, an inclination to fly off in the direction of a tangent to the circle, or in a line perpendicular to the diameter, which inclination increases with the rapidity with which a body revolves.

Instances of centrifugal force, which is the name the tendency of a body to recede directly from a central point has received, are of constant and familiar occurrence. It is this which gives the projectile force to a stone thrown from a sling, which always darts off in a tangent to that part of the circle from which it is liberated, as from *m* to *d*, fig. 33.

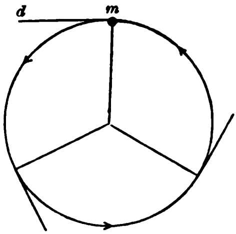


Fig 33.

Suspend a glass of water by a twisted string; allow the string to untwist; the surface of the water, which at first was horizontal, will sink in the middle and rise at the sides, from its tendency to fly off from the centre: this tendency will increase with the rapidity with which the vessel is allowed to revolve.

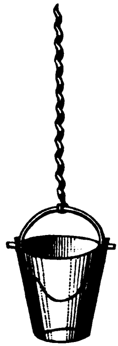


Fig. 34.

178. We see from what has now been said, that all motion not interfered with will be in a straight line, and that consequently any curvilineal motion will require more than one force to produce it. The above laws will have prepared us for entering upon the investigation of the forces concerned in producing the movements of the planets round the sun; which, for the sake of simplicity, we will assume to be performed in circular orbits.

Suppose a planet A (fig. 35) at its creation to have received an impulse in the direction A E; it would have continued to move in that direction until some force had deflected it from a straight line (from Laws I. and II.);

but if, on its arrival at B, the attraction of the sun had begun to operate upon it in the direction B C, the planet

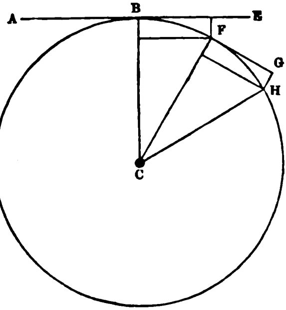


Fig. 35.

being now under the influence of two forces, one of which (the projectile) is uniform, while the other (the attractive) is accelerated, it would describe the curve B F (from Law IV.). But (from Law VI.) it would now have acquired a centrifugal tendency, or an inclination to fly off in the tangential line F G; which centrifugal inclination, combined with gravity, would cause it to describe the next portion F H of the curve. Now in the case we have supposed, the curves B F, F H are parts of a circle; and since both the attractive force and centrifugal force must then be equal, it is obvious that not only will the body complete the curve and arrive at B, but will continue to circulate round C (from Law I.).

179. It is clear that the projectile force must bear a particular relation to the attractive force, in order that the curve may be a complete circle. Sir I. Newton has shewn that to produce this result the projectile force

must be equivalent to the velocity which the planet would acquire in falling through half the radius of the circle; in every other case the planet, through the greater or less proportion between the projectile and attractive forces, would describe curves differing from a circle, varying its distance from its centre, C. Now such is, in fact, the case with the planetary orbits.

Before taking into account the deviation of the orbits of planets from a circular form, it will be proper to explain what is meant by the CONIC SECTIONS.

180. Sir Isaac Newton has shewn that any body attracted by another in the same manner (as will shortly be pointed out more at length) as the planets and comets are attracted by the sun, may describe, as its orbit, either of the conic sections; that is, either an ellipse, a parabola, or an hyperbola. The conic sections will be understood from what follows.

1. If a cone be cut by a plane which passes obliquely through its slant sides, the section will be an ellipse, as A B C D, fig. 36: such are all the planetary orbits, and also those of the comets whose orbits are known to us.

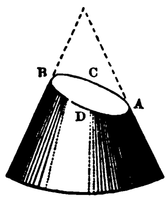


Fig. 36.

2. If a cone be cut by a plane which is parallel to its slant side, the section will be a parabola, as F G H, fig. 37: such are, probably, the orbits of many comets which have only once been seen or recognised by astronomers.

3. If a cone be cut into two parts by a plane which, being produced, would meet the opposite cone, the section is called an hyperbola, as H I K, fig. 38. It has not

yet been determined whether or not any heavenly body does describe a curve of this kind.

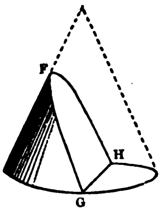


Fig. 37.

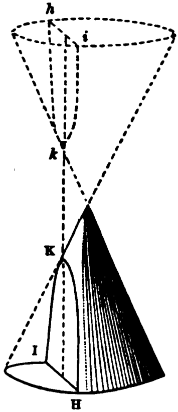


Fig. 38.

181. When speaking of the planetary orbits, we shall have frequent occasion to refer to the ellipse.

The properties of this figure are demonstrated at length by writers on the conic sections; we shall allude, in the present instance, only to one, inasmuch as that will suffice to shew the nature of the curve.

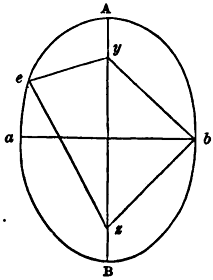


Fig. 39.

Let A *a* B *b*, fig. 39, be an ellipse; take half the longer diameter, and with this opening and the centre *a* or *b*, describe an arc cutting A B in the points *y*, *z*; these points are termed the foci of the ellipse. If from these foci two lines be drawn meeting at any point in the circumference, it can be demonstrated that their sum will always be equal to the longest diameter: thus,

$$e y + e z = b y + b z = \text{A} z + \text{B} z = \text{B A}.$$

From this property of the ellipse we derive an elegant and facile mode of drawing the figure; for having found the foci, and in them having fixed two pins, let us fasten to them the ends of a thread equal in length to the longest diameter. Stretch the thread with a pencil, and pass round from A to B; then will half the ellipse be described: do the same from B to A, and the figure will be completed. A moment's reflection will shew that the nearer the foci are to each other, the less will the ellipse differ from a circle; when they coincide, the figure will become a circle.

182. All the planetary orbits are elliptical, having the sun not in the centre as S, but in one of the foci as *y*. A B and *a b* are the major and minor axes of the ellipse; S *y*, the distance from the centre of the ellipse to one of the foci, is the eccentricity of the planet's orbit. This varies with every planet, and even in the most eccentric is very small; in short, were an ellipse to be delineated proportionately to the elliptic form of the earth's orbit, the eye without measurement could not distinguish it from a circle; the orbits of some comets are, however, very eccentric, as we have mentioned before.

If we consider half the longer diameter of the earth's orbit, as S A, to be 1, the eccentricity of its orbit S *y* will be equal to ·0167836, or about $\frac{1}{60}$.

183. The point of a planet's orbit where it ap-

proaches nearest to the sun is termed its PERIHELION, as A, supposing the sun to be at *y*; the point of greatest distance is its APHELION, as B. In the case of the moon moving round the earth, the point of its nearest approach to the earth is called its PERIGEE, and the most remote point its APOGEE.

The line joining these two points, as well as that joining the perihelion and aphelion, is the line of APSIDES; each of the points A and B is termed an APSIS. A line drawn from the sun to a planet in any part of its orbit is termed a RADIUS VECTOR.

TRUE ANOMALY is the angle made by two lines drawn from the focus or centre of motion, one to the perihelion, or perigee, and the other to the place of the revolving body.

MEAN ANOMALY is the angle made by a uniform angular motion about the focus as a centre.

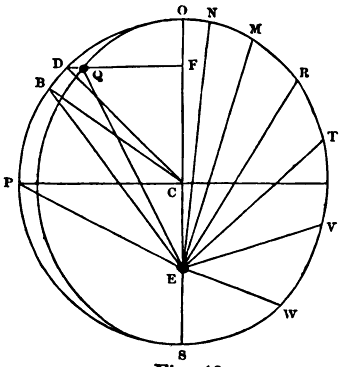


Fig. 40

These definitions will be elucidated by reference to fig. 40. Let O V S Q be a planet's orbit; E the place of the sun in the focus of the ellipse; C a point intermediate between O and S; from centre C describe the semicircle O P S. O S is the line of apsides; O the aphelion; S the perihelion; C E the eccentricity of the orbit. Let Q be the true place of the planet; B the place it would have if its orbit were circular and its motion uniform; draw F Q perpendicular to S O, and produce it to D; the angle S E B is the mean anomaly; S C D is the eccentric anomaly; S E Q the true anomaly; and S E B—S E Q the equation of the centre.

When the planet is in the apsides, then B and Q fall together in O and S, and here there is no equation of the centre, the mean and the true anomalies being equal. But the greatest equation of the centre will be when the planet is at its mean distance from the sun; which point will be found by drawing C P perpendicular to O S and joining E P.

184. We are now prepared to investigate the forces which caused the planets to assume the elliptical form of orbit.

If we suppose the projectile force which the planet at its creation received from the hand of the Almighty not to have been exactly of that velocity which it would have acquired in falling through half its distance from the sun, but to have been less or greater, the planet would certainly either have approached the sun, or increased its distance from him: in either case its velocity would vary; and, in consequence of the increased or diminished distance from the sun, his attraction on the planet would vary also.

185. To be more explicit. If while a projectile

force would carry a planet from A to F, fig. 41, the attraction of the sun at S would draw it from A to H; it would be found at the end of a certain time at O, and would have approached nearer to the sun at S than it was at A, S O being less than S A; so that its orbit would not be a part of a circle described round S.

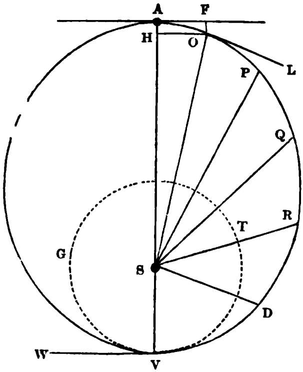


Fig. 41.

In consequence of the planet's having diminished its distance from the sun, his attraction on the planet is greater than before in the proportion of SA^2 to SO^2; still greater will it be at P, Q, R, D; greatest of all will it be at the perihelion V, where if we suppose, for the sake of illustration, $SA = 2SV$, the attraction of the sun on the planet at V will be to his attraction on it at A as 4 : 1.

It may at first sight appear unaccountable why, as the sun's attraction thus increases, the planet does not, after a few revolutions, fall into the sun. Why this catastrophe does not happen may be thus explained :

In the descent of the planet from its aphelion A to O, in consequence of its approximating the sun, the superior power of his attraction makes it revolve more rapidly; so that its velocity at O is greater than it was at A. But from Law VI. it appears, that with its velocity its centrifugal tendency must increase; so that its inclination to fly off in the tangent O L is greater than it was at the point A in the tangent A F; still greater is this tendency at P, Q, R and D successively. At the point V, where it is the greatest, the sun's attraction is also most powerful; otherwise there would be, we should suppose, a probability of the planet's leaving the sun in the direction of the tangent V W; but as it recedes from S, the attraction lessens, with it the velocity decreases, consequently the centrifugal tendency does so too; so that precisely the same course is gone over on the opposite side of the curve, as was described by the planet in its descent from A to V; when it arrives at A, the same course is gone over again, for the same forces come into operation under the same circumstances as at first, on the supposition that the planet is undisturbed by the attraction of other celestial bodies.

186. In no phenomena of the world of nature is the wisdom of the Deity more strikingly shewn than in the adjustment of these two forces. Were the Great Controller of Nature for one moment to allow the centrifugal force to outbalance the attractive, the planet would fly off into infinite space. If the projectile force were such that the attractive force could not recover the body, so to speak—that is, could not compel it to describe a curve returning into itself—the body would describe a parabola, or an hyperbola.

To describe a parabola, the projectile velocity must be equal to that which would be produced by a body in falling through the distance of the planet from the focus: a less projectile velocity would cause the planet to describe an ellipse; while a greater would cause it to describe an hyperbola.

On the other hand, were the attractive force to gain the ascendency, the planet would whirl round in a series of curves, gradually decreasing in magnitude till it rushed into the sun. But so accurately have they been adjusted, that from the first moment of creation till the present time, no confusion, no interference has disturbed, or ever will disturb the beautiful equilibrium.

In this general view of the planetary orbits, many points of the highest importance have been omitted. To enter into them fully would require great nicety of mathematical calculation; to pass over them entirely would dismiss from our consideration some of the most wonderful instances of the accuracy of modern science, and of the beauty of the arrangement of the forces which regulate the solar system.

187. We are not to suppose that the sun remains stationary in the focus of the planetary orbits: strictly speaking, there is only one stationary point in the whole system, and that is the centre of gravity of the whole. A few words on this subject will explain what we mean.

If we unite two balls of different weights by a wire, and suspend them by a string attached to it, the point of suspension, when the balls exactly balance each other, will be their centre of gravity. Give them a whirling motion, and they will both describe circles round this centre of gravity, which alone will remain fixed: the heavier ball will describe a circle smaller in inverse proportion to its weight, compared with the circle described by the lighter body, for the distance of the body A (fig. 42) from the centre of gravity C bears the same proportion to the distance of B as the mass or weight of B does to that of A; that is,

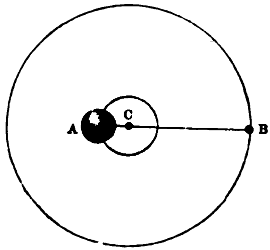


Fig. 42.

A C : C B :: B : A.

Now, provided the whole solar system was only one planet revolving round the sun, these two balls would not inaptly represent it, for the bodies are as closely united to each other by gravity as these are by the wire A B.

188. If we add other bodies to these two, the centre of gravity will change its position, but will still be the point where, when the system is supported, there will be stable equilibrium.

In the case of the sun and planets, from their constant change of position with respect to each other, it is plain that they must constantly vary their position with respect to the centre of gravity; the sun being sometimes on one side (so to speak) of the centre of gravity, and sometimes on the other, according as the planets are distributed; the mass of the sun, however, so much surpasses that of all the members of the solar system besides, that his distance from the centre of gravity is never very great, as we shall have occasion again to remark.

189. Now, not the slightest movement is made by the smallest planet without disturbing the equilibrium of the whole system, and a corresponding motion of all the rest must take place to restore it. If the attraction of the sun on a planet diminishes in the way we have seen in § 185, and the planet therefore recedes from him, and consequently from the common centre of gravity, the attraction of the planet on the sun decreases also (from Law V.), and he recedes so far from the centre of gravity as to restore the equilibrium. Nor is this the case with one planet only, but with every planet; at all times they are changing their position with respect to each other and the sun; not one instant therefore is the sun stationary, for every one of their movements must be accompanied by a corresponding change of position, however small, on his part. Now the extreme difficulty of calculating, so accurately as has been done, the places of the heavenly bodies, will be easily imagined when, in addition to this circumstance, we consider that not only is there this reciprocity of attraction between the sun and planets, but that the planets mutually attract each other; so that no planet describes, during any two revolutions, exactly the same curve. If, for instance, the earth should approach very near the planet Jupiter one year, its orbit would be elongated towards him: perhaps the next year at the same period, Jupiter's attraction would draw the earth in an opposite direction; that part of the earth's orbit would then, so to speak, be flattened. Moreover, such of

the planets as are provided with satellites are disturbed by them; for the regular curve of the orbit is not described by the planet itself, but by the centre of gravity of the primary and satellites. Again, the plane of the orbit will also suffer disturbance in its inclination; for if we suppose Jupiter to lie above the earth's orbit, the line of attraction will cause the earth, when passing him, to ascend somewhat towards him; perhaps in another part of the earth's orbit she may meet with Saturn, whose orbit we will imagine to lie on the opposite side; the consequence will be, that the earth will advance somewhat in a contrary direction to meet him. To these effects are given the name of PERTURBATIONS: in calculating them the aid of the most refined mathematical analysis must be called in—the motions, the masses, and the distances of all the planets at every instant of time must be perfectly known; and yet so completely has this branch of astronomy been mastered, that, for years in advance, the exact spot in the heavens which will be occupied by the most insignificant body of our system can be predicted with undoubted and astonishing accuracy.

190. Even if at any time all the planets were on one side of the centre of gravity and the sun on the other, the mass of the sun so far exceeds that of the planets collectively, that the centre of gravity would still fall within the surface, or nearly so, of the sun.

Again, should it so happen that the planets are so distributed that those on one side of the sun exactly balance those on the other, the centre of gravity will coincide with the centre of the sun.

In any case the centre of gravity of the system and that of the sun so nearly coincide, that we are justified in using the popular expression and speaking of the sun as the centre of the solar system.

191. It may be asked, how can any human contrivance, as that of the two balls before called in to our aid, of which the centre of gravity is of necessity supported, bear any resemblance to the planetary system? What supports the centre of gravity of the sun and planets?

To this it may be sufficient to reply, that, in any contrivance to illustrate the solar system, we are obliged to counteract, by some support, the attraction of the earth, which would cause it to fall to the ground. But the solar system is so disunited from any bodies extraneous to itself, that there is nothing to disturb or draw from its position the centre of gravity of the whole; which retains, as far as we have the means of judging, the exact situation, in the particular point of infinite space, which was originally assigned to it by the Almighty Creator: unless, indeed, the whole has a motion round the centre of the universe, of which the later discoveries of science seem to give a distant intimation.

192. Amidst all the variations, then, which we have enumerated, is there nothing stable? Has the Great Author of nature launched those bodies into space with any probability of collision? subject to disturbances which sooner or later will bring about the destruction of the whole system, or so change the character of the orbits of the planets that their adaptation to present circumstances will no longer continue? that variations, minute individually, will so accumulate as at last to involve all nature in confusion?

Not so has the great Architect left his work. To supply answers entirely satisfactory to these inquiries would lead us more deeply into the mathematical branch of the subject of physical astronomy than the nature of this treatise would admit; we can only glance at a few of the more obvious proofs of the sustaining hand of Omnipotence.

Many of these variations are periodic; that is, they vibrate on each side of an imaginary fixed line or plane. Thus, the position of the earth's orbit is variable; but the disturbing forces on each side counteract each other in an extended period of time, being in fact equal to that in which the planets will again have, each and all, the same position with respect to each other as they have at any given instant of time. The amount of the variation in the position of the ecliptic is at present 48″ per century, and its extreme vibration on each side of its mean position 1° 21′; having attained which on one side, it will return gradually to its original position. The like holds good with respect to the orbits of the other planets.

193. Other perturbations are secular; that is, they are completed in incalculably long periods of time: as the eccentricity of the earth's orbit, which has been, since the earliest age, diminishing, and will continue so to do till it becomes a circle; when its form will resemble an oval, again attain its maximum degree of eccentricity, and then again approximate to a circle. The period required for this fluctuation is one to which the whole history of the human race is, as it were, a point.

194. Other phenomena are constant; that is, they are subject only to variations which in time are accu-

rately compensated. The mean length of the longest diameter of a planetary orbit, that is, its major axis, and the time of its diurnal, as well as the mean period of its annual revolution, are among these.*

From these facts, and from others understood only by themselves, mathematicians have deduced the certainty of the permanence of the system, subject to those laws which now obtain throughout it. Nor will the circumstances of the bodies composing it materially vary, nor the system itself, or any individual member of it, come to destruction, even at a period indefinitely remote, unless the same Voice which at first summoned it into being shall again interfere and pronounce its doom.

195. We have alluded to the relative masses of the sun and planets. Presumptuous as it may appear that man should compare the density of those mighty and distant bodies, yet has the philosophy of Newton brought this within the reach of human intellect. In the explanation of a part of astronomy so profound, it is difficult to make the method by which this wonderful result has been attained clear to those who cannot follow his train of mathematical reasoning. We shall, however, endeavour, by following out the principles already laid down, to give some notion of the possibility, at least, of such measurement being effected, with the hope that such an attempt will be satisfactory, and render the subject in its principal outlines intelligible.

196. We have seen in § 169, that the earth causes the moon to descend from a tangent to her orbit $16\frac{1}{12}$

* These subjects are most agreeably and philosophically reasoned out in Sir John Herschel's "Astronomy."

feet in a minute of time, and the manner in which this may be calculated was shewn.

It has also been stated (§ 161), that the force of attraction is measured by the distance through which it causes a body to move in a given time, and that this force increases directly as the mass is increased (§ 158). Now if the earth had twice its present density, *i. e.* if the mass under the same volume were twice as great, it follows from these premises that the moon in one minute would be drawn through $16\frac{1}{12} \times 2$ or $32\frac{1}{6}$, and if its density were increased tenfold, the moon would be drawn through $16\frac{1}{12} \times 10$ or $160\frac{5}{6}$ feet in one minute (refer to fig. 29, where c *b* is the space alluded to); but since with the increase of the attractive force the centrifugal becomes more powerful to counterbalance it, the combined effect of these two would cause the moon to revolve round the earth, on the former supposition, in half the time it now does, in the latter in one tenth of that time. Now, if it had so happened that there was a planet revolving round the sun at the same distance that the moon revolves round the earth, our task of comparing the masses of the two central bodies would be soon accomplished; for we should only have to calculate, in the manner shewn in § 169, the deflection from a tangent in a given time (viz. c *b* in fig. 29) of the moon and of the planet, and the proportion would give us the proportion of the masses of the two central bodies; for the amount of attraction at equal distances is in direct proportion as the masses. The relative differences in the masses of the moon and planet would introduce no error into our computation, for we have already seen (§ 162) that attraction acts equally on all bodies at equal distances.

But there is no planet situated at the same distance from the sun that the moon is from the earth, and hence the calculation becomes more involved; but may still be easily understood, if we bear in mind that the attractions are inversely as the squares of the distances.

Let us first ascertain the deflection of the earth from a tangent caused by the sun's attraction. Proceeding in the same way as in that already pointed out for ascertaining the deflection of the moon produced by the earth's attraction (viz. C *b* in fig. 29), we shall find that the proportion between the distance through which the moon will be drawn by the earth, and that through which the earth will be drawn by the sun in the same time, will be as 1 to 2·2. Now, as we have already seen (§ 158), the whole amount of attraction is in a ratio compounded of the ratios of the masses directly, and of the squares of the distances inversely, that is letting F stand for the attractive force of the sun measured by the versed sine of the arc which the earth describes, in one minute of time, viz. 2·2; and *f* for the attractive force of the earth on the moon measured by the versed sine C *b*, through which the moon would be drawn in a minute of time, viz. unity or 1; also the ratio of D to *d* for that of the distances of the earth from the sun, and of the moon from the earth, which is as 400 : 1; and M to *m* for the ratio of the masses of the sun and earth, which we desire to know; then

$$m : M :: f d^2 : F D^2$$

(by the *Principia*, prop. 74, theor. 34), that is $m : M :: 1 \times 1^2 : 2{\cdot}2 \times 400^2$ or $m : M :: 1 : 352{,}000$; so that the mass of the earth is to that of the sun as

1 to 352,000; or it would take 352,000 earths to make a body equal in bulk to the sun.

197. In like manner, by marking the deflections of one of the satellites of those planets which are provided with them from a tangent to its orbit, and comparing it with the influence of the earth on our moon, the proportional density of that planet may be found. The mass of the planet Jupiter, which, next to the sun, is the largest body by far in our system, has lately been very accurately determined by the Astronomer Royal from a series of observations on the position of his satellites, made with the most delicate instruments, adapted to the measurement of extremely minute quantities.

198. There now remain those planets which are unaccompanied by satellites. Their densities are known by means of their perturbations, compared with what their orbits ought to be as deduced from theory; but upon this branch of the subject the plan of this treatise demands silence, inasmuch as it is too complicated to be made intelligible without more of mathematics than would accord with our design. Knowing the diameter and the mass of a heavenly body, a simple proportion will enable us to work out its mean density as compared with that of another body. See more on this subject in Part I., under the head of "The Earth;" where will be found an account of the methods adopted in measuring the density of our planet.

199. The following are the densities of the different bodies of our system, that of the Earth being 1—

Sun	·26	Earth	1	Saturn	·11
Mercury	2·95	Mars	·79	Uranus	·26
Venus	·99	Jupiter	·23	Moon	·75

We may present to the mind clearer notions of the relative densities of the planets, by remarking that the planet Mercury is about the density of quicksilver; the density of Venus and the Earth is that of steel; of Mars and the Moon as diamond; of the Sun, Jupiter, and Uranus, as resin; and that of Saturn as deal.

200. Those planets which are nearer to the sun, not only revolve round him in a shorter space of time from the circumstance of their orbits being less extensive, but their rapidity is much greater, as might be anticipated from what has been already stated. For the attraction of the sun is greater on a nearer planet than on one more remote, in inverse proportion to their distances squared; but since, with the force of attraction, the centrifugal tendency must also be greater to counteract it, it follows that these two forces combined cause a nearer planet to revolve round the sun with much greater rapidity than one further removed from him. Hence the motion of Mercury in his orbit is much more rapid than that of the Earth; while that of the Earth is much quicker than that of the planets Jupiter or Saturn.

201. To the celebrated astronomer Kepler we are indebted for the discovery of several curious and beautiful arrangements in the solar system; three of these, usually known by the name of Kepler's Laws, we are now prepared to understand.

I. The orbit of the Earth, and also the orbits of the other planets, are ellipses, of which the Sun occupies the common focus.

Little thought the philosopher Plato, who discussed with his disciples the doctrine of the conic sections, of the beautiful adaptation of their properties to the motions of the celestial bodies. Let us, from the circumstance of the properties of the conic sections having existed as naked truths for twenty centuries before the time of Kepler, learn not to despise mathematical speculations, the advantages of which are not immediately apparent. The ancient geometricians imagined that the heavenly bodies must necessarily move in circles, and all their reasoning respecting them proceeded upon this supposition. Kepler was the first to discover, by patient and accurate observation of the planet Mars, that his orbit was of an elliptic form; and thus he paved the way for a more perfect development of the orbicular motions of the planetary system. Compare § 121, on the orbit of the earth.

202. II. That the radii vectores, or lines drawn from the sun to a planet at any part of its orbit, describe equal areas in equal times.

Referring to figure 40, we will suppose the earth to take the same time to pass from the points S to W, W to V, V to T, T to R, &c.; and in that case the spaces S E W, W E V, V E T, T E R will all be equal in area.

203. III. The squares of the periodic times of any of the planets are to each other as the cubes of their mean distances from the sun.

The value of this law will appear when we consider that, knowing the distance of any one planet—say, for instance, the earth—from the sun, we can, by its aid, calculate the distance of any other.

Let us assume, for simplicity, the distance of the earth from the sun as 1; the length of the year of Jupiter* and that of our own are known, we wish to find his distance. The law gives the following proportion :

Square of Earth's period	:	Square of Jupiter's period	::	Cube of Earth's dist.	:	Cube of Jupiter's dist.
1 × 1		11·86 × 11·86		1 × 1 × 1		140·5596

The cube root of the latter number is 5·2, which is the proportion between Jupiter's distance and the Earth's.

204. A German astronomer, Bode, has lately endeavoured to establish a singular proportion which appears to hold good between the planetary distances; it is "that the interval between the orbits of any two planets is about twice as great as the inferior interval, and only half the superior one ;" *i.e.* the interval between the orbits of the Earth and Venus is double that between Venus and Mercury, and only half the distance between the orbits of the Earth and Mars : in other words, the distances of the planets beyond Mercury form a geometrical series, whose ratio is 2. It is supposed that the same proportion holds good with respect to the distances of the satellites from their primaries : but on this head astronomers have not as yet arrived at any direct conclusion. To convey a clearer idea of this law, let a represent the distance of Mercury, b the distance of the planet Venus minus that of Mercury, then :

$a =$	distance of Mercury.
$a + b =$	. . . . Venus.
$a + 2b =$	. . . . Earth.
$a + 4b =$	. . . . Mars.
$a + 8b =$	. . . . the Asteroids.
$a + 16b =$	. . . . Jupiter.
$a + 32b =$	. . . . Saturn.
$a + 64b =$	. . . . Uranus.

* Equivalent to 11·86 of our own.

Although both Adams and Le Verrier, in calculating the disturbing effect of the unknown planet on Uranus, assumed its distance from the sun to be in accordance with this law, yet an accurate determination of the elements of Neptune's orbit from observation has shewn that, in this instance, it entirely fails. "The interval between its orbit and that of Mercury, instead of being double the interval between those of Uranus and Mercury, does not in fact exceed the latter interval by much more than half its amount. This remarkable exception may serve to make us cautious in the too ready admission of empirical laws of this nature to the rank of fundamental truths; though, as in the present instance, they may prove useful auxiliaries, and serve as stepping-stones, affording a temporary footing in the path to great discoveries."*

* S. J. Herschel.

PART III.

PRACTICAL ASTRONOMY.

DEFINITIONS.

205. 1. An angle is the inclination of two lines to one another, which meet together, but are not in the same direction.

Since the principal part of Practical Astronomy consists in the right measurement of angles, it will be quite necessary to entertain clear notions of what an angle is before we proceed further. Let A and C, fig. 43, be two objects from which rays of light meet the eye at D; A D C will be the angle they subtend at the point D. It is possible that two other objects, at very different distances, may subtend the same angle: thus F and G form, at the point D, the angle F D G, which is identical with the angle A D C. The length of the lines which form an angle has nothing to do with its measurement, which takes into account only the inclination of the lines.

To measure angles, we suppose a circle to be described from the angular point as a centre. This circle is divided into 360 degrees, each of which is subdivided into sixty minutes, and each of these again into sixty seconds. If it be required to measure the inclination of two lines drawn on paper, as A D and C D in the page before us, we should apply the centre of a brass quadrant, semicircle, or circle, termed a protractor, which

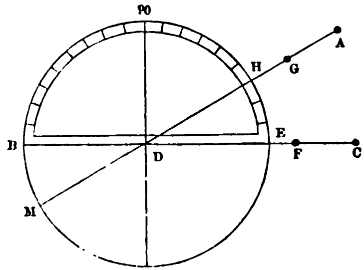


Fig. 43.

always accompanies a case of mathematical instruments, to the angular point D, and make the edge D E coincide with the line D C: we then observe the number of degrees intercepted between E and H, the point where the line A D cuts the semicircle, which will be the measure of the angle required; in this case 30 degrees.

Simple as this process may appear, it is exactly similar in principle to that which the most elaborate astronomical instrument is made to perform. We may suppose, for instance, the circle H E M B to be the outline of an astronomical circle, E B to be a horizontal line, H M to be a telescope directed to the star A, whose angular height above the horizon we wish to ascertain: this height will be the number of degrees in the arc H E, or its equal B M, which may be read off on both sides of the circle. Indeed, the advantage of an entire circle in measuring angles is, that the mean of the two or more arcs read off may be taken, and thus the errors of centering or of graduation may be compensated. Suppose the value of the arc to be 30 degrees 5 minutes 45 seconds, the expression would thus be abbreviated, 30° 5′ 45″.

206. 2. A PLANE TRIANGLE is a figure contained by three straight lines, which at the points of meeting form three angles. The length of the sides will always be indicated by lineal measures, as yards, miles, &c.; the values of the angles (the sum of which, under all circumstances, will be equal to two right angles, Euclid, i. 32) in degrees, minutes, and seconds.

207. 3. PLANE TRIGONOMETRY is the science which treats of the properties of plane triangles. By means of certain proportions always holding good between the three sides and three angles of a triangle, we are able, by the aid of this branch of mathematics, when any three of these six quantities are known (provided that one of these known quantities be a side), to find the other three.

208. 4. A SPHERICAL ANGLE is formed by the meeting of two lines on the surface of a sphere or globe. To understand this and the following definition, it will be necessary to consult the celestial and terrestrial globes:

Trace any two meridians, as those of London and Petersburg, from the equator northwards; they will meet at the north pole, and there form a spherical angle, which, measured on the equator, will be found equal to 30°.

The measure of a spherical angle will always be taken on a circle 90° every way distant from the angular point. Thus, in the last example, the measurement of the distance of the two meridians which met at the pole was reckoned on the equator.

209. Refer to fig. 3, Plate VIII. Z x p and Z y m are vertical circles passing through the stars x and y, and meeting the horizon in the points p, m, 90° distant from Z; the arc p m is the measure of the spherical angle p Z m.

The point which is 90° distant from any great circle on a sphere (that is, a circle which divides the sphere into two equal parts) is the pole of that circle: thus, the north and south poles are the poles of the equator; and on the celestial globe, the pole of the ecliptic is every way distant 90° from that circle. The zenith and the nadir are the poles of the horizon.

210. A SPHERICAL TRIANGLE is formed by the intersection of three great circles. Draw a line from London to Petersburg on the terrestrial globe: the portions of the meridians of those places between them and the pole will form two sides of a spheric triangle; and their distance, represented by the line joining them, will be the third side. Both the sides and angles of a spheric triangle are expressed in degrees, minutes, and seconds.

Again, in fig. 3, Plate VIII., N y is the north polar distance of the star y; N x that of the star x; x y the angular distance of those stars. These three arcs form the spheric triangle N x y.

211. By the principles of SPHERICAL TRIGONOMETRY we are able, from any three quantities being known, out of the six which compose a spheric triangle (viz. the three sides and three angles), to find the other three. Problems on the globes are, for the most part, a rough method of working problems in spherical trigonometry. It will be our object in this part of astronomy to explain to the reader the principles on which the science

of Practical Astronomy is founded; but it would not be consistent with the plan of this work to go into the numerical solution of the various questions which may arise: such is the province of trigonometry; to the study of which, in its most agreeable form, it is hoped that the present treatise will form a fair introduction. The use of the globes, also, will be rendered much more agreeable after the explanations and elucidations which follow; and the student will feel much greater pleasure in the performance of problems on them when he is acquainted with the principles on which they are founded, than can arise from merely following the rules which usually precede them.

SECTION I.

OUR POSITION IN THE UNIVERSE.

212. THE solar system, with its central luminary the Sun, may be considered as entirely detached from any of those stars which are distributed throughout space. We may imagine ourselves isolated from all other systems, but surrounded by them on all sides at immeasurable, but not equal, distances. Presuming that the organs of vision are the same in other planets as our own, we may conclude that the inhabitants of planets which are probably circulating round the fixed stars, only know of our system by observing the light of our sun, which, before it will have reached them, will have dwindled down to that of a twinkling star.

Of the fixed stars our knowledge is very limited;

nor will this be a matter of surprise, if we take into account their distances from us, of which some notion may be formed from the following considerations.

213. Suppose *h*, *i*, *k* (fig. 44) to be three fixed objects, as houses or trees, at unequal distances from the road *l m*; in passing from *l* to *m*, these objects will evidently appear to vary their position with respect to objects at a much greater distance; and the nearest object will undergo the greatest change of position, as will be seen

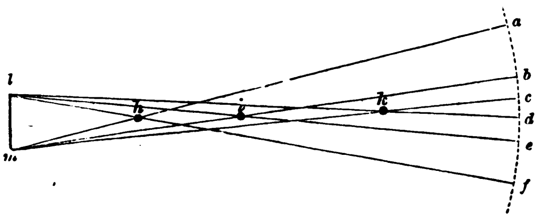


Fig. 44.

by comparing the space *a f* with the spaces *b e* and *c d*. Now it will easily be imagined that, when the proportion between the space *l m* and the distance *l k* is very great—as, for instance, if *l m* be two yards, and *l k* six miles—in that case the very distant object *k* would not appear to change its position at all to a person passing from *l* to *m*.

214. Again, let us place ourselves at *h*, *i*, *k*; it will be immediately seen that the angle under which the line *l m* is viewed at each position successively will be less and less, until we can easily conceive a distance so great that the line *l m* would subtend no angle at all, or that it would diminish to a point or become indistinguishable. The angles under which *l m* is viewed

from the points *k*, *i*, *h*, viz. *l k m*, *l i m*, *l h m*, are the parallactic angles of the line *l m*.

215. With this introduction we are prepared to enter upon the consideration of the annual parallax of the earth's orbit.

Let A B C D (fig. 45) be the earth's orbit, with the sun S in the centre. The axis of the earth *ns* remains

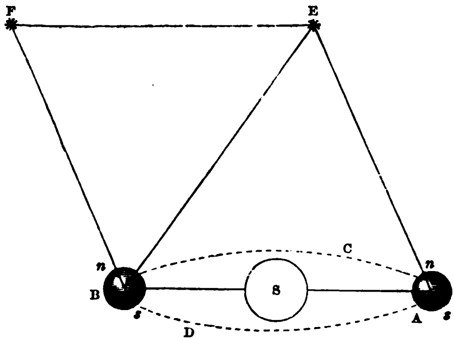


Fig. 45.

parallel to itself during the whole of the earth's revolution; that is, it always points in the same direction. We should suppose, then, that as in summer the axis points to the star E, so that in winter it would point to another star, F, the distance between which and the former would be equal to the whole diameter of the earth's orbit. But it is an established fact, that so great is the distance of the nearest fixed star compared with the diameter of the earth's orbit, that the angle A E B is inappreciable; or, which is the same thing, that the space of 190,000,000 miles, the distance from A to B, when viewed from the nearest fixed star, would dwindle down to a point, in the same manner as the space AB in the figure would do if viewed from the distance of a mile: it follows, then, that the same star is over the pole at all seasons of the year, and that those over the equatorial regions also retain their position in whatever part of its orbit the earth may be; and that the motion of the earth in its orbit will cause no difference whatever in the configuration of the stars, so minute would be the circle described by her in her yearly revolution when compared with the distance of those bodies.

216. Thus, then, we see that the system of which our earth forms an insignificant individual, and which yet contains within its sphere bodies of surprising magnitude, whose distances the mind labours to comprehend, is entirely unconnected with any of those unnumbered stars which illumine the heavens. Nay, more; not only might our earth be destroyed, but even the whole system with its central luminary might be annihilated, and no effect would be felt by the least remote of these bodies; and the only annunciation of such a catastrophe to its inhabitants, if any, would be, that a small star once seen in a remote quarter of the sky had ceased to shine. Were the parallactic angle of the earth's orbit so little as one second, which some have concluded it to be, it could not have escaped the minute and accurate observations of modern astronomers. In this case the distance of the nearest star would be 19,200,000,000,000 miles. Through this space light, which travels from us to the sun in 8¼ minutes, would occupy three years in traversing.

217. If the nearest star in the heavens be separated from us by such an immeasurable interval, what must

be the distance of those whose light is scarcely discernible by our best telescopes! Some, perhaps, are so remote, that the first rays of light which they sent forth may not yet have arrived within the limits of our system; while others, which may have been extinct for centuries, will continue to appear to shine till the last ray which they emitted shall have reached the earth.

SECTION II.

DOCTRINE OF THE SPHERE.

CELESTIAL GLOBE—CIRCLES OF THE SPHERE—RIGHT, PARALLEL, AND OBLIQUE SPHERES—DEFINITIONS OF ASTRONOMICAL TERMS.

218. THE conclusion to which we are led by the preceding considerations is, that the solar system is situated at an immense distance from, and is independent of, any bodies extraneous to it; and that however we might change our situation within the limits of the system, such change of position will cause no alteration in the configuration of the starry heavens. This circumstance greatly facilitates the labours of astronomers; for it is evident that if there were no fixed points of reference, which there would not be if the relative position of the fixed stars were variable, the greatest confusion would attend every attempt to represent the face of the heavens, or to determine the position of a heavenly body; but since the stars never change their relative position, it is plain that they may be made to serve the purpose of marking the places of the planets, or any other celestial body which may change its place from time to time.

219. For convenience of reference, astronomers have

supposed various circles to be drawn in the heavens, which will come under our notice in this part of the treatise.

The most available and useful instrument for illustrating the doctrine of the sphere (as the knowledge of these circles is termed), is the CELESTIAL GLOBE, which is a delineation of the fixed stars in their proper positions: that it is by no means so correct a representation of the heavens as the terrestrial globe is of the earth, may be seen at a glance. Were we transferred to the moon, or any other body at no great distance from the earth, we should see it of the form presented to us by the terrestrial globe; but in no imaginable position could we view the heavens as they are represented on the celestial globe, on a convex sphere; they appear to us as delineated on a concave surface, while we look up at them from beneath. Now, in order to understand in what manner the celestial globe represents the heavens, we must imagine the eye to be in the centre; then, if the surface on which the stars are depicted were transparent, a glance through this surface, when the globe was duly rectified, would be directed to the corresponding star in the heavens, which would be seen immediately above its place on the globe. Or, to make the matter still clearer, we may suppose our position to be on a small terrestrial globe within the celestial, and that their two axes coincide. Occasionally the celestial globe has been made of glass, with the stars on the surface, and a terrestrial globe within it, which was made to turn round from west to east by machinery, thus illustrating the motion of the earth and the diurnal apparent motion of the heavens very completely. Such instruments, however, are not practically useful; and no misunderstanding will arise in the use of the celestial globe, if the student will bear in mind that when it is turned on its axis from east to west, this movement represents no real but only an apparent motion of the heavenly bodies, caused by the revolution of the earth in an opposite direction.

A very large globe eighteen feet in diameter, wherein thirty persons could conveniently sit, was constructed by Dr. Long, at Pembroke College, Cambridge, in the last century: its frame-work was of copper and iron; while all the stars visible in the latitude of Cambridge were depicted on the concave surface; thus affording a very correct picture of the celestial hemisphere. What follows, on the circles of the sphere, will be much more easily understood if the student refers to both globes as he proceeds.

220. Imagine yourself placed in the centre of a vast plain, or on the surface of the sea, where no objects intervene to prevent your seeing distinctly all around. The junction of the sky and sea will not be gradual, they will not be shaded off, as it were, one into another, but the line where they meet will form all around a well-defined circle, of which you are the centre: this circle will divide the heavens into two equal parts, one of which will be visible, the other unseen. This circle is termed the HORIZON: in a globe it is represented by the flat wooden circle which surrounds it. Refer to fig. 3, Plate VIII.

221. Let O be the place of an observer: then will H R be the horizon, or boundary of his view, which evidently divides the heavens into two equal parts, H Z R and H D R, the upper only of which will be visible.

Let him stand facing the south, towards H; then, in the course of an evening, he will remark the stars on the western side gradually to disappear, while others, not before seen, will rise in the east. A moment's consideration will convince him that there must be one point (called by astronomers the CULMINATING POINT), on arriving at which, each heavenly body ceases to ascend and begins to descend. It is found by observation that a line perpendicular to the horizon, drawn through the culminating point of any one star, will pass through the culminating point of all the others: thus, let the dotted curves represent the daily path of the stars a, b, f; they will culminate at the points c, c', c'', all which lie in the vertical circle H Z; which, passing over the head of the observer at O, will cut the horizon in the north and south points. The point immediately over the head of the observer, Z, is called the ZENITH; the opposite point, D, the NADIR.

This circle is called the MERIDIAN, from *meridies*, noon-day, because at noon the sun arrives at it. On the celestial globe it is represented by the brass circle perpendicular to the horizon.

222. These definitions will be rendered more intelligible, if the student will take the trouble to determine the position of the meridian of the place he resides in, which may be done roughly, but sufficiently accurately for our present purpose, in the following simple manner. Erect a stick in the ground, taking care, by applying a plumb-line, that it be quite perpendicular: observe the length of its shadow on a sunny morning at eight or nine o'clock, and with this length for a radius, describe a circle round the stick, marking the exact point where the

shadow touched it: about three or four o'clock in the afternoon the shadow will reach the circle on the opposite side: mark the point as before. If now you bisect the arc between the two points, and draw a line from the point of bisection to the end of the stick, this will be a due north and south, or meridian line; and on it, at noon, the shadow of the stick will always fall. If this observation be taken within a week before or after Midsummer, it will be sufficiently accurate to determine the solar noon throughout the year.

223. If any globe or sphere be made to revolve on its axis, two points on its surface will remain fixed, and every other part of the surface will describe a circle round these fixed points, greater or less in proportion to its distance from them, the greatest circle being equidistant from the two. This will be seen on turning round the terrestrial globe: the fixed points are the POLES, *n*, *s*; the greatest circle described is the EQUATOR, *e q* in the drawing.

Produce the axis of the earth, *n s*, to the celestial concave, N S, then will it become the AXIS OF THE HEAVENS, round which in twenty-four hours all the heavenly bodies will appear to revolve; the two points N and S only being stationary. With us, in the northern hemisphere, there is fortunately a star so near the north pole, that for ordinary purposes it may be considered exactly over it: a most gratifying verification of the facts now stated may be experienced by watching, on a starlight evening, all the other stars performing their revolutions round the pole-star as a centre, in circles smaller or larger according as they are nearer to it or more remote. A circle drawn in the celestial concave (E Q in the figure), immediately over the equator, is the EQUINOCTIAL LINE.

224. Whatever may be the situation of an observer on the surface of the earth, the elevation of the pole in degrees above the horizon will always be equal to his latitude, or his distance in degrees from the equator.

This problem, the importance of which in practical astronomy is incalculable, may be thus proved (Plate VIII., fig. 3).

O *e* is the latitude of the observer at O, which arc measures the angle *e* C O, which is the same as the angle Z C E; N C R is the height of the pole N above the northern point of the horizon R. We have, then, to prove that

the angle Z C E = the angle N C R.

N C E is a right angle, or 90°; so also is the angle Z C R; but these two angles contain the part Z C N common to both: if this be taken away, the remainders Z C E and N C R will be equal.

225. The elevation of the equator above the horizon will always be equal to the co-latitude, or the difference between the latitude and 90°; for Z C E is the latitude, and Z C H is a right angle; and therefore E C H = the difference between these.

226. Hence, when we wish to represent the position of the sphere of the heavens for any particular place, we must elevate the pole as many degrees above the horizon as are equal to the latitude of that place. It must be borne in mind, however, that the celestial sphere has no motion at all resembling the vertical motion of the brass meridian of the celestial globe; but by this we make one horizon serve for every place, whatever may be its

latitude: whereas on the earth every place, however little removed to the north, south, east, or west of another, has a different horizon, the sun and stars rising, setting, and culminating a little earlier or a little later, as the case may be.

This will readily appear from the following considerations. Suppose a place in the same parallel of latitude as London, but differing in longitude two hours; the elevation of the pole being the same, the heavens will present exactly the same appearances as are visible at London; the same stars will rise and set; the days and nights will be of the same length; but the time of every occurrence will be two hours later, if the longitude of the place be west; earlier, if the longitude be east.

Again, suppose a place situated on the meridian of London, but nearer to or further from the equator; the elevation of the pole will be either greater or less, and consequently the whole configuration of the heavens will be changed. But every astronomical phenomenon visible to both that place and London will be seen at the same instant of local time in both; the sun will culminate at the same instant at both places; and, since the noon settles the hour of the day, every other event will be announced at London and at the place in question as occurring at the same moment of time.

227. It is from the different positions of the horizon of observers situated on different parts of the earth, that the celestial concave presents those peculiarities to which have been given the names of Right, Parallel, and Oblique Spheres.

I. Right Sphere.

1. A place on the equator, and which consequently

will have no latitude, will have the poles in the horizon (fig. 46), *n* and *s*, lying in the line H R.

2. All the parallels of latitude on the terrestrial globe will be perpendicular to the horizon.

3. All the heavenly bodies will rise and set at right angles to the horizon, and will continue just as long a time above the horizon as they do below it. For, let the dotted line *g h k i* represent the diurnal path of a heavenly body *p*, the sun for instance; this path will be at right angles to the line H R, and the part above the horizon, *h g i*, will be equal to the part below, *h k i*. Now as the motion of the earth in its daily revolution is equable, the semicircle above the horizon will be described in the same time as the one below, the sun always taking twelve hours to describe the arc *h g i* in the day, and the same time to describe *h k i* in the night. The days and nights here will then be equal throughout the year.

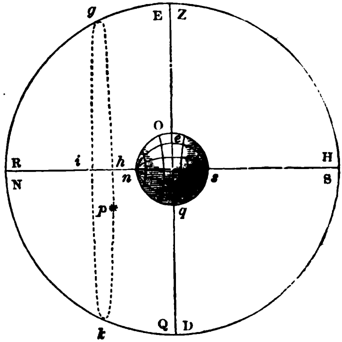


Fig. 46.

4. The whole of the stars in the heavens will, during

the year, be visible to the inhabitants of the regions on the equator; for it will be seen that there is no part of the heavens, from the equinoctial line to either pole, which, at some time or another, does not arise above the horizon.

II. Parallel Sphere.

228. Very different would the phenomena of the heavens be to an inhabitant of either pole. His latitude being 90°, the elevation of the pole will be 90°. Observe,

1. The equator makes no angle with the horizon; but these two circles, E Q and H R, coincide (fig. 47).

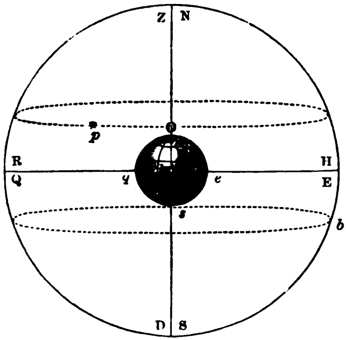


Fig. 47.

2. All the parallels of latitude will be parallel to the horizon.

3. If you remark a heavenly body as *p*, you will observe that during the whole of its revolution its distance from the horizon never varies, but its daily motion is parallel to that circle.

4. None of the stars in the southern hemisphere, that is, those below the equinoctial, will be visible, while those in the northern hemisphere will never disappear. It follows, then, that during six months of the year, when the sun is below the equator, he never rises above the horizon; while during the other six, being above the equator, he never sets, but moves round in a spiral curve nearly parallel to the horizon. There will therefore be only two natural days at the poles, each day being six months in length.

III. Oblique Sphere.

229. If you depart from the equator, either to the north or south, the pole will be elevated as many degrees above the horizon as will be equal to your latitude or distance from the equator, as we have before shewn. To illustrate this position of the sphere of the heavens, let us assume the latitude to be that of London, $51\frac{1}{2}°$ north (fig. 48).

1. In this latitude, or, indeed, in any other between 0° and 90°, all the heavenly bodies rise and set obliquely; their diurnal paths making with the horizon angles equal to the co-latitude: thus, C G H = L F H = E C H.

2. If a heavenly body be on the equator, its diurnal path will be on the line E C Q: which line is divided by the horizon into two equal parts in the point C: in this case half of its diurnal revolution will be above the horizon, and half below. When the sun is thus situated, whatever be the latitude of the place, the day and night will be equal: this

takes place on the 21st of March and 23d of September. Those bodies to the south of the equinoctial line will, in northern latitudes, have the greater

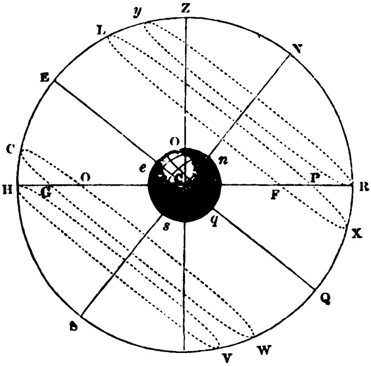


Fig. 48.

part of their diurnal path below the horizon, as G W O, and the smaller above, as G C O: on the contrary, those to the north of the equinoctial have the greater part of their daily path above the horizon, as F L P, and the smaller below, as F X P. Now the sun varies his distance from the equinoctial, ranging about $23\frac{1}{2}°$ on either side of it. When north of this circle, as at F, the days will be more than twelve hours long, inasmuch as more than half his diurnal path will be above the horizon: again, when south of the equinoctial, less than half of his diurnal path being above the horizon, the days will be shorter than twelve hours. In the southern hemisphere, where the south is the elevated pole, the same circumstances obtain, except that the days are there the longest when the sun is south of the equinoctial line.

3. There is a circle R *y*, as far distant from the elevated pole as is equal to the latitude, the stars included within which never descend below the horizon. Thus, with us, there are certain constellations, as Draco, the Great Bear, &c., which never set, and which are visible on every starlight night throughout the year, performing their incessant revolutions round the north polar star, which remains fixed: such stars are termed CIRCUMPOLAR STARS, and the circle including them, THE CIRCLE OF PERPETUAL APPARITION.

4. At the same distance from the depressed pole will be another circle, H V, including all those stars which never rise: thus, with us, many of the constellations in the southern hemisphere are never visible. This is termed THE CIRCLE OF PERPETUAL OCCULTATION.

As we approach the equator, the diurnal path of the heavenly bodies will form a greater angle with the horizon, and the celestial concave will more and more nearly resemble a right sphere; as we advance towards either pole, there will be a continual approximation to a parallel sphere, the days and nights becoming more and more unequal in length.

230. From Z, the zenith, or point immediately over the head of the observer at O (Plate VIII., fig. 3), let there be drawn arcs to the horizon, which may be continued to the nadir D: these are VERTICAL CIRCLES; the portion between the zenith and horizon being evidently

equal to 90°. The circle passing through the east and west points, one half only of which is shewn in the figure, is termed the PRIME VERTICAL, Z D. The vertical circles serve to measure the ALTITUDE of a heavenly body, that is, its height in degrees above the horizon; thus the altitude of y is the arc ym; of x is the arc xp; the complement of the altitude yZ, or xZ, is the ZENITH DISTANCE.

231. The vertical circles on which the altitude of a heavenly body is measured cut the horizon, as in the points p, m; the distance of these points from the north or south points of the horizon, Hp or pR, Hm or mR, are the AZIMUTHS of those bodies at the moment when the altitude is measured.

232. The arc aC, which measures the distance of a heavenly body a from the east or west points of the horizon at the time of its rising or setting, is its AMPLITUDE; in this instance we say from the east towards the south; lC is the amplitude of l from the east towards the north.

The DECLINATION of a heavenly body is its distance from the equinoctial line; thus, ky is the declination of y towards the north; rx is the south declination of x.

The NORTH POLAR DISTANCES of these bodies will be 90° — the declination if it be north, + the declination when it is south; that is, Ny and Nx will be the north polar distances of y and x.

As the sun is the dominant body in the heavens, so his orbit—THE ECLIPTIC—is the principal circle in the celestial sphere.

The LONGITUDE of a heavenly body is reckoned on the ecliptic, commencing with the first point of Aries, where the equinoctial is cut by the ecliptic.

233. By referring to Plate IV., fig. 37, it will be seen that the earth's axis forms with its orbit an angle of 66° 32′; it follows, as the same figure will shew, that the equator forms with the orbit an angle of 23° 28′, and therefore that the equinoctial line in the heavens must cut the ecliptic in two points. Let it now be supposed that when the sun has arrived at one of those points—travelling north—a particular star comes to the meridian of a place with him, *i. e.* culminates at noon precisely, which will occur on the 21st of March; on the 22d, in consequence of the earth's change of place in the interval, the sun will have advanced to the eastward, so that 3 min. 38 sec. of sidereal time will elapse between the arrival of the star at the meridian and the solar noon; on the 23d, 7 min. 16 sec., and so on; the star anticipating the arrival of the sun at the meridian by slightly unequal intervals each successive day till the 21st of March on the next year, when it will be found that the sun having increased his distance from the star 24 hours, or one entire day, they will both arrive at the meridian at the same instant.

Now the distance of the sun from the first point of Aries—the intersection of the equinoctial and ecliptic—measured on the equinoctial, is termed the RIGHT ASCENSION, in this case of the sun; but we may also speak of the right ascension of any other heavenly body, which will be the time elapsed between the arrival of the equinoctial point at the meridian of any place, and the arrival of that heavenly body at the same meridian. This definition will receive elucidation from the celestial globe, where it will be seen that the equinoctial line is divided into twenty-four hours, commencing at the first of Aries, one of the points where the ecliptic intersects it; by these the right ascension is reckoned, which is usually given in hours, minutes, and seconds.

234. We have seen that the equator forms with the ecliptic, or sun's path, an angle of 23° 28′; it follows that the sun will range on each side of the equinoctial to that extent: the distance of the sun from the equinoctial at any particular time is termed his DECLINATION. In order to find the place of a heavenly body in the celestial sphere, nothing more is requisite than to ascertain its right ascension and declination at the time given, and its place is known in the same manner as we may find a place on the terrestrial globe, by knowing its latitude and longitude.

235. The ancients, from time immemorial, divided all the stars in the neighbourhood of the ecliptic, to the extent of 8° on each side of it, into twelve constellations, which are termed the Signs of the Zodiac (from ζωδιον, *an animal*), most of them being designated after some animal: their names and characteristics are, ♈ Aries, the Ram; ♉ Taurus, the Bull; ♊ Gemini, the Twins; ♋ Cancer, the Crab; ♌ Leo, the Lion; ♍ Virgo, the Virgin; ♎ Libra, the Balance; ♏ Scorpio, the Scorpion; ♐ Sagittarius, the Archer; ♑ Capricornus, the Goat; ♒ Aquarius, the Water-bearer; ♓ Pisces, the Fishes. The following Latin hexameters will assist the memory in calling to mind the order of the signs:

Sunt Aries, Taurus, Gemini, Cancer, Leo, Virgo,
Libraque, Scorpius, Arcitenens, Caper, Amphora, Pisces.

236. Though the planes of the orbits of the planets do not exactly coincide with that of the earth, yet their inclinations are so small, that these constellations include them in every variety of position : the angles formed by them with the ecliptic are as follows: Mercury, 7° 0′; Venus, 3° 23′; Mars, 1° 51′; Jupiter, 1° 19′; Saturn, 2° 29′; Uranus, 46′; Neptune, 1° 47′. The distance of Mercury, it will be thus seen, whose orbit is the most inclined, can never be more than 7° north or south of the ecliptic. The orbits of the Asteroids are more inclined; and those of comets are found at all angles of inclination from 0° to 90°.

237. We express the LONGITUDE of the sun by naming the sign and degree of that sign in which he is situated: the whole circle of the ecliptic being divided into 360°, a twelfth part, or 30°, will be the number of degrees in a sign. It is more usual at the present day, however, to indicate the sun's longitude in degrees, reckoning from the first point of Aries all round the ecliptic: thus the longitude of the sun on Jan. 1, 1844, was 10 signs 11° 1′ 2″, or 311° 1′ 2″, or 11° 1′ 2″ of Aquarius.

238. As the ecliptic is the principal circle in the heavens, CELESTIAL LATITUDE is reckoned from it, either north or south. On the celestial globe it will be observed that the lines of longitude all meet in the north and south poles of the ecliptic, while the lines of latitude are drawn parallel to that circle. The sun can have no latitude. The longitude of any other heavenly body is the point where a circle, passing through the heavenly body and through both poles of the ecliptic, cuts the ecliptic. The place of a heavenly body may

be found, when its latitude and longitude are known, in the same manner as it may be when the right ascension and declination are given.

239. All the planets revolve round the sun in the order of the signs, or from west to east: thus, a planet would pass from Aries to Taurus, and thence to Gemini, and so on; this motion is termed DIRECT. Not only so, but the Earth, as well as the Sun and all the planets, turn on their axes from west to east: nay more, all the satellites revolve round their primaries from west to east, with the exception of those of the distant planet Uranus; here we find that, contrary to analogy, the motions of his satellites are RETROGRADE, or from east to west.

Comets, as if in every particular different from the other bodies of the system, are observed to move in very many instances in a retrograde direction, or contrary to the order of the signs.

240. The points where the orbit of any planet crosses the ecliptic, or orbit of the earth, are called its NODES. The nodes of all the planets are observed not to be stationary in the ecliptic, but to have a very gradual retrograde motion on that line. Underneath are the positions of the ascending nodes of the planets from the commencement of the present century; the descending node of each being 180° distant. The ascending node ☊ is the point of the ecliptic cut by the planet as it travels north of that line: the descending ☋ as it travels south.

	Longitude of ascending node.		
Mercury	45°	57′	30″
Venus	74	54	12
Mars	48	0	3

	Longitude of ascending node.		
Jupiter	98°	26′	18″
Saturn	111	56	37
Uranus	72	59	35
Neptune	130	5	11

241. To enter into an extended account of the cause of the retrogradation of the nodes of the planetary orbits on the ecliptic, would, from its abstruse nature, be inconsistent with the plan of this work: this subject may be found most elegantly explained in Sir John Herschel's *Outlines of Astronomy.** Suffice it to say, that their orbits are mutually disturbed in consequence of the planets rising, during one half of their revolution round the sun, above the ecliptic, and during the other half sinking below the plane of that circle; they all the while operating upon each other through the attraction of gravity, and mutually disturbing the regularity of the curves they respectively describe. The result of all these disturbances, when summed up, appears to be, that while the inclination of their orbits remains the same, or oscillating with an almost imperceptible movement on each side of an imaginary fixed plane, the points where the orbits cross that of the earth will constantly slowly recede; the forces tending to impress that motion on the nodes, upon the whole, preponderating over those which would cause them to advance. The rate of recession of the nodes of any planet will ever be less than 1° in a century, and in most cases less than half that quantity.

* See also *Penny Cyclopædia*, vol. xi. p. 393, article "Gravitation," which was written by the Astronomer Royal.

SECTION III.

CATALOGUES AND MAPS OF THE STARS,

MAGNITUDES, NUMBER, AND MODE OF DISTINGUISHING THEM.

242. By measuring the right ascension and declination of the stars with great accuracy, for which purpose observatories have been founded in different parts of the world, astronomers have been enabled to catalogue the stars, and to indicate distinctly the exact point occupied by each one in the heavens.

At a very early period, probably as remote as the time of the Argonautic expedition (B.C. 1200), the whole face of the heavens was mapped out into constellations, or groups of stars: these were fancifully supposed to have a resemblance to certain figures of men or animals, and were supplied with names accordingly. This division, originally founded on no scientific basis, the moderns have retained; while the first formers of a catalogue of the stars of the southern hemisphere advanced one step further in absurdity, by introducing such constellations as the "air-pump," the "sculptor's tools," the "chemist's furnace," the "sextant," and other mathematical instruments. The only advantage of the division into constellations is, the facility they afford for roughly pointing out the position of a planet, the moon, or a comet; for more accurate reference we must have recourse to the right ascension and declination of a heavenly body, which will enable us to fix upon its position with the greatest nicety.

243. The most ancient catalogue of the stars is that

made by Hipparchus (B.C. 120), who was induced to undertake the labour by remarking the sudden appearance of a new star: being laudably anxious to afford to posterity the means of judging of the heavens as they appeared in his day, he commenced and completed an account of the position and magnitude of 1026 fixed stars. This catalogue, enlarged and improved, may be found in the works of Ptolemy, the celebrated geographer of Alexandria, who flourished A.D. 170. Ptolemy's catalogue gives the latitude and longitude of 2000 stars, arranged in forty-eight constellations.

As may be supposed, the invention of the telescope has brought into view and assisted in defining the places of thousands of stars which were unknown a few centuries ago. The united labours of European astronomers have succeeded in bringing this branch of astronomical science to the highest point of perfection. In the catalogue published by the British Association, the right ascension and declination of 8377 stars are laid down with great accuracy.

244. The Celestial Globe exhibits the figures of the constellations, and such of the stars as are visible, without the aid of the telescope; and it is a most valuable auxiliary in obtaining a knowledge of the positions of the stars. Its place may be supplied, but very inefficiently, by maps of the stars; of which those published by the Useful Knowledge Society, with the "Companion," by Mr. Augustus de Morgan, are the most available. The disadvantage of these maps is, that some constellations are of necessity only to be traced by consulting two maps, part appearing in one and part appearing in the other; while from the projection adopted,

(the gnomonic,) the bordering constellations of each map are much enlarged and distorted. In making use of the celestial globe no such difficulty exists. Let the globe be duly rectified, by placing the brass meridian exactly north and south, so that it may coincide with the true meridian of the place: let the pole be elevated as many degrees above the horizon as are equal to the latitude of the place you may be in: bring the sun's place for the day of observation to the meridian, and, having set the index to XII. turn the globe westward till the index points to the time of the evening; then will you have an accurate representation of the heavens for that instant, each constellation being exactly above its representative on the celestial globe. By continuing to turn the globe westward as the time passes, the student of astronomy will soon become acquainted with the diurnal motion of the heavens—the silent and imperceptible advance of the constellations from the eastward till they culminate, and eventually set. Facing northward, he will observe the beautiful revolution of the circumpolar stars round the Pole Star, which will ever appear fixed, as the centre of the celestial movements. Again, turning southward, he will remark (and after a few evenings fully comprehend the cause) that the diurnal arcs of those stars which rise and set decrease in size as they recede from the pole; till in the far south a star will rise no higher than a few degrees above the horizon, and describe an arc of small duration. A few evenings thus employed will tend more to explain the principles of the celestial sphere, than months spent over the globes without actual inspection of the heavens themselves.

245. The stars are said to be of the first, second, or third magnitudes, according to the gradations of the light they emit. The brightest stars are of the first magnitude: after the sixth magnitude they are termed telescopic stars. Sir John Herschel estimates the light of the first six magnitudes to be in the proportions of 100, 25, 12, 6, 2, 1. On maps of the stars, or on the celestial globe, the magnitudes are distinguished by the different sizes or shapes of the stars.

The number of stars visible to the naked eye on a starry night will not be more than 1000: of the whole number of stars, 17 are of the first magnitude, 76 of the second, 223 of the third.

The letters of the Greek alphabet are used to designate the largest stars in any constellation: thus, *α* Canis majoris denotes the brightest star in the Great Dog; *β* Orionis, the second-sized star in Orion; *γ* Leonis, the third in size of the constellation Leo. When the stars of any constellation are so numerous that the letters of the Greek alphabet are exhausted, those of the English are used; and if more stars remain to be designated, recourse is had to numerals: it will thus appear that the Greek letters always indicate the largest stars in a constellation.

SECTION IV.

DETERMINATION OF THE POSITIONS OF THE STARS BY THE METHOD OF ALIGNMENTS.

246. THE following method of tracing the relative position of the constellations will facilitate an acquaint-

ance with the principal stars, and will be found useful in connexion either with maps of the stars or the celestial globe.

We will suppose the day of observation to be January the 1st, at eight o'clock in the evening; though the directions given will apply equally well on any other day of the year, to such of the constellations as may at that time be above the horizon, if it be borne in mind that they will then be differently circumstanced with regard to that circle.

The most remarkable constellation in the northern hemisphere is the Great Bear. Occupying as it does a large space in the heavens, and in our latitude being always visible, it may be discovered without difficulty, by remarking its form on the globe; and by means of it, when once known, we may gain acquaintance with the other constellations.

Four of the seven principal stars composing the Great Bear are in the form of a trapezium. Two of them, α and β, called the Pointers, point directly to a star in the Little Bear, which is so near the north pole, that it has obtained the name of Polaris, or the Pole Star. On the 1st of January, at eight o'clock, the Great Bear will be midway between the horizon and the north Polar Star, in the direction N.N.E. The Pole Star is in the extremity of the tail of the Little Bear, which constellation resembles the Great Bear in form, but is inferior to it both in the space it occupies in the heavens, and in the magnitude of its component stars.

Between the Great and Little Bear lies part of the tail of Draco; which constellation half surrounds the Little Bear, and returns into itself with a serpentine curve. The two bright stars in the head, β and γ Draconis, are about as far from Polaris the other side of the meridian, as the Pointers are on the east.

Continue the line formed by the last two stars in the tail of the Great Bear about five times their distance, and it will pass near a bright red star (which will be below the horizon, however, at the time we are supposing): this is Arcturus in Boötes.

The bright star called Cor Caroli may be found in line with α in the tail of Draco, and ζ in the tail of Ursa Major: at the time we are supposing, it will be just above the horizon in the N.N.E.

Cassiopeïa will be near the zenith directly opposite to the Great Bear, the Pole Star being nearly equidistant from both.

The line which is formed by the Pointers and Polaris being continued will run between Cepheus and Cassiopeïa; the former adjoining Draco.

The same line continued beyond Cassiopeïa will pass by β and α Pegasi; these two, with α Andromedæ and γ Pegasi, form an irregular square. The most northerly forms the head of Andromeda; the opposite one is called Markab; the other two, γ and β Pegasi, are Algenib and Scheat. The diagonal of this square being continued toward the north will meet β and γ Andromedæ and α Persei; this last, at the time we have supposed, being very near the zenith. These seven stars, it will be remarked, are not unlike the constellation of the Great Bear on a large scale, and in a reversed order.

Join α and γ Ursæ Majoris: when prolonged, this line will reach α Persei; and, further on, Algol, in Medusa's head, a star rendered singular from its constantly varying its brilliancy every three days.

Produce a line formed by joining γ and β Pegasi towards the north, it will pass through the centre of Cygnus. The bright star Vega, or α Lyræ, will be below Cygnus, towards the north; on the other side, lower down towards the horizon, Delphinus will be setting due west.

Gemini will be found by joining o and β Ursæ Majoris, and producing it south. The two principal stars are Castor and Pollux.

Facing the S.E., on the day and hour in question, you will have before you the most splendid constellation in the heavens, Orion, with his belt and sword; the former being three bright stars at equal distances. The line of these three continued some distance to the south will point to α Canis majoris, or Sirius, the brightest star in the heavens.

Above Orion, to the westward, will be the red star Aldebaran, in the eye of Taurus; in the neighbourhood of which are the two beautiful clusters, the Hyades and Pleiades: these latter have retained till the present time the names by which they were known to the poet Homer 950 years before the Christian era. See the Odyssey, v. 121 and 271.

SECTION V.

THE APPARENT MOTIONS OF THE HEAVENLY BODIES.

STATIONARY, DIRECT, AND RETROGRADE APPEARANCES OF THE PLANETS — GEOCENTRIC AND HELIOCENTRIC LONGITUDE — TRANSIT, CONJUNCTION, OPPOSITION, OCCULTATION.

247. WERE our appointed dwelling-place in the centre of the system, nothing could exceed the grandeur of the celestial movements contemplated from that position. All the planets might then be seen performing their annual courses in circles around us; the slightest disturbance or alteration in the inclination of their orbits would instantly be detected: in short, nowhere would astronomy be studied with such advantage as in the central orb of the sun. The next eligible post, could such a one be obtained, would be some fixed point within the system, where, although the celestial motions would be distorted, yet we should be tolerably well able to reduce them to what they would appear to an inhabitant at the centre. But our position is far inferior to either of these: we are placed on a planet midway between the centre and the circumference of the system, which planet is itself in motion; and hence, in every observation which we make on the movements of any other heavenly body, we must make an allowance for our own motion, which is ever rapid and unceasing. Moreover, our position is never, so to speak, above the other members of our system, from whence we could, as it were, look down upon their orbits; on the contrary,

our planet revolves in almost the same plane with the others, and hence the orbit is, in the instance of an inferior planet, presented to us edgewise; that is, it is projected among the fixed stars in a line, or in a very eccentric ellipse not much differing from a straight line; precisely as an iron hoop, held so as for one side to be hidden, or nearly so, by the other, would appear to an eye situated in its plane. It will be immediately perceived that the study of apparent motions, and of the laws by which the true motions may be deduced from the apparent, is of the utmost consequence in astronomy. A few ideas on this subject will be as much as we can present, consistently with the plan of this work.

248. If we suppose the earth for a time to be stationary in its orbit, a planet nearer to the sun than it during one entire revolution would appear to us to vibrate on each side of that luminary, to approach him, pass by him, and having reached its limit on the other side, to return, and arrive at the point from whence it set out.

On the same supposition of the fixedness of the earth, a planet more distant than itself from the sun would appear to revolve round it; although, as its distance would at one period be much greater than at another, its apparent diameter would be less in the former position than in the latter.

249. Let *y*, in fig. 16, Plate III., be such a position of the earth, *m* a superior planet, the dotted line its orbit round the sun S; *a h g f x* the orbit of an inferior planet. By imagining the eye at *y*, the phenomena described will be immediately understood. The inferior

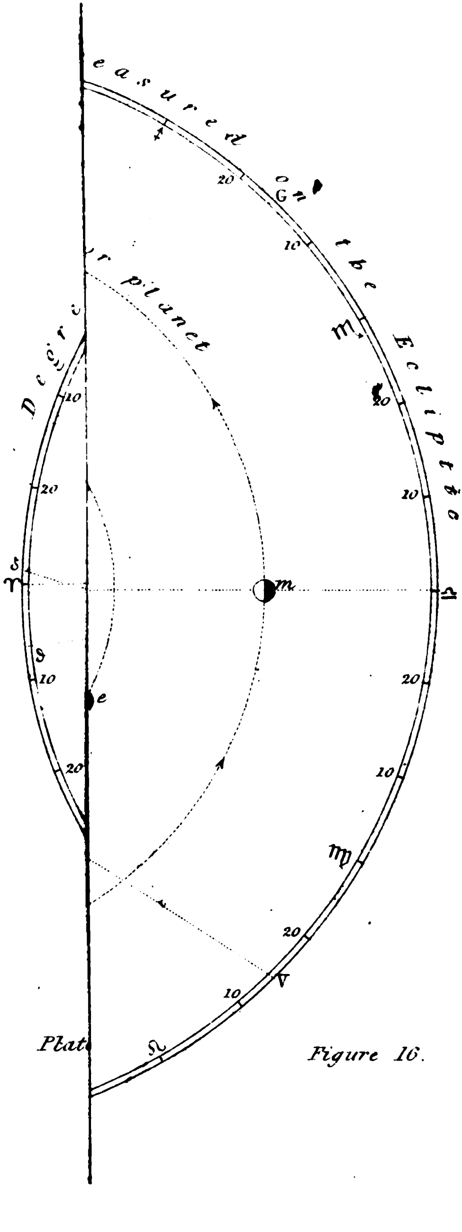


Figure 16.

planet would pass from *v*, through *x z f* to *g*, describing the arc V G among the fixed stars in the zodiac, according to the order of the signs; from *g* to *v* it would appear to describe the same arc, but contrary to the order of the signs, or in a RETROGRADE DIRECTION: this arc, being viewed edgewise, will appear as a line, or very nearly so.

250. A superior planet, as *m*, in performing its revolution round the sun, would also revolve round the earth, because its orbit would include that of the earth; but at X it would approach much nearer the earth (which we are still supposing to be stationary at *y*) than at *m*. This occurs with respect to the planets Mars, Jupiter, Saturn, Uranus, and Neptune, which are found sometimes in the neighbourhood of the sun; in which case they come to the meridian at or near mid-day (S and *m* being on the same side of the earth), while at other times they are on exactly the opposite side of the earth to what the sun is, or in opposition to him, and arrive at the meridian at or near midnight (see the positions X and S in reference to *y*); a most satisfactory proof that their orbits are exterior to that of the earth.

251. For it will be remarked that an inferior planet, after increasing its ELONGATION (which is the angular distance from the sun, as S *y g* or S *y v*) to a limited extent, returns to him again; and in no possible position in its orbit can it be seen on any other side of the earth than that at which the sun appears. The nearer the planet to the sun, the less will be its greatest elongation: in the case of Mercury, the angle S *y g* is never more than 28°; in that of Venus it is 47°. The planet, in its passage from *f* to *h*, or from *w* to *x*, will for a

short space of time not appear to move from its position, n consequence of its directly approaching towards or receding from the earth; it is here said to be STATIONARY. These phenomena prove that the planets Mercury and Venus are nearer the sun than we are; and since they obtain with these only, it follows that the earth is the next in succession from the sun.

252. With all these irregularities in the apparent motion of a planet, it might be thought almost impossible to determine two points whereby we might discover its periodic time. If our station were at the centre S, the periodic time would be that elapsing between two successive appearances of the planet in conjunction with a fixed star; but it must be remembered, that not only are we out of the centre of motion, as at *y*, but that the earth is all the time advancing in the same direction as the planet round the sun, though not quite so rapidly as the inferior planet itself. The consequence of this motion will be, that the stationary points will constantly vary their position, as also the points of the greatest elongation; while certain modifications will be introduced in the rate of its direct and retrograde motions.

Amidst all apparent uncertainties, however, the exact time of the planet's crossing the ecliptic may be known. We have stated that the orbit of every planet cuts that of the earth in two points, called its nodes: now, whether the motion of the planet be direct or retrograde, or whether it appear to move not at all, at the instant of its crossing the ecliptic, the precise moment of this important occurrence may be ascertained. If, then, we observe the elapsed time between two successive ascents above or descents below the ecliptic, such will be its periodic time.

253. It will be easily seen that the place of a planet, seen from the earth, will in general differ greatly from its place as seen from the sun, but not always. The planet X, as seen from the earth *y*, or from the sun, at S, will in either case be referred to the point ♈. The same will be the case with a planet when at *m*, which will be referred both by the earth and sun to ♎, because in both instances the three bodies are in one and the same straight line. But the planet, when at *b*, will be referred by the inhabitants of the earth at *y*, to 10° of the sign ♋; by the sun, to 0° of the same sign: the former is termed its GEOCENTRIC LONGITUDE, the latter its HELIOCENTRIC LONGITUDE.

Should it so chance that an inferior planet is in either its ascending or descending node when between the earth and the sun, as at *a*, it will be observed to pass like a dark spot across the disc of the sun. Such appearances are called TRANSITS; and they are of the utmost importance in determining certain calculations, which could not be done without their aid. They are of unfrequent occurrence, and when they happen are watched by astronomers with the greatest anxiety. Indeed, one of the principal objects of our government in sending out Captain Cook on one of his expeditions was to make remarks on the transit of Venus in the southern hemisphere. They afford a most irrefragable proof of the planets Mercury and Venus being nearer to the sun than we are.

254. A few remarks on the movements of a superior planet will conclude the subject of apparent motions.

Let *n* be the position of the earth, and *p* that of Mars, at a particular instant: if the earth were stationary, the planet would move round it according to the order of the signs; but the earth's motion is more rapid than that of Mars, from its being nearer to the sun (see § 200); hence it will describe the arc *n y* while Mars describes *p* x. At the part nearest *p*, the planet Mars will appear to move according to the order of the signs, except that for a short period, as the earth approaches him, and they travel on for a time together, he will be apparently stationary. The earth, however, will soon outstrip and pass by him at or about x. In some part of his orbit between x and *c*, which we will suppose to be performed in the same time that the earth takes to describe the arc *yd*, he will appear slowly to retrograde; as when one vessel outsails another, the slower will appear to move backward when referred to fixed objects on shore.

That part of the earth's orbit between *e* and *n* we will suppose to be described in the same time as Mars takes to pass from *b* to *m*: here his motion will be direct through ♋, ♌, and ♍.

After the earth leaves *n*, and Mars *m*, there will be another stationary point not far from the direction of a line joining *n m*.

The same explanation will apply to the movements of all the superior planets.

255. Two heavenly bodies seen in the same quarter of the heavens are said to be in CONJUNCTION. If *y* be the earth, s the sun, and *m* Mars, the sun and Mars would be in conjunction. An inferior planet would be in its inferior conjunction with the sun at *a*, and in its superior conjunction at *z*.

If two heavenly bodies are in opposite quarters of the heavens, or distant from each other 180°, they are said to be in OPPOSITION. Thus a planet at X, and the sun at S, would be in opposition to each other, if viewed from the earth at *y*.

The inferior planets cannot ever be in opposition to the sun, as the diagram will shew.

The term SYZYGIES applies to either of these last two definitions.

256. Should a heavenly body pass over and obscure the light of another, such an occurrence is termed an OCCULTATION. The moon frequently is observed to pass over and hide from view those stars which lie in the neighbourhood of her orbit. The times of such occurrences may be found in the *Nautical Almanac*, under the head of "Occultations of the Fixed Stars by the Moon."

257. From what has been said of the movements of the planets, and the position of the earth's orbit with regard to them, it is clear that their apparent paths are exceedingly different from their real. The student who wishes to trace these paths among the stars for any length of time, would do well to procure the *Nautical Almanac*, in which the Right Ascensions and Declinations of the planets are given. Let him mark, with a brush full of vermilion, upon a celestial globe, the points which they occupy, at intervals of three or four days during several months; and, by joining these points with a fine line, he will be able to remark their direct and retrograde movements, and their stationary positions: he will thus acquire in a few hours a more correct idea of their apparent motions than can be ob-

tained by any other means. Or the same may be done with a black-lead pencil on maps of the stars. In globes the zodiac is divided by fine lines into degrees, for the purpose of facilitating this delineation of the apparent paths of the heavenly bodies. A damp sponge will obliterate the colour without the slightest injury to the globe.

258. When Copernicus first promulgated the true system of astronomy, which assumes the sun to be the centre, in opposition to that of Ptolemy, who considered the earth to be immovably fixed, while the planets and the sun revolve round it, he was fully aware that the planet Venus ought, in point of fact, to present phases similar to those of the moon. What must have been the gratification of the followers of that philosopher, when the telescope of Galileo, directed to that planet, shewed his reasoning to be based on truth, and that the Copernican system alone could account for the appearances of the heavens! By referring again to fig. 16, Plate III., it will be at once seen that any planet included within the earth's orbit must present phases similar to those of the moon. Let the earth be at *y*, and *a h g f*, &c., the orbit of an inferior planet, either Venus or Mercury: at *z* the portion of the planet enlightened by the sun—namely, its whole disc—will be turned towards the earth; at *a*, on the contrary, only the dark side will be so directed. At *g* and *v*, half of its illuminated disc will be seen; while between *f* and *z*, and *x* and *z*, the planet will appear gibbous, or more than half enlightened. At *h* and *w* a crescent only will be presented to the earth.

259. The planet Mars, exterior to the earth, will

sometimes appear gibbous, and at others circular; at x and *m*, for instance, the whole of his illuminated disc will be directed towards the earth, while at *b* only about eight-tenths of it will be seen. The planets Jupiter and Saturn are so far distant, that no variation in their discs is perceptible.

In the *Nautical Almanac* will be found a "Table shewing the Illuminated Portion of the Discs of Venus and Mars" for every month in the year.

When Venus appears to the eastward of the sun, she shines in the evening after sunset; when west of him, she rises before him. In the former case she is termed the evening, in the latter the morning star.

SECTION VI.

ON DETERMINING THE DISTANCES AND DIAMETERS OF THE SUN, MOON, AND PLANETS.

PARALLAX — HORIZONTAL PARALLAX — PARALLAX IN ALTITUDE — NONE IN THE ZENITH — TRANSITS OF MERCURY AND VENUS — MANNER OF DETERMINING THE PARALLAX OF THE SUN FROM A TRANSIT OF VENUS—METHOD OF MEASURING THE DISTANCE OF AN INFERIOR PLANET FROM ITS GREATEST ELONGATION—OF A SUPERIOR PLANET FROM ITS ARC OF RETROGRADATION.

260. In the pages immediately following, it will be our endeavour to present to the reader such considerations as may enable him to form some idea of the method which astronomers adopt in measuring the distances of

the earth from the sun, moon, and planets, and which we hope may tend to remove from the mind any doubt of the accuracy of their statements.

We begin by referring to the difference of position which the sun, the moon, or a planet will assume among the fixed stars, which are at an infinite, or, rather, incalculable distance, when viewed by two observers in different parts of the globe (refer to fig. 7, Plate VI.). This difference of position is termed its PARALLAX; and when the heavenly body is in the horizon of one of the observers, such difference is termed its HORIZONTAL PARALLAX.

To an observer at A, a heavenly body B will appear in the horizon either rising or setting, and he would refer its position among the fixed stars to the point G, in a circle immeasurably distant, although the limits of the diagram compel us to contract its dimensions.

Another observer at A′ will have the same body, which we will suppose to be the moon, in the zenith; a line joining C, the centre of the earth, and his position will pass through B. This observer, then, views the object as it would appear from the earth's centre, and refers it to the point E; a position distant from the former by the arc E G. Now, on the supposition of the two observers remarking the position of the moon at the same instant of time, and afterwards comparing notes, the measure of this arc will be known, and consequently the value of the angle E B G, which is equal to the angle A B C (Euclid, i. 15), or the angle which the earth's semidiameter would subtend when seen from B, the moon. Now, since the triangle C A B is right-angled at A, we know A C, the earth's semi-diameter, the angles C B A and

C A B; whence may be found the side C B, by the following proportion:

Sine A B C : : rad. : C A : C B.

In the case of the moon, her mean horizontal parallax is 57′ 12″; therefore,

As sine 57′ 12″ : rad. : : 3956 miles, the earth's semi-diameter : 237765, the moon's mean distance.

261. Her diameter may be easily found when her distance is ascertained (see fig. 8, Plate VI.): the angle E C G is that subtended by the diameter of the moon; half of this will be E C B, which is one angle of the right-angled triangle E C B, of which the base C B is known, whence the perpendicular E B may be easily found by trigonometry: this multiplied by 2 will give E G, the diameter of the moon, which is about 2000 miles: her mean distance is usually stated to be 240,000 miles.

262. The plane seen edgewise, as the line A G in fig. 7, Plate VI., is termed the SENSIBLE HORIZON of an observer at A; a plane parallel to it passing through the centre of the earth, as C X, is his RATIONAL HORIZON. It will appear from the figure that a heavenly body may be above the rational horizon for some time before it rises above the sensible horizon and becomes visible to the observer at A, which it will not be till it has arrived at B or D.

263. As the heavenly body rises above the horizon, its parallax will become less and less; thus, at H its place, as seen from the centre, will be S; from A will be W; its arc of displacement S W being less than E G: when at N, Q T will be less than S W; while at M, in the zenith, its parallactic angle will vanish, and its position, as seen from C and also from A, will be I.

When the horizontal parallax of a body is known, its parallax for any altitude may be found from the following proportion:

As rad. : sine of apparent zenith distance : : sine of horizontal parallax : sine of parallax in altitude.

For in the triangle A C H,

A C : C H : : sine A H C : sine C A H or its supplement M A H.

Again, in triangle A B C,

A C : C B : : sine A B C : sine C A B, or radius.

And, since the antecedents are equal, the consequents are proportional; therefore

Sine A H C : sine M A H : : sine A B C : rad.

Or,

As rad. : sine M A H : : sine A B C : sine A H C.—Q. E. D.

Another method. A C being known, and C H found, as before; in the triangle H A C given C H=C B; the angle H A C=supplement of zenith distance, whence, by trigonometry, angle A H C may be found, which is the parallax in altitude.

The general effect of parallax, as may be seen from the figure, will be to cause a heavenly body to appear nearer the horizon than its true place, as seen from the centre of the earth; its true altitude will therefore be its observed altitude + parallax.

264. The horizontal parallax will be less for a body more distant, as at D; where, by tracing the visual lines as before, it will be seen to be depressed only by the small arc F G. Here an exact proportion will be found to exist between the distances and the horizontal paral-

laxes of any two bodies: for, by the principles of trigonometry, in the triangle C B D:

As sine B D C : sine C B D or its supplement A B C : : C B : C D.

That is, the distances of two bodies will be in the inverse ratio of the sines of their horizontal parallaxes.

265. Now, as the planets and the sun are much more distant from the earth than is the moon, it follows that the horizontal parallaxes of those bodies are much less than hers: the sun's, indeed, is so small that it cannot be determined by direct observation, but may be calculated from the parallax of a planet, by the last-mentioned proportion. To determine the parallax of a planet with any degree of precision, the best instruments, the most practised observers, and a combination of most favourable circumstances, are requisite: as a very minute error in measuring the angle A D C would introduce an enormous error into the calculation of the line C D, it is not surprising that great anxiety should be shewn to determine this angle with minute exactness. For this purpose, the transit of the planet Venus over the sun's disc affords facilities which astronomers have embraced with the utmost ardour, and look forward to with the most intense interest. The transits are of unfrequent occurrence, taking place at intervals of about eight and 100 years. The following table shews the dates of a few of the more recent and future transits of that planet:

Dec. 4, 1639	Dec. 6, 1882
June 5, 1761	June 7, 2004
June 3, 1769	June 5, 2012
Dec. 8, 1874	

The transits of Mercury are more frequent; but they are of little use in determining the parallax of the sun. The following are the dates of the transits of that planet, commencing with the present century.

Nov. 8, 1802	May 8, 1845
Nov. 11, 1815	Nov. 9, 1848
Nov. 4, 1822	Nov. 11, 1861
May 5, 1832	Nov. 4, 1868
Nov. 7, 1835	

266. The transits of Mercury and Venus form an important link in the chain of evidence by which the Copernican system is upheld: they satisfactorily prove, 1st, that these planets are nearer to the sun than the earth; and, 2dly, that they shine not by their own light, for they pass over the sun's disc as dark round spots. The transits of the inferior planets serve the purpose, moreover, of determining the places of their nodes, and thence the inclination of their orbits—data absolutely requisite for the construction of accurate tables of their motions. How many times since the Creation had these planets crossed the solar disc unknown to mortals! for not till 1631 was a transit the subject of man's observation. In that year Mercury was observed by several astronomers; but only one, the celebrated Gassendi, has left a record of this fact, which is embodied in his treatise, entitled "De Mercurio in Sole viso." The transit of Venus, announced for the 6th of December of the same year, occurred during the night, and therefore could not be watched by European astronomers: the following, of 1639, was remarked by our countrymen Horrocks and Crabtree, who had the distinguished honour of being the only individuals who watched and recorded the first transit of Venus ever

witnessed by human eye. Withdrawn from the distracting turmoil of political strife with which England was then unhappily agitated, these young men, with a few friends, spent their retirement in the cultivation of the science of astronomy, which they prosecuted with all the enthusiasm of genius. The works and tables of Kepler and other astronomers of the period were constantly consulted by Horrocks; amongst others, those of Lansberg, which, though in general not worthy of reliance, happened in this case to predict a transit of Venus for 1639, whereas Kepler had announced that no other would occur for more than a century. By comparing the two sets of tables, and correcting one by the other, Horrocks found that a transit might be expected on Dec. 4, 1639. Communicating this result to his friend Crabtree, they both were gratified by seeing Venus on the sun's disc on that day, though they were unfortunately prevented by circumstances from noting the times of ingress and egress: enough was remarked by them, however, to enable astronomers to fix the elements of the planet's orbit with greater exactness than had ever been done before. Horrocks, moreover, whose name should never be forgotten by English astronomers, was the originator of a theory of the lunar orbit, which is said to have been of some use to Sir Isaac Newton in his explanation of the theory of gravitation. Neither he nor Crabtree lived long to enjoy the distinction they had acquired as observers and writers on astronomical science; they both died at the early age of twenty-two.

Had Horrocks and Crabtree been successful in marking the beginning and end of the transit of Venus, their observations, unless corresponding remarks had been made in the southern hemisphere, would not have availed for the great purpose which these transits have since been made to serve, namely, determining the parallax of the sun: indeed, they were unacquainted with the possibility of attaining this result, which was first suggested by Mr. J. Gregory, in 1663. This suggestion was followed up by Dr. Halley, in a paper communicated to the Royal Society in 1691; in which he still more clearly pointed out the means which astronomers should adopt to observe a future transit with advantage. From the transit of 1761 the mean parallax of the sun was deduced, and found to be 8″·65.

The parallax of the sun, as now received by astronomers, is the result of observations made in various parts of the globe on the transit of Venus in the year 1769. Expeditions were sent out by the various European Governments (that under the command of the celebrated Captain Cook, to Tahiti, is well known), for the purpose of watching this transit from points on the earth differing very considerably in latitude. The principles on which these observations were made may be easily understood, if, in the explanation, we leave out of view various minute corrections and reductions, which were necessary before the parallax could be deduced.

267. In fig. 49, let *e* be the situation of an observer in a northern country; *d* that of another in the southern hemisphere, which, to avoid complexity, we will suppose to differ in latitude from the former exactly 90°, and to be on the same meridian, and that moreover the sun is in the horizon of the observer at *e*, and in the zenith of the observer at *d*. The observer at *e* will trace the planet across the sun's disc, as it outstrips the earth by its mo-

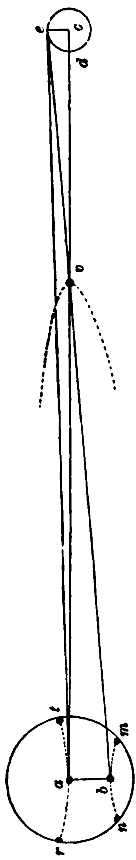


Fig. 49.

tion in its orbit, in the line *m b n*, and will mark the exact time of ingress at *m*, and its egress at *n*. The observer at *d* will watch her passage across in the direction *t a r*, taking care to mark the time of ingress and egress, as did the other. By comparison of these times, aided by micrometrical admeasurements, the space *a b*, or the angular distance of these two lines at the central time of transit, may be deduced: this will be the measurement of the displacement of Venus, in consequence of her being viewed by observers differently situated on the earth's surface, namely, at *e* and *d*. Now, although we are supposing the distances both of the planet and the sun to be unknown, astronomers have long been acquainted, from the theory of gravity, with the proportion they bear to each other; for, by comparing the rapidity of the earth in its orbit with that of Venus (see "Physical Astronomy," § 196), the power of the sun's attraction on each may be deduced, and thence their relative distances.

Now the distance of the Earth from the Sun compared with that of Venus was thus found to be as 95 to 68—*i. e.*

$ac : av :: 95 : 68$; and therefore
$cv : av :: 27 : 68$.

By comparing the space *a b*, which measures the angle *a v b*, with the sun's angular diameter obtained from observation, its value becomes known in minutes and seconds of arc, and hence the value of its equal, viz. the angle *e v c*, which is the horizontal parallax of Venus; *e c* is the earth's semi-diameter also supposed to be known; hence we get

$$c\,v = \frac{e\,c}{\tan.\,evc} = \text{distance of Venus from the Earth;}$$

$$\text{but } c\,v \;:\; a\,v \;::\; 27 \;:\; 68;\ \text{or } a\,v = \frac{c\,v \times 68}{27}$$

and $av + cv = ac$ the distance of the sun from the earth; and ac : ce : : rad. : tan. of the sun's horizontal parallax, viz. the angle *e a c.*

The method above pursued is not that which would be adopted in practice, but is simply intended to shew the possibility of ascertaining the distance of the sun from the transit of Venus, and to trace by the aid of trigonometry the various steps in the process; which for this purpose has been divested of all the various complications arising, amongst other sources, from the spheroidal figure of the earth, and her rotation during the time of observation.

It will now be easily understood why the transits of Mercury are of little avail in determining the parallax of the sun. As he is much nearer to the sun than to the earth, the space *a b* would be much smaller than *e c*, and therefore a small error in measuring it would incur a much greater in calculating the distance *v c*; as will be easily perceived by copying fig. 49, and advancing *v* much nearer to *a*.

268. If the two observers are not situated at exactly

90° from each other, nor under the same meridian, as can seldom be the case, very minute and accurate calculations must be made of their difference in latitude and longitude; and their observations will be subject to various reductions before they can be rendered available. A mean of all the observations taken of the last transit of Venus, on June 3, 1769, made in different quarters of the world, and in different latitudes, from Kamtschatka to the Cape of Good Hope, gives $8''\cdot5776$ as the mean horizontal parallax of the sun.

A transit of Mercury or Venus can only occur when the sun chances to be in the ascending or descending node of the planet at the instant of its crossing the ecliptic. Now, from the complex combined motion of the Earth and the planet, a long period elapses before the same circumstances again occur.

269. It will appear, then, from what has now been explained, that we assume the earth's diameter as the basis from which to determine the distance of the moon, the planets, and the sun. The distance of the earth from the sun being known, we are enabled to take other measurements in the system, simply by observing angular distances: for instance, we may determine the distance of an inferior planet by measuring its angular distance from the sun at the time of its greatest elongation. In fig. 16, Plate III., let *v* be the situation of Mercury at the time of its greatest elongation, which will be measured by the angle s *y v*; draw *v* s, which will be perpendicular to the tangent *y v* (Euclid, iii. 18); then, in the right-angled triangle s *y v*, we have given s *y*, the distance of the earth from the sun, and the angle s *y v*; whence may be found s *v*, the distance of Mer-

cury at the time of observation. This planet is found to vary its greatest elongation from the sun very considerably, the angle s$y$$v$ varying from 28° 48′ to 16° 12′; whence we conclude that its orbit is very elliptical. The planet Venus, on the contrary, shews but a slight deviation from a circular path; her angle of greatest elongation ranges between 47° 48′ and 44° 57′.

The distance of a superior planet from the sun may be found by measuring the arc through which it appears to retrograde, when in opposition to the sun. Let x in fig. 16 be the place of Mars in opposition, and y that of the earth; y γ the arc described by the earth in a short period of time—say one day; x β the arc described by Mars in the same time; the periodic times being known, these arcs may be found simply by dividing 360° by the number of days occupied in one revolution.* We have before stated that the nearer to the sun a planet is, the more rapid is its motion round him: thus, the Earth will pass by Mars, which planet will appear to retrograde through the arc ♈ δ, whereas in fact he has been moving through ♈ θ; that is to say, at x the geocentric and heliocentric longitudes of Mars will be the same; the arc θ δ will be the difference between the geocentric and heliocentric longitudes of Mars when at β—the former will be found from observation, the latter from tables of the planet's motion. Now, in the triangle s γ β, the angle s β $\gamma = \theta$ β δ, the difference between the heliocentric and geocentric places of Mars; the angle β s γ, which is the difference between the angular advance of the Earth and Mars between the two

* This will only give the mean motion: a correction must be introduced, which is here neglected, to prevent confusion.

observations, and the side s γ are given; whence may be found by trigonometry s β, which is the distance of Mars from the sun.

Or, the distance of one planet being known, we may find the distance of another, by the application of the third law of Kepler, as shewn in § 203.

SECTION VII.

ON TIME.

REGULARITY OF THE EARTH'S MOTION—SIDEREAL DAY—SOLAR DAY—APPARENT AND MEAN TIME—METHOD OF DETERMINING MEAN SOLAR TIME FROM SIDEREAL, AND THE CONTRARY—TO FIND THE MEAN TIME OF TRANSIT OF A FIXED STAR—TROPICAL, SIDEREAL, AND ANOMALISTIC YEAR.

270. ONE of the most important elements in astronomical observation is an exact measurement of time. To obtain this, some standard, not depending on mere sensation, is evidently requisite. Happily, in nature there are certain motions which are ever invariable; and the time taken to accomplish these may be so divided and subdivided as to assist the astronomer in his observations, as well as to answer all the purposes of common life.

Now, it has been found by repeated and continual observation, that the exact time which elapses between two successive arrivals of a star at the meridian of any place, which space of time constitutes a sidereal day, is ever and unchangeably the same; and that not only is the duration of a sidereal day, that is, the time the earth takes to turn on its axis, constant, but that, during every part of the earth's rotation, its motion is equable; in other words, the earth revolves with a uniform velocity.

271. The difference between the solar and sidereal day has already been alluded to (§ 233). Suppose the sun and a star to culminate at the same instant on a particular day; on the following day, the sun, from the earth's advance in her orbit, will have passed to the eastward of the star; and therefore the earth must make an additional portion of a daily revolution before the meridian which has arrived opposite the star will be opposite the sun; which portion of a diurnal arc will always be equal to the number of degrees and minutes the sun is in advance of the star. Now the sun describes a complete circle of 360° in the year; in that time, then, the earth will have to perform a diurnal arc of 360°, which will occupy 24 hours of sidereal time, before the meridian of any place, having left the star, will overtake the sun; but this complete revolution will bring the sun and the star on the meridian at the same instant. We see, then, that the 365 solar days, which constitute the year, will contain 366 sidereal days. The length of a sidereal day is uniformly 23 hrs. 56 min. 4·092 sec. of solar reckoning; and the difference between it and a mean solar day of 24 hrs. is 3 min. 55·908 sec., or 3 min. 56 sec. nearly.

272. We say a MEAN SOLAR DAY, because the days reckoned by two successive appulses of the sun to the meridian will be found to be of unequal duration; indeed, on comparing them with a well-regulated clock, it is found that no two days in the year are of the same

length, but that the corresponding days of every year very nearly agree. This variation arises from two causes, the first of which is, the unequable motion of the earth in its orbit.

It was shewn in § 179, that the orbit of the earth is not circular, but elliptical; and in § 184 that motion in an elliptical orbit is not uniform, but performed more slowly about the aphelion, increasing in velocity till the earth arrives at its perihelion. Now, if the orbit of the earth were a circle, whose plane coincided with that of the equator, the earth's motion would be equable, and then the difference between a solar and sidereal day would ever be the same; it would in fact be equal in arc to 360° divided by the number of days in the year, or 0° 59′ 8″·33, and in time to 24 hours divided by the same number of days. But near its aphelion the earth's daily arc is no more than 57′ 12″; the meridian of a place will then turn forward through less than a mean arc after leaving a star (as we have supposed in § 271) before it arrives opposite to the sun; or, in other words, before the sun culminates: apparent noon will therefore occur before mean noon. Near her perihelion the earth will describe a daily arc of 1° 1′ 9″. Here, then, apparent noon will be behind the mean; for the earth must describe an arc greater than the mean diurnal arc before the sun will be on the meridian. When the earth is exactly in her aphelion or perihelion, and when, also, she is at two other points between these, mean and apparent time will be the same, as far as this cause is concerned.

273. The other cause of the want of uniformity in the length of the solar days arises from the circumstance

of the plane of the equator not coinciding with the plane of the ecliptic, so that the sun's apparent motion in longitude is not equal to his motion in right ascension. The celestial globe will assist us in rendering this cause apparent. Put spots of colour at every 30° on the ecliptic, and others at every 30° on the equinoctial, beginning at the first of Aries. Those on the ecliptic will represent twelve positions of the true sun during the year; those on the equator the corresponding positions of a fictitious sun, whose orbit we will suppose to coincide with that circle. Turn the globe from east to west, and you will observe that from Aries to Cancer the real sun will arrive at the meridian before the fictitious: at Cancer the two will be on the meridian together; from Cancer to Libra the equatorial sun will anticipate the real, *i.e.* mean time will be before the apparent. From Libra to Capricorn the apparent time will be before, and from Capricorn to Aries after the mean time; the two coinciding, however, at the first point of each of the signs mentioned, *i.e.* four times a year.

The solar days then, it will appear, are subject to an inequality from two causes—the time between two successive apparent noons being sometimes greater and sometimes less than a day of mean duration. Now it is found that if the deficiency and excess all the year round be registered and compared, they will neutralize each other, and the result will be a mean solar day of 24 hours' duration. To this day clocks and watches are set; and, supposing their rate to be constant, we should find that they agree with apparent time at only four periods in the year; namely, on or about April 15, June 15, September 1, and December 24.

The operation of these two causes combined has been calculated, and is regularly given in almanacs for every day in the year, under the head of "Equation of Time." The time found by observation of the sun must be corrected (a certain quantity being added or subtracted) to give MEAN TIME, according as the almanac indicates whether mean or clock time is before or after apparent time.

274. In reckoning time, astronomers always begin the day at noon, and count 24 hours till the noon of the next day. The civil day begins at midnight, and reckons 12 hours ante meridiem, or before noon, and 12 hours post meridiem, or after noon. June 25, 23 hours, astronomical reckoning, will thus appear to be June 26, 11 hours a.m.; while June 25, 6 hours, will, in civil reckoning, be equivalent to June 25, 6 hours p.m.

275. The student who wishes to pursue Practical Astronomy beyond the mere elements, must, as a matter of course, be provided with the Nautical Almanac, where only can be found those accurate calculations of the places of the heavenly bodies which will assist him in his pursuit. All these are adapted to the meridian of Greenwich; if, therefore, his meridian is to the east or west of Greenwich, it will, in some cases, be necessary to obtain a Greenwich date corresponding to the time of his observation by turning the longitude in degrees into time, and adding the result to the time at the place, if it be west, and subtracting it if east. Longitude may be turned into time by the following proportion :—

As 360° : 24 hours ; or as 15° : 1 hour : : long. in degrees : long. in time.

If a place, for instance, is in longitude 15° west, and I require the sun's declination at noon at that place, I turn 15° into time, namely, 1 hour, and add it to the local time to get the time at Greenwich, which will be 1 hour p.m.; I then take the sun's declination for 1 hour after noon from the Nautical Almanac, which will be his declination at the time of my observation.

276. A problem of very great importance, and of constant recurrence in Practical Astronomy, is to determine mean time from sidereal, and the contrary. A clock shewing sidereal time is so regulated as to point to 0 h. 0 m. 0 sec. when the first point of Aries, from whence is reckoned R.A. and celestial longitude, is on the meridian, and it will consequently always point out the right ascension of the meridian; or, when a heavenly body is on the meridian the sidereal clock shews its R.A. The sidereal day, like the solar, is divided into 24 hours, each of which differs, by a certain quantity, from the length of an hour of mean solar time. The divisions on the hour-circle of a celestial globe are hours of sidereal time, as the globe only represents the effect of the earth's rotation, without regard to its annual revolution. Bring the first point of Aries to the meridian, set the hour-index to XII, and as the globe is turned on its axis from east to west, the hour-circle will shew the right ascension in time of each star as it passes the meridian, and will thus be a good illustration of a sidereal clock.

From what has been stated respecting sidereal time, the reason of the following proportion, by which mean time may be converted into sidereal, or, by reversing it, sidereal into mean, will be immediately apparent.

As 23 hours 56 minutes 4·09 seconds, the length of a sidereal day (mean reckoning) : 24 hours of sidereal time : : any interval of mean time : its equivalent interval of sidereal time.

In the Nautical Almanac will be found two tables constructed from this proportion, entitled "Table for converting Intervals of Mean Solar Time into Sidereal Time," and the contrary, which facilitate the reduction materially. The following explanation will render the use of them clear.

Under the head of "Sidereal Time at Mean Noon," in the last column at page II. of each month, will be found the R.A. of mean sun at noon at Greenwich; and in p. XX. of each month, the mean time of the meridian passage of the first point of Aries, which may be considered as the mean solar time at sidereal noon, or when a sidereal clock shows 0 h. 0 m. 0 sec.

277. TO CONVERT SIDEREAL TIME INTO ITS EQUIVALENT OF MEAN SOLAR TIME.—Rule. Copy from p. XX. the mean time of the preceding transit of the first of Aries, which must be corrected for difference of longitude between the place of observation and Greenwich, by allowing in west longitude − 9·85 seconds per hour, and in east +, to obtain the local time corresponding to the time of sidereal noon; turn the given sidereal time into its equivalent mean solar time, by the table before referred to, and the sum of these two quantities will be the corresponding mean time.

TO CONVERT MEAN TIME INTO SIDEREAL.—Rule. Copy out the sidereal time at preceding mean noon, changing the sign for correction for diff. long., add to it the interval of mean time after having changed it into sidereal by the help of the table adapted to that purpose.

Examples of each of these processes will be found worked out in the "Explanation" of the contents of the Nautical Almanac.

278. A very important problem, viz. that of ascertaining the mean time of the meridian transit of a fixed star, demands our notice at this stage of the present work. The Nautical Almanac contains a most accurate table of the "Apparent Places of 100 Principal Fixed Stars," which serve as tests by which to try the accuracy of instruments, or as fixed points from which to calculate the place of a heavenly body whose exact R.A. or declination is unknown.

To find the mean time when either of these "Greenwich stars," as they are termed, will pass the meridian is in fact to find the mean time corresponding to the hours, minutes, and seconds of its R.A.; or to find at what hour of mean time the meridian will have the same R.A. as that of the star.

RULE. From the R.A. of the star subtract the R.A. of mean sun at noon of the day, given under the head of "Sidereal Time at Mean Noon," corrected for difference of longitude, the remainder will be equal to the distance of the star from the meridian at mean noon in sidereal time; convert this into mean time by the help of the table in the Nautical Almanac, the result will be the time the mean clock will shew when the star culminates; if the chronometer, or mean-time clock, does not shew this time, the difference will be its error.

EXAMPLE. To find the mean time of meridian passage of Aldebaran, July 30, 1852, at Southampton.

As the R.A. of the star is less than S.T. at mean noon, it will culminate before noon of the 30th.

	h. m. s.
R.A. of Aldebaran	4 27 26 14
	+ 24
	28 27 26·14
Sidereal time at mean noon of the 29th + 0·92 sec. for diff. long. . } =	8 29 9·91
Hour-angle at noon in S.T. . . =	19 58 16·23

To convert 19 hrs. 58 min. 16·23 sec. sidereal time into mean time.

Sidereal time. h. m. s.		Mean time. h. m. s.
19 0 0	=	18 56 53·24
58 0	=	57 50·50
16	=	15·95
·23	=	·23
Mean time of star's transit, July 29,		19 54 59·92

Or in civil time, July 30, 7h. 54m. 59·92s. A.M.

279. Before dismissing the subject of time, it will be necessary to explain what is meant by

1st. A TROPICAL, OR CIVIL YEAR. It is the time elapsed between two successive passages of the sun through the same equinoctial or solstitial point, viz. 365 days, 5 hrs. 48 min. 49·7 sec.

2d. A SIDEREAL YEAR is the time the sun takes between his departure from any fixed star till his return to that star, which, in consequence of Precession (see § 79), is longer than the tropical year by 20 min. 20 sec., being 365 days 6 hours 9 min. 9·6 sec. The observation of this difference by the early astronomers led to the discovery of the Precession of the Equinoxes.

3d. THE ANOMALISTIC YEAR is the interval between two succeeding passages of the sun through the same apsis: it is found to be 4 min. 42 sec. longer than a sidereal year. This fact indicates that the line of apsides, or the line joining the greatest and least distances of the earth from the sun, has a motion of 12″ *in consequentia*, or according to the order of the signs among the fixed stars.

SECTION VIII.

THE SUN-DIAL.

280. THE most simple instrument for measuring time is the sun-dial; upon the construction of which, in former times, great pains were bestowed. Since the more general diffusion of portable time-keepers, and the introduction of the telescope in astronomical observations, dials have been less in repute: as, however, a good dial, well fixed, will always give a near approximation to solar or apparent time at any hour of the day, and by the application of the equation will thus serve to regulate a common clock or watch, and since its construction illustrates the doctrine of the sphere, a few words on the subject of dialing may not be amiss.

Let us suppose N S D, Plate VIII. fig. 51, to be a glass globe, with meridians drawn through every 15° on the equator: these will be hour-circles. Let this globe be placed in the sunshine, with its axis, which we will suppose to be opaque, elevated to the latitude of London. The meridian which points due south must be numbered XII., as the sun will be on it at that hour. Now, since the distance of the sun is so great that the earth viewed from him would appear no larger than Mercury does to us, no perceptible error will arise from the centre of the glass globe not coinciding with that of the earth, which theoretically it ought to do.

Suppose the opaque plane D B to pass through the centre, so that the angle N E B $= 51\frac{1}{2}°$: this will represent the horizon of London. As the sun advances to the first meridian from the central one, viz. F, the opaque axis will throw a shadow on the horizontal plane, which will point out the direction of the one-o'clock hour-line. One hour afterwards the sun will be over the next meridian G, and the shadow of the opaque axis will indicate the position of the two-o'clock hour-line: in like manner, the shadow of the opaque axis will point out the other hour-lines as long as the sun is above the horizon. In practice, the meridian lines are done away with; but the principle of dialing is better understood by supposing them visible.

The spaces on the horizon between the hour-lines are the hour-arcs: these are the bases of spherical triangles, whose sides meet at the pole. Thus, N C B is a spherical triangle; the angle N B C is a right angle; N B is equal to the latitude $51\frac{1}{2}°$. The vertical angle C N B is the hour-angle, measured on the equator by the arc E a: in this case it is equal to $15° \times 6$ or $90°$, whence the base C B may be found by spherical trigonometry, which will be the distance in degrees from the XII. o'clock, or south line.

A vertical dial differs from a horizontal, in that the opaque plane passes through the zenith.

281. Plate VIII. fig. 52, represents a very elegant universal dial, by Adams: it may be adapted to any latitude, and will shew the time very correctly, if rectified with due care. Here the hour-circle is made to coincide with the plane of the equator, and is therefore divided into twenty-four equal parts; each of these represents an hour of solar motion, which, when measured on the equator, will always be equable. The gnomon *n s* is parallel to the axis of the earth, and may be elevated or depressed by the graduated arc *b s* to correspond to the latitude of any place between the equator and either pole: the shadow of the gnomon will then indicate the time on the circle *a b c d*, representing the equator. The foot of the dial may be placed perfectly horizontal by means of the foot-screws *e*, *f*, *g*, and, which is of the utmost consequence, due north and south by means of the COMPASS shewn at *m*.

As this is the first time we have had occasion to allude to that valuable auxiliary to nautical science, it will be appropriate to spend a short time in describing its construction, and pointing out its use.

SECTION IX.

ON THE COMPASS.

282. IF a bar of steel be nicely balanced on its centre, and afterwards rubbed with a magnet, it becomes endued with the property of pointing in the direction of the north; disturb it as you may, it will, after vibrating from side to side, at last remain steady in its original

direction. Knowing the northern point in the heavens, the south will be opposite to it; the east on your left hand as you face the south, the west on your right These are the four cardinal points. The portions of the circle described with the pivot of the balanced needle for a centre, intercepted between these, are subdivided into eight, making in all thirty-two points of the compass.* Independently, then, of any observation of the heavenly bodies, or of known objects on land, the sailor is thus provided with the means of ascertaining the direction in which his ship is sailing, or is able to direct her in the proper course; even in the darkest night this infallible monitor never forsakes him; in reliance upon its directions he still steers with confidence towards his destined haven.

283. We should fall into error, however, if we considered the north indicated by the needle (for such is the balanced bar called) to be identical with the meridian line determined astronomically, or by the method pointed out in § 222. It is a singular circumstance, that the magnetic north deviates from the true north by a quantity which varies, and that by no fixed law, in different latitudes: indeed, the VARIATION OF THE

* The points of the compass, which appear in general so complicated to landsmen, are easily understood by attending to the following simple rules:—

1st. When the letters indicating two points are united, the point meant is half way between the two: thus, N.E. is half way between N. and E.; S.S.W. half way between S. and S.W.

2d. When the letters are joined by the word *by*, the point meant is the one which comes next after the first, going towards the second: thus, S. by W. is next to S. going west; N.E. by N. is next to N.E. going north.

NEEDLE, as it is called, differs in the same place in various years; and if more minutely watched, it will be seen, during twenty-four hours, to vibrate slightly on each side of its mean position. Hence, for the more exact purposes of astronomy, its aid is of no avail; and on board ship the compass, from time to time, is corrected by comparing the sun's azimuth, indicated by it, with that deduced from astronomical observation at the same instant.

In 1850, at Greenwich, the variation of the needle was 22° 30′ to the west of north; so that, to find the true north, we must bring the needle over 22½° west, by turning the compass card, dial, globe, or whatever instrument we wish to rectify; then the line marked north and south will be nearly in the plane of the meridian of the place we may be in, provided its latitude differs only by a small quantity from that of London.

284. The following table will shew the variation of the needle for certain periods during the last 270 years: it arrived at its maximum of westerly variation about the year 1820; since which time it has approached the true north two degrees.

At London in

1576	the variation	was	11° 15′ E.	1780	the variation	was	22° 10′ W.
1622	„	„	6 0 E.	1796	„	„	24 0
1657	„	„	0 0	1806	„	„	24 8
1666	„	„	1 35 W.	1820	„	„	24 34
1720	„	„	8 0 W.	1845	„	„	23 30
1747	„	„	17 40	1850	„	„	22 30

285. The variation of the needle is not the only singular and inexplicable circumstance attending it. If

a needle be nicely balanced horizontally before it is magnetized, after it is imbued with magnetic influence the north pole of the needle will be found to DIP, or decline from the horizontal line. The dip will differ at different positions on the earth's surface: in the latitude of London, at the present time, it is about 68° 40′. Capt. Sir F. Parry found, in lat. 70° N. and long. 100° W., that the needle hung perpendicularly to the horizon. This point, then, was the MAGNETIC POLE of the earth; or, here the earth's magnetic attraction on the needle was at its maximum. The magnetic equator is a curve of double curvature, and crosses the geographical equator at several points. On this magnetic equator the needle is perfectly horizontal.

It is usual in compasses used for levelling and surveying, to have a sliding ring of brass running on the southern bar of the compass, which may be so adjusted as to keep the needle in a horizontal position; for it is hardly possible to make the southern half so much heavier than the northern, as to insure that the needle after it is magnetized shall have no dip at all. In such compasses, as well as in those adapted to astronomical purposes (as that, for instance, by which the dial in fig. 52, Plate VIII. is set due north and south), the plate is divided into degrees and parts of degrees, which are reckoned towards the east, commencing with the north, from 0° to 360°.

SECTION X.

THE TIME-KEEPER AND TRANSIT INSTRUMENT.

MODE OF RECTIFYING THE TRANSIT INSTRUMENT, AND METHODS OF BRINGING IT INTO THE PLANE OF THE MERIDIAN.

286. THE observations connected with practical Astronomy must be regulated by far more correct instruments than those we have just described. Observatories calculated for registering the phenomena of the heavens are fitted up with instruments of the most elaborate workmanship and enormous size, at an expense which is usually defrayed by government or some public body; such as those at Greenwich, Cambridge, Oxford, and Edinburgh, the most important of which are described at full by the Rev. R. Main, of the Observatory, Greenwich, in a small work published by Mr. Weale. It will be our aim to describe such astronomical instruments as are portable, obtained at a comparatively small cost, and which may be used in a garden or lawn, or, at all events, will not require a costly building in which to establish them. By confining ourselves to these, we may hope to benefit such as already possess them, by familiar directions for their adjustment and use, or to direct any who may desire to cultivate Practical Astronomy, in the purchase of instruments adapted to that pursuit: at the same time in describing these we shall, in part, be explaining those employed at the most elaborately-furnished observatory; for the principles of construction of a small instrument are generally the same as those of the most

perfect of the same kind which the Astronomer Royal can command.

287. To begin with those adapted to the accurate measurement of time: if we wish to verify any of the facts laid down in the preceding sections, we must be furnished either with an astronomical clock or a chronometer; a common watch, however well it may be adapted to keep time for general purposes, is of little use when referred to the heavenly bodies; here we want a measure of time which shall be correct from second to second, and which shall vary but a very minute quantity in the twenty-four hours; and that quantity the same from day to day—an instrument in fact which shall shew time with a regularity nearly equal to that of the diurnal motion of the earth.

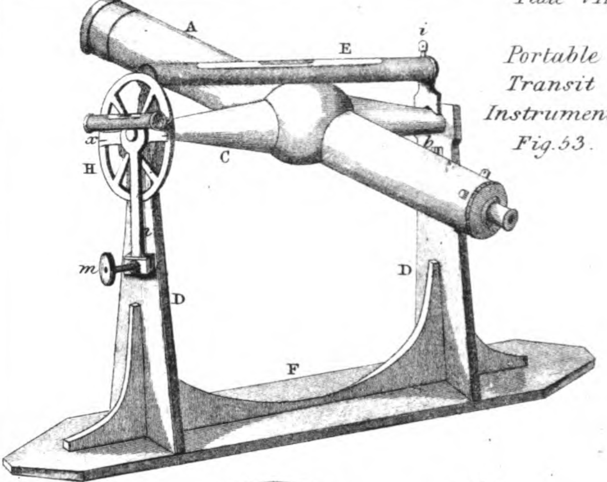
Astronomical clocks are now usually constructed with mercurial pendulums; they are regulated either to mean solar, or to sidereal time; and any one who has been at the cost of a fixed observatory will certainly furnish it with one of these valuable time-keepers. The advantage of a sidereal clock for astronomical purposes will appear, if we call to mind that the time shewn by it is always the Right Ascension of the meridian; to find then when a heavenly body will culminate, we have only to observe when the clock points to the h. m. s. corresponding with its R.A., and the heavenly body will then be on the meridian. If a clock shewing mean time is made use of, certain reductions must be gone through at an expense of time and labour before the same result can be attained (see § 278).

In the absence of an observatory, as in the instance of the amateur observer, who only occasionally determines the true time—or in the case of the navigator observing on shore—or of the scientific traveller, whose circumstances prevent his remaining long in one place, the chronometer will be a tolerable substitute for the astronomical clock.

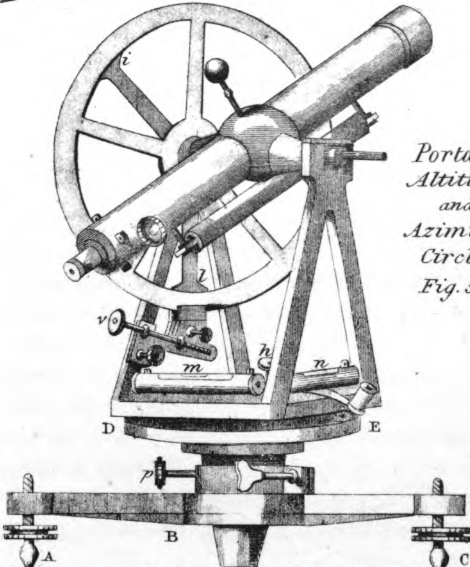
288. The transit instrument is employed for determining the rate of either of these time-keepers; and when this is ascertained, for working problems connected with the determination of the longitude, and, in established observatories, for determining with extreme accuracy the Right Ascension of the fixed stars. The drawing, fig. 53, Plate VII., shews a portable transit, the telescope of which is generally in length from 12 to 20 inches. The portable transit instrument is a valuable accession to the apparatus of the scientific traveller, who by its aid may determine the rate of his chronometers on shore, and ascertain the longitude of the place he may be in. Various principles laid down in different parts of this treatise may be exemplified by it in a very pleasing and striking manner, as will be shewn in this division of the work.

The telescope A is fixed at right angles to the axis C, which terminates in cylindrical pivots well turned and smooth: these are supported in notches or Y's, on the upper end of the vertical standards D D; so that the telescope has only one motion, and that perpendicular to the horizon: when the instrument is properly rectified, this motion will be performed in the plane of the meridian, and any heavenly body seen on its central wire will be on the meridian. To assist in determining the exact centre of the field of view, there is placed within the telescope a system of wires, consisting of at

Plate VII.



Portable Transit Instrument. Fig. 53.



Portable Altitude and Azimuth Circle. Fig. 55.

least five vertical wires and one horizontal wire; these are shewn in figure 54, Plate VIII., which may be supposed to represent the field of vision of the transit telescope, with the sun approaching the central vertical wire.

289. Before the transit is ready for use, five adjustments must be gone through; three of these may be considered permanent, and are usually completed by the maker; for the other two, relating to the position of the axis, the observer must rely upon his own skill, aided by directions which will here be given.

1. The wires should be perfectly vertical: direct the telescope to a distant object, and bringing it upon the central wire, move it up and down, and if the wire continues to cut the object in every part of the field of view, this adjustment is perfect.

2. The focus of the object-glass and that of the eye-glass must meet on the wires: this may be tested by bringing the point where the middle vertical and horizontal wire cut each other on a distant object; if on moving the eye slightly up and down, the object appears to separate from the wires, this is a defect which must be remedied by moving the eye-glass in or out till the wires are seen sharply defined, and then adjusting the focus of the object-glass to distinct vision by the button at the side of the telescope; the foci of both glasses will then meet on the wires.

3. The line of collimation must coincide with the axis of the telescope; that is, the central vertical wire must be exactly in the optical axis of the telescope. Observe an object cut by the meridian wire; remove the telescope from the supports D D, and make the extremities of the axis change places; if the object ap-

pears cut as before, the adjustment is complete; if not, half the error must be corrected by the adjusting screws of the diaphragm carrying the wires, which are shewn at the eye-end of the telescope, and the other half by the azimuthal screw at or near *b*; and the operation must be repeated till, on viewing the object with the axis of the telescope in either position, the central wire is found to cut it similarly. This will be no test of the horizontal wire being in the line of collimation, but here a small deviation from the centre of the telescope is of no consequence. Care must be taken in making this adjustment that the verticality of the wires is not disturbed. These three adjustments are usually completed by the maker, and are not very liable to derangement.

290. The support of the instrument, F, may rest on any surface which is nearly horizontal. To one extremity of the axis, which extends beyond the support, is attached a graduated circle, H; this circle turns with the axis, and is read off by a double vernier* *x*, attached to a spirit-level: this level is set horizontal by the arm *n*, which arm admits of clamping by the screw *m*; the circle may by its help be set to the meridian altitude of any heavenly body whose transit we may wish to observe. (See for the method § 299.) The wires of the telescope, which are seen easily enough in the day-time, require to be illuminated if we wish to observe the meridian passage of a star at night; for this purpose the further arm of the axis is hollow, a lamp is fixed opposite to the extremity, and the light thus admitted

* The vernier is a beautiful contrivance for subdividing the arc by means of the index, which will be better understood by inspection and vivâ-voce explanation, than from any written description.

is reflected by a small annular mirror, placed at an angle of 45° in the interior of the telescope, down the tube to the eye-piece.

291. The former adjustments being supposed to be correct, we have now to level the axis; for if the axis be not perfectly horizontal, the circle described by the telescope will not be perpendicular to the horizon; and consequently, even should it, when horizontal, point due north and south, it will deviate more and more from the meridian as it is directed towards the zenith. We now call to our aid the level E, which is usually detached, but may be made to stride from pivot to pivot, as in the drawing, or to hang below the axis by means of arms; this level indicates by the rise of the bubble which end of the axis is the higher—the small screw at *b* will depress that end: bring the bubble half way towards the middle by it, and correct the other half of the error by the screw at *i*; lift off the level and turn it end for end; if the bubble be still in the centre, the adjustment is perfect; if not, correct as before half the error by the small screw at *i*, and the other half by the screw before used (at *b*). The operation must be repeated till, on repeatedly reversing the level, the bubble will continue to remain in the centre.

292. The instrument is now ready for the important operation of bringing it into the plane of the meridian. For this purpose several methods may be adopted, and the surest way of perfecting the problem will be by testing the instrument by them all. Various calculations involving algebraic formulæ are adopted with large transits to ascertain the value of the deviations, which will be treated more fully hereafter.

293. If all the preceding adjustments of the instrument are complete, it may be brought near the meridian by one observation, if the true time at the place be known. Find the time when one of the standard Greenwich stars will pass the meridian; and having determined the meridian approximately by means of a compass, by allowing for the variation, having also rectified the instrument, wait till the star is just about to culminate. Watch the star carefully when it has entered the field of the telescope, counting the seconds in the meantime: move the instrument by the azimuthal screw after the star, keeping the meridian wire on it, and stop at the instant when the calculated time is indicated by the time-keeper. Lower the telescope to the horizon, and set up a distant mark, which, when bisected by the central wire, will serve to recover the meridian at any future time—the mark might be a small white circle of metal marked with a black cross: it must be firmly fixed, so as not to be liable to accidental removal. The difficulty, however, is, to find the exact time at the place — and hence the importance of an acquaintance with some other methods of determining the due north and south line.

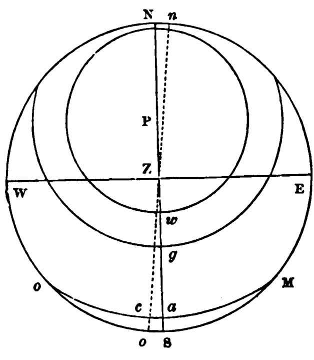


Fig. 50.

294. Before entering upon these, a clear understanding of the adjoined figure

will be necessary: if it be studied attentively, the reason of every rule will clearly appear. N W E S represents the horizon of any place; N S the true meridian; E W the prime vertical or east and west line; P the pole; Z the zenith; *n o* a false meridian, which we will suppose to be the plane of the circle, described by a transit instrument which has not yet been brought into the true meridian. Now, since all vertical circles meet in the zenith, the false and true meridian will cross each other in that point; the greatest deviation will be in the horizon, as N *n*, *o* S; and the error will be less and less as the altitude increases. Take Capella, a circumpolar star; in describing its diurnal arc, it will appulse both the meridians at its upper transit *w* at or near the true time, for the two meridians there nearly coincide; but at its lower transit, if, as in this case, the deviation be east of north, it will arrive at the true sooner than at the false meridian, which will not be reached till it has described an arc nearly equal to N *n*; if the deviation were west of north, it would approach the erroneous meridian before it passed the true.

Again, let M *o* be the portion of the diurnal arc described by a star which does not rise very high above the southern part of the horizon. If the assumed meridian deviate west of south, its transit will happen later than it ought, seeing that it will arrive at *a* before it reaches *c*. The nearer the horizon the star may be, the greater the arc it will have to traverse between its transits of the false and true meridians (compare a transit at *g* with one at *a*). If the deviation be east of south, the true meridian will be passed after the false will have been approached. On the principles here laid down are founded the following methods of bringing a transit into the plane of the meridian, which need not be explained separately, if the above preliminaries are clearly understood.

295. Method I. Observe the meridian transit of a circumpolar star both above and below the pole: if the times of its describing both the eastern and western portion of its diurnal arc are equal, the instrument is properly adjusted; if not, the error must be corrected by giving the instrument a slight motion in azimuth, to the westward when looking north, if the interval between the first transit above the pole and the transit below the pole be greater than the interval between the transit below the pole and the second transit above it; eastward, if the latter interval be greater. The observation must be repeated till the two intervals are found to be of equal duration.

The five wires are placed by the maker as nearly as possible at equal distances from each other, and in observing the transit of a star, the times of its crossing all five must be noted, and the mean of the whole may be expected to be nearer the truth than the result of one observation on the central wire.

296. To take a transit of a heavenly body, watch the object as it enters the field, catch the second from the clock, and reckon the beats by ear, while the eye is watching the object's passing the first wire; if the instant of the transit corresponds with a beat of the clock, write down the second in the work-book, continuing the counting at the same time; if the object passes rapidly,

it may be as well not to move the eye from the glass till all the five wires are passed; if the transit of either wire occurs between two beats of the pendulum, the space between must be estimated and written down as a decimal of a second. The instant the 5th wire has been passed and the transit recorded, before ceasing to count look at the clock and observe whether the second agrees with the reckoned one; if it does, no mistake has been made in the reckoning; then write down the minute belonging to the second at which the last wire was passed. Add up the seconds only, and multiply by ·2, which is equivalent to dividing by 5; the quotient will either be nearly equal to the number of seconds indicated by the transit over the middle wire, or will differ from it by a multiple of 12, which must be subtracted from it, or added to it if necessary, to bring out the seconds of the mean of the time of the transit across the five wires; reckon backward for the minute, and prefix it with the hour shewn by the clock; the result will be the mean of the times of the transit over the five wires.

It will at first be troublesome to continue the reckoning of seconds at the same time that the seconds and decimals of seconds are written down; but a little practice will render it far more easy than could have been supposed.

The process described is much shorter than dividing the sum of the whole series of observations by 5, and the result will be the same; as may be seen from the following example:

Transit of

ζ Aquilæ by the above method.	ζ Aquilæ by the longer method.
1	18 59 1
20·8	18 59 20·8
40·5	18 59 40·5
0·5	19 0 0·5
19 0 20·5	19 0 20·5
83·3	5)94 58 23·3
× ·2	
16·66	
+ 12 × 2 = 24	h. m. s.
18 59 40·66 time of transit.	18 59 40·66

297. The first method of determining the meridian supposes that the rate of the timekeeper will remain uniform for 24 hours, and that the instrument, during that time, is stationary and undisturbed—a condition seldom attainable, except in a regular observatory. In the following method the instrument need only remain fixed for a short time, and the regularity of the clock, or chronometer, is not required for even one hour.

Method II. Take the transits of two known circumpolar stars: δ Ursæ Minoris and 51 Cephei, whose places are given in the Nautical Almanac, will suit the purpose well, as they differ nearly 12 hours in right ascension. If the difference of the observed times of their transits be equal to the difference of the stars' right ascensions, the azimuthal error is 0, and the instrument is in the meridian; if these quantities are unlike, the instrument deviates by a quantity and in a direction which may be judged of as in the case of a single circumpolar star: the azimuthal error of the instrument must be corrected by repeated approximations as before.

298. The following method, however, will occupy less time than either of the foregoing, and will require regularity in the timekeeper for a very short interval; indeed, in some cases, where the observer's view is confined, it is the only one that can be adopted.

Method III. Choose two stars which have nearly the same right ascension, but differing at the very least 40° in declination, one, of which must culminate near the zenith. The upper star will pass near the true time whether the instrument be in the plane of the meridian or not, but the lower star will be more or less affected by any deviation, in proportion to its proximity to the horizon. Observe the difference in the times of their meridian transit, and compare it with the difference of their R.A., which, if the timekeeper shew mean time, must be first converted into mean time for that purpose: if these two differences are exactly equal, the instrument is in the plane of the meridian; if not, the telescope points east or west of the true meridian. Assuming the upper star to culminate at its proper time, and that the observed interval is less than the difference of R.A., the telescope (looking south) will be east of the true meridian. If the observed interval be too great, the deviation is west. The angle of deviation may be found as follows. To the log. of difference of interval in seconds add the log. cosine of the declination of each star, the log. secant of the sum of their declinations, and the log. secant of the latitude; the sum, rejecting 40 from the index, will give the log. of the number of seconds of deviation in time, which multiplied by 15 will give the number of seconds of arc.

When this problem is performed with the altitude and azimuth instrument, the azimuth circle will enable the observer to correct the deviation, as it is divided into degrees, minutes, and seconds.

299. The telescope of the portable transit instrument is generally of sufficient power to shew stars, at least of the first magnitude, in the day-time. To identify stars, or to fix upon that portion of the meridian at which they will arrive, we call in to our aid the circle attached to the axis, which need not, in general, be divided lower than minutes. When the bubble of the spirit-level is in the centre, the verniers having been set to the meridian altitude, the telescope will be adjusted.

To find the meridian altitude of a heavenly body, or the zenith distance at the time it culminates, which is the difference between its meridian altitude and 90°, we adopt the following method:—

Rule. Write down the latitude of the place, marked N. or S.; underneath this write the declination of the object, marked N. or S.: if the names are unlike, the sum of these two quantities, or if they are like, the difference will be the zenith-distance; 90—Z.D. = meridian altitude. If the circle be set to this quantity, the star will appear in the telescope some time before the calculated instant of meridian passage. If great correctness is required, apply the correction for refraction in altitude, taken from suitable tables, with the sign +.

300. The meridian having been determined by either or all of the above methods, the true time may be ascertained any day, at noon, by a meridian observation of

the sun. Observe the exact time when the sun's western limb approaches each vertical wire, which, as the telescope inverts, it will do from the right-hand side of the field of view. Do the same when the other limb transits each wire, add these times together, and divide the sum by 10, which will be the instant that the sun's centre was on the meridian. As it will often happen that, in cloudy weather, only one limb can be observed, the time of the sun's semi-diameter passing the meridian is given in the Nautical Almanac and all other ephemerides, which must be added to the time of passage of the western limb, or subtracted from that of the eastern, to give the time of the passage of the sun's centre.

The instant the sun's centre is on the meridian will be apparent noon—apply the equation of time, and the result will be mean noon. With this correction, the time shewn by a chronometer or mean-time clock should be 0 h. 0 m. 0 s.; if it is not, the difference is its error, fast or slow, + or —, as the case may be.

The error of a timekeeper may also be determined by observation of the transit of any one of the standard Greenwich stars. Find the time of the star's transit, if the clock or chronometer shew mean time, by the rule given in § 278; the comparison of this with the observed time will give the error. Observations either of the sun or star, continued from day to day, and compared with the time shewn by any timekeeper, will give its rate, gaining or losing; which, if the workmanship be good, will be uniform, and of trifling amount.

SECTION XI.

ON THE ALTITUDE AND AZIMUTH CIRCLE.

301. We now proceed to describe an instrument which is of very extensive use in Practical Astronomy—the altitude and azimuth circle; or altazimuth circle, as it has lately been designated. A drawing of a small one of modern construction is given in Plate VII. fig. 55.

A, B, C are the foot-screws by which the horizontal plate D E is levelled. The telescope has an axis similar to that of the transit instrument; but the vertical circle carried by this axis is much more minutely divided than that of the transit need be for the mere identification of stars. The drawing is a representation of an astronomical circle made by Adie of Edinburgh. The vertical circle is eight inches in diameter, divided on silver, and read off to 10″ by three verniers; the horizontal circle is six inches in diameter, also divided on silver, and read off to 10″ by two verniers. The advantage of more than one vernier is, that the opposite verniers correct one another, in case of bad centering, or errors of division. By this instrument altitudes of a heavenly body may be taken when it is not in the meridian; while by clamping the instrument in the meridian, it will admit of all the adjustments, and answer the purpose of a transit instrument.

302. The horizontal circle has a motion in azimuth, produced by turning the screw at *h*, by which the whole of the instrument may be turned so as to bring 0°, or zero, into the plane of the meridian, or upon any par-

ticular object. When the zero is in the meridian, and the telescope is turned to a star east or west of that circle, the vernier at E, and another exactly opposite, will point out its azimuth.

Underneath the telescope is a spirit-level, by which it may be placed in a horizontal position : by means of this, the zero of the vertical circle may be determined by the following methods :

1. When the telescope is horizontal, or rather, when on turning the instrument completely round, the bubble of the level underneath remains in the centre, mark the degrees, minutes, and seconds shewn by the three verniers, and take the mean by dividing the sum of them by three. This will give the zero approximately. Bring the cross wires on a terrestrial object, and take its angle of elevation. Turn the instrument half-way round in azimuth, reverse the telescope, and bring the cross wires on the same object; the measure of the angle in this position ought to differ 180° from the former reading; if it does not, an index error will be the result, which will be half the excess above 180°; which error must be regularly applied : + to the angles measured with the instrument in the same position as that which gave the least elevation; — to those indicated by the instrument in the reversed position.

2. Observe the meridian altitude of a star on a certain night, by direct observation; find its depression on the following night by remarking its image reflected from the surface of mercury, which forms the artificial horizon : the point midway between these readings-off will give the zero, or horizontal point of the instrument, which, if the observations are well performed, will

agree with that part of the arc determined by the former method, after the index correction was applied.

3. In cases where expedition is required, and the latitude of the place is well known, find the meridian altitude of a standard Greenwich star; then from the Nautical Almanac, determine what its meridian altitude ought to be, in the manner shewn in § 299; the difference, if any, between the observed and computed altitudes will be the index correction, + or —, as the case may be.

303. A tripod-stand accompanies the instrument; but for astronomical purposes it will be better to fix it on a stone pillar, and, in the absence of a fixed observatory, to provide a waterproof covering strained over hoops, which may be lifted off without touching the instrument: this will be a protection against damp, and, which is of more consequence in correct observations, from the effect of the sun's rays, which might cause an unequal expansion of the parts of the instrument, and produce a deviation, which the sensitive levels will immediately point out.

304. After the horizontal plate is rectified by means of the foot-screws and the levels *m n*, the same adjustments for collimation and causing the telescope to describe a vertical plane must be gone through as with the transit (see § 289). For this latter purpose there is a striding level, with a scale noting the seconds of deviation of the bubble, which must be applied to the axis. A reflecting eye-piece is also provided, for viewing objects near the zenith: this consists of a small mirror within the usual eye-piece, placed at an angle of 45° with the axis of the telescope. By this the image is reflected

in such a manner that it may be seen by looking in at the side of the telescope, even when it is in the zenith. Without it, an elevated object could not, in some cases, be viewed without discomfort; in others, it could not be seen at all.

Instruments of this construction serve to demonstrate many astronomical facts, and perform approximately various interesting problems; they are much used on extensive surveys in various parts of the world, not only for determining the latitude and longitude when unknown, but for taking angles subtended by terrestrial objects for the purpose of forming correct maps or charts of extensive districts. The Admiralty often supply them to surveying-ships, to be used on shore as opportunity may offer.

The altazimuth circle at Greenwich, on the plan of the Astronomer Royal, is the finest instrument of the kind which has yet been produced.

In large observatories, mural circles, six or eight feet in diameter, are fixed against stone walls in the plane of the meridian: these are read off by three or six micrometer-microscopes on various parts of the arc; and a mean of all the observations taken by them will give the measurement of an angle with wonderful exactness. By means of these it is that the altitudes, whence are deduced the declinations, of the heavenly bodies are observed from day to day, and the result tabulated, and rendered available.

In the description of the author's instruments which follows will be found an account of the mode of performing the nicer adjustments of the transit instrument, transit circle, and equatorial. The transit circle moves only in the meridian, and therefore determines meridian altitudes only; but as the transit of a star may be taken at the same time, the R.A. and dec. may be deduced from one observation.

SECTION XII.

ASTRONOMICAL PROBLEMS.

METHOD OF DETERMINING THE MERIDIAN BY EQUAL ALTITUDES—THE LATITUDE AND LONGITUDE—PROBLEMS IN SPHERICAL TRIGONOMETRY—LUNAR DISTANCE—OF FINDING THE TIME FROM THE ALTITUDE OF THE SUN, WHEN NOT ON THE MERIDIAN.

305. WE will suppose the student of astronomy to have procured one of the instruments described in the preceding paragraphs: our aim will now be to direct him in the application of it to the purposes of astronomical observation.

The meridian must first be determined exactly, after the methods pointed out in the case of the transit instrument (§§ 295-298): the altazimuth instrument has however this advantage over that instrument, viz. that when the deviation from the true meridian is ascertained, the instrument may be moved through any number of minutes or seconds on the azimuthal arc. The altazimuth circle will enable us, moreover, to determine the meridian very correctly by means of equal altitudes of the sun or a star. This we may designate

Method IV. Find a star's altitude at least three hours before it culminates, marking at the same instant its azimuth by bringing it on the intersection of the central vertical and horizontal wire: clamp the vertical circle, and be ready, at the same interval after its meridian passage, to observe when the star has exactly the same altitude and azimuth. The meridian will be the point of bisection of the arc passed over by the index, measured on the azimuth circle: thus, if the arc passed over between the two observations is found to be 75° 14′, turn the instrument eastward of the last observation 37° 37′, and the telescope will be in the plane of the meridian. This is clearly a correct performance of the problem described in § 222, depending in both cases upon the fact of the heavenly body's altitude being the same at equal distances on each side of the meridian.

If the time when the first altitude is taken be noted, and again on the second observation, by a timekeeper, the mean of these times will give the time shewn by it when the star was on the meridian.

306. Having determined the meridian, and ascertained the rate of the timekeeper, the next desideratum is the latitude of the place of observation, which may be determined as follows:

Method I. Find the meridian altitude of the sun's upper or lower limb; subtract or add the sun's semidiameter, taken from the Nautical Almanac; correct for refraction, and parallax if extreme nicety be required, but this may generally be neglected: the result will be the true altitude of the sun's centre; 90° — this altitude will be the zenith distance, which must be marked with the letter N or S, of the elevated pole: under the Z. D. write the sun's declination, marked N. or S.; take their sum if alike—their difference if unlike—for the latitude. By referring to fig. 3. Plate VIII., the reason of this rule is evident. Let H c'' be the meridian altitude of the sun at c'', Z c'' will be the zenith distance, E c'' the declination : E $c''+c''$ Z $=$ E Z, which measures the angle E C Z, the latitude of the observer at O.

EXAMPLE. April 12, 1845, at Cumberland Place, Southampton. Observed altitude of sun's upper limb, 48° 6′ 30″ : required the latitude.

Altitude of sun's upper limb . .	48° 6′ 30″
— Semi-diameter	15 57
Ap. alt sun's centre	47 50 33
— Refraction	0 0 52
True altitude	47 49 41
Zenith dist., N.	42 10 19
Declination, N.	8 44 15
Latitude N.	50 54 34

Method II. Find the meridian altitude of a circumpolar star when above the pole, and again when below the pole : half the sum of the two altitudes, after they have been corrected for refraction, will give the latitude. In Plate VIII. fig. 3, M R + P R divided by 2 = N R, the height of the pole or latitude of the place (§ 224).

307. The next object of the astronomer will be to determine the longitude of the position chosen for his observations; that is, the difference in time between his meridian and that of Greenwich.

Suppose a chronometer so accurately constructed as to go uniformly in all seasons, climates, and under all circumstances; such a timekeeper, set to Greenwich time, and compared with the time of the day under any other meridian, found in the manner explained in § 300, would point out the difference of time between that place and Greenwich; which, turned into degrees, would be the longitude, west or east, according as the time at the place is after or before Greenwich time.

The whole problem, then, of finding the longitude resolves itself into ascertaining the time at Greenwich corresponding to the time of any occurrence under any other meridian. Now although chronometers are, at the present day, constructed with most wonderful accuracy, yet, subject as they are, on long voyages, to derangement from the motion of the ship, and in various climates to differences of temperature, it is quite necessary to have some means of determining the longitude entirely independent of their rate. An observer remarks a phenomenon in the heavens, aware that at all those places where it is witnessed at all, it will be visible at the same instant of time. Now, on the supposition that he can become acquainted with the time at Greenwich when this was seen, and that the true time of its occurring under his meridian, *i e.* the local time, is known, the difference of these times would give the longitude of the place.

Such a phenomenon is an eclipse of one of Jupiter's satellites. In the Nautical Almanac may be found the configuration of the satellites of that planet for every evening of any month during which they may be visible, with the exact instant of the occurrence of an eclipse of any one of the four when it will be seen at Greenwich. Let us suppose that an eclipse of the first satellite, predicted to happen Jan. 2, 9 hrs. 34 min. 10 sec. at Greenwich, is found at Southampton to occur 9 hrs. 28 min. 34 sec. Southampton time; the difference between these times will give the longitude in time 5 min. 36 sec., which converted into degrees will be 1° 24′, west, because the time is less than that at the Greenwich Observatory.

308. An eclipse of the moon will answer the same purpose roughly. Observe the local time of the beginning or end of an eclipse; compare it with the time given in the Nautical Almanac when the eclipse begins or ends at Greenwich : the difference of the times will give the longitude as before.

309. For ascertaining the longitude of a place by another method, the Nautical Almanac supplies a list of "Moon-culminating Stars;" *i. e.* stars which come to the meridian very near the time of the moon's meridian passage. The following explanation is given of the use of these tables at the end of the almanac, with full directions for working the problem :

"The determination of the difference of meridians is effected by comparing the differences of the observed right ascensions of a moon-culminating star and the moon's bright limb at the two meridians. If the moon had no motion, the difference of her right ascension and that of a star would be constant at all meridians; but in the interval of her transit over two meridians her right ascension will have varied, and the difference between the two compared differences will exhibit the amount of this variation, which, added to the differences of the meridians, shews the angle through which the westerly meridian must revolve before it comes up with the moon : hence, and knowing the rate of her increase in right ascension, the difference of longitude may be easily obtained."

310. The longitude may also be obtained by remarking the occultation of a fixed star by the moon, and comparing it with the Greenwich time of the same occurrence. The method of working this problem is too complex for description in this place.

311. The method of "lunar observations," which is that most in use at sea for determining the longitude, depends on the same principle as that of "moon-culminating stars." As the motion of the moon in her orbit is very rapid, amounting to about 13° daily, or 32″ in a minute of time, she rapidly increases her distance from a fixed star or the sun. If the angular distance between the centres of the sun and moon, or between the moon's centre and a star, be ascertained, and also the time at Greenwich when the distance of the two bodies from each other was the same, the difference between the Greenwich time of the occurrence and the time at the place of observation, will give the longitude. This problem is very complex, and requires most minute accuracy; for a small error in any of the observations would produce a great error in the longitude deduced from them. The method of working it out may be found in any treatise on navigation. The principle will be explained in the next section.

PROBLEMS ON THE SPHERE.

312. The following are a few of the various problems which may be worked out by spherical trigonometry, the altitudes and azimuths being taken by the astronomical circle: it will assist the reader in

understanding them if a celestial globe be used in illustration.

313. 1. Given the obliquity of the ecliptic and the sun's declination, required his longitude and right ascension. Refer to fig. 3, Plate VIII.

Let C be considered the first point of Aries, *x* the place of the sun, *x r* his declination; then the angle *r* C *x* is the obliquity of the ecliptic; these are given: C *x* the longitude, and C *r* the right ascension are required.

The spherical triangle C *r x* is right-angled at *r*; in this triangle are known the angles *r* C *x*, *x r* C, and side *r x*, whence may be found the sides C *r* and C *x* (see § 210).

314. 2. Given the R.A. and dec. of two stars, required the distance between them.

Let *x* and *y* be the stars, *x r* and *k y* their declinations, C *r* and C *k* their R.A. In the spheric triangle N *x y*, given the angle *y* N *x*, the difference of the R.A. of the two stars, N *x*, N *y* their north polar distances, whence may be found *x y*, the distance between them.

315. 3. Given the latitude of the place and the sun's declination to find the time of his rising.

Let *l* be the sun's place, *l g* his dec., N R the latitude, then Z N *l* is a spheric triangle, of which the side Z N is the co-latitude, N *l* is the polar distance, Z *l* is 90°; all three of these are known, whence may be found the angle Z N *l*, the hour-angle from the meridian measured on the equator by the arc E *g*; this is the apparent time of the sun's rising.

316. 4. In the same triangle with the same data may be found the angle N Z *l*, measured by the arc *l* R,

Plate VIII.

Fig. 3.

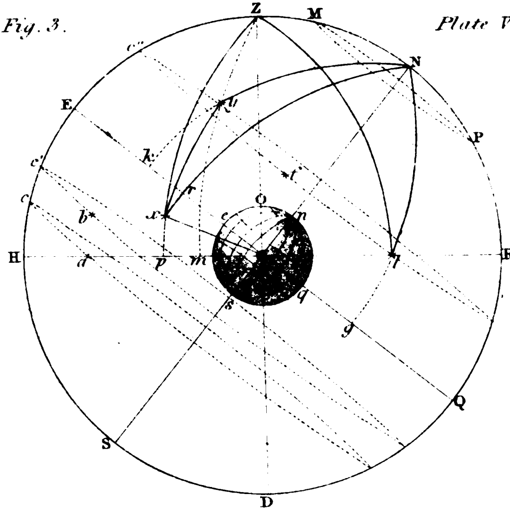
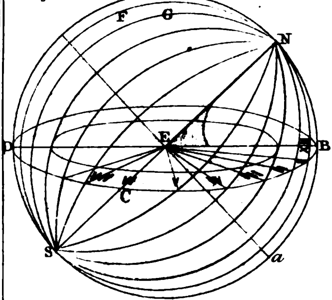


Fig. 51.



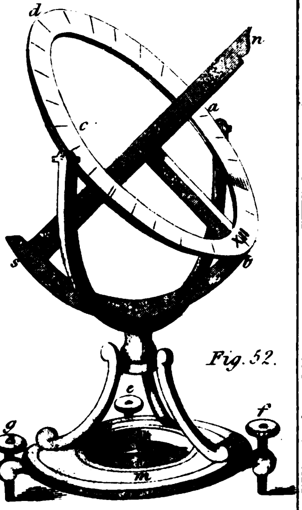


Fig. 52.

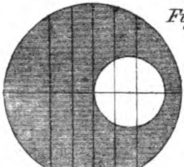


Fig. 54.

which will be the rising amplitude of the sun measured from the north.

317. 5. Given the apparent distance and apparent altitudes of the sun and moon, to find their true distance.

Let Z be the zenith, M the apparent place of the moon, and S the apparent place of the sun; *m* the true place of the moon, *s* the true place of the sun; then Z S will be the zenith distance of the sun, and Z M that of the moon, and S M the apparent distance. In the spherical triangle Z S M, given the three sides, whence find the angle S Z M.

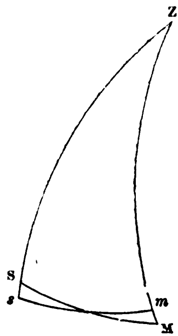


Fig. 51.

Correct the sun's altitude for refraction and parallax, whence obtain the true zenith distance Z *s*.

Correct the moon's altitude for refraction and parallax, whence obtain the true zenith distance Z *m*.

With the two sides Z *m* and Z *s*, and included angle S Z M (= *s* Z *m*), find *s m* the true distance.

This problem constitutes what is called "working a Lunar" at sea. Having found the true distance of the sun and moon, and the time at the ship when the observation was taken, ascertain from the Nautical Almanac at what time at Greenwich the distance of the two bodies was the same: the difference between this and the ship time will be the longitude in time.

318. 6. Given the latitude of the place and the sun's declination and altitude, find the azimuth and the time.

Let N R, as before, be the latitude, x the sun's place, $x\ r$ his declination, $x\ p$ his altitude, p R his azimuth from the north; then in the spheric triangle Z x N, given Z N the co-latitude, Z x the zenith distance or co-altitude, x N the polar distance, whence may be found the hour-angle from noon Z N x, and the angle x Z N measured by the arc p R, which is the azimuth from the north.

As this is a most important problem, being the best method of ascertaining the time at sea, and the variation of the compass, and being moreover equally applicable on land: and as the solution is easily managed by any one who is acquainted with logarithms, we shall give the best rule for working out the problem with an example at full: the altitude of the sun must be taken when he is at least three hours from the meridian, and the time of the observation must be noted by the chronometer.

FOR THE TIME.

RULE. Under the latitude write the sun's declination, each with its proper name marked N or S: if the names are *alike*, take their *difference*; if *unlike*, take their *sum*. Under the result put the zenith distance of the sun's centre; take the sum and difference of these two quantities, and their half sum and half difference; add together the log. secants of the two first terms, and the log. sines of the two last; divide the sum by two, and the quotient will be the log. sine of half the hour-angle; this, in time, doubled, will be the apparent time when the sun is *west* of the meridian; 24 − hour-angle will be the apparent time when the sun is *east*; apply the equation, and the mean time will be known.

In taking out the sun's declination and the equation of time, allow for the sun's change in dec. during the number of hours before or after the noon of the day of observation, and also for the difference of longitude.

Example. At Southampton, April 17, 1845, the true altitude of the sun's centre, after applying corrections for parallax and refraction, was 22° 24′ 20″; the declination at the time 10° 35′ 33″; time by chronometer 4 h. 25 m. 18 sec.: required the true time and error of timekeeper.

Latitude .	50° 54′ 40″ N.
Declination	10 35 33 N.
	40 19 7
Zen. dist. .	67 35 40
	107 54 47
	27 16 33
½ sum . .	53 57 23
½ diff. . .	13 38 16

Sec. .	0·200294
Sec. .	0·007462
Sin. .	9·907712
Sin. .	9·372506
	2)19·487974
Sin. .	9·743987
½ hour ang. . .	33° 41′
Hour ang. . . .	67 22
In time . .	4 h. 29 m. 28 s.
Equation. .	−30
True time .	4 28 58
Timekeeper .	4 25 18
Error . . .	−3 40

FOR THE AZIMUTH.

Rule. Add together the co-latitude, zenith distance, and polar distance, and take half the sum; from which subtract successively the polar distance, co-latitude, and zenith distance. Add the log. cosecant of the half sum, the log. cosecant of the first remainder, and the log. sines of the two last: divide the sum (rejecting 20 from the index) by two, and the result will be the log. tangent of half the azimuth, which doubled will give the azimuth; in this case, from the north towards the west, because the altitude is decreasing.

If it be required to find the variation of the compass, find the compass-bearing of the object at the time its altitude is taken; the difference between this bearing and the azimuth found as above will be the variation.

By students who wish to prosecute Practical Astronomy, most valuable assistance will be derived from Professor Narrien's *Practical Astronomy and Geodesy*.

SECTION XIII.

THE TELESCOPE.

TWO KINDS OF TELESCOPES, REFRACTING AND REFLECTING—CAUSE OF THEIR MAGNIFYING AND ILLUMINATING POWER—ACHROMATIC TELESCOPES—OF WHAT SIZE USUALLY MADE—HOW TO JUDGE OF A GOOD TELESCOPE—GREGORIAN, CASSEGRAINIAN, AND NEWTONIAN REFLECTORS—OBJECTS IN THE HEAVENS MOST WORTHY OF OBSERVATION, AND HOW TO FIND THEM.

319. The value of the telescope may be appreciated by contrasting modern with ancient astronomy; the latter for the most part consisted in performing approximately problems on the sphere, and in calculating eclipses of the sun and moon. The preceding parts of this work will shew how small a portion these elementary subjects form of the science in its present state; and although we

acknowledge that much of the advance of astronomy must be attributed to the establishment of the true theory of the universe, yet the minute accuracy of which modern astronomy boasts, has arisen from the application of the telescope to instruments intended for angular admeasurement; while our knowledge of the physical constitution of the bodies of our system, of the existence of nebulæ, of the components of the Milky Way, and of the complex systems of the compound stars, is derived solely from the disclosures of the telescope, which may be regarded as the revealer of the secrets of the universe.

How enthusiastic must have been the delight of Galileo when he, the first of mankind, directing his "optic glass" to our satellite, descried

> ———— "New lands,
> Valleys, and mountains on her dusky globe!"

How elevated his pleasure when he discovered four attendants around another planet answering a purpose similar to our moon! A gratification akin to his, though somewhat inferior in degree, awaits every individual mind to whom the wonders of the heavens have not been revealed by the telescope: the novelty and sublimity of the sight remain for all who have never witnessed them; while to those who are partially acquainted with them, every new increase of optical means will be an additional source of unalloyed gratification.

In what will be said respecting telescopes in this part of the present treatise, we shall not regard the rationale of their construction, but rather the work they will perform. The science of optics embraces the one, the other comes properly under the head of Practical Astronomy.

320. Astronomical telescopes are of two kinds, refracting and reflecting: in the former an image of the object viewed is formed by a lens, termed the object-glass, which *refracts* the rays from the object into one point; in the latter the rays of light are *reflected* by a concave speculum or mirror, by which an image of the object viewed is produced. The point where the image is distinctly formed by the lens or mirror is the focus; and the distance of this point from either the one or the other is the focal length of the telescope.

321. The following considerations may assist in understanding in what manner an object is magnified by a telescope. The size of an object depends upon the space it occupies in the field of vision, or upon the angle under which it is seen. If a refracting telescope be directed to the sun or the full moon, an image of either object may be received upon a piece of transparent paper held in the focus. Now this image viewed from a distance equal to that of the centre of the object-glass will subtend exactly the same angle as the sun or moon itself will when viewed with the naked eye. This may be shewn by cutting out from the paper a circle exactly the size of the image in question; this, held at such a distance from the eye as is equal to the focal length of the object-glass, will exactly cover the sun or moon of which it is the image. Suppose this distance to be forty-two inches; we can, with the unassisted vision, view an object as near as six inches; if then we approach to within six inches of the image, we view it under an angle seven times as large as we do the object it represents, or as we do the image itself at the distance of forty-two inches. By the application of another

lens, termed the eye-glass, we can view the image nearer still; suppose the focal length of the eye-glass to be $\frac{4}{10}$ of an inch, the image will appear under an angle fifteen times as great as it did to the unassisted eye; 15×7 or 105 will then represent the magnifying power of the telescope. From this explanation will be readily understood the usual rule for ascertaining the magnifying power of a refracting telescope, viz. divide the focal length of the object-glass by the focal length of the eye-glass, and the quotient will give the magnifying power; thus $42 \div \frac{4}{10} = 105$ as before.

322. The principal reason of the superior distinctness of a telescope over unassisted vision arises from this fact: the pupil of the eye when viewing an object takes in a certain number of rays of light from it; but on contemplating that object through a telescope, it receives as many more rays in proportion as the object-glass or speculum is larger than the pupil itself; in other words, the object appears as brilliant as it would were the pupil of the eye to be enlarged to the size of the lens or mirror by which the image is formed. From this it appears that there is a limit to the magnifying power of the eye-glass, by which the image formed in the focus of a telescope may be viewed; for, since the quantity of light concentrated there is constant, it follows that the higher the magnifying power applied, the greater will be the diffusion of the light; hence, with a higher power the object becomes less bright; its edges will be less sharp and defined; its shadows lighter, and the details less distinct. Where there is a superabundance of light, as in viewing a double star of the first magnitude, this dispersion of light is not of so much conse-

quence; but faint objects, as nebulæ, would vanish under the application of a high magnifying power. The relative illuminating powers of telescopes of the same class will be in proportion to the squares of the diameters of the object-glasses in refracting telescopes, or of the large specula in reflecting; thus the illuminating power of a reflecting telescope of four inches aperture will be to that of one of six inches aperture as 16 to 36. The eye-glass of a refracting telescope in general consists of two plano-convex lenses; and since a portion of light is lost in every transmission through a lens, the image viewed is inverted, inasmuch as to bring it to its natural position several other lenses would be requisite. In viewing the heavenly bodies this is of no consequence; and for land objects an eye-tube is always supplied by the maker, which represents them as they appear to the naked eye.

323. If you take a single lens and with it form an image of the sun, this image will not be a perfect circle, as it ought to be for distinct vision, for such a lens will not refract all the rays falling upon it to a single point; and the various rays overlapping and interfering with each other will cause an image in its focus to be distorted and coloured. The distortion arises from the fact that no convex lens will refract all the incident rays to one point so as to produce a perfect image; and the false colours, from an unequal refrangibility of the rays composing white light; that is to say, the seven coloured rays, which are united in a perfectly colourless image, will be subject to unequal refraction, and thus the image will be surrounded with prismatic colours. The former imperfection is termed the *spherical aber-*

ration; the latter the *chromatic aberration.* To get rid of these in some degree, the earlier observers constructed telescopes of even more than 100 feet focal length, so that the curve of the lens should have a very large radius. A telescope of Huygens, now in the possession of the Royal Society, has its focus at a distance of 123 feet, the object-glass is quite detached from the eye-glass, and the tube is dispensed with altogether. To the great advantage of astronomical science, our countryman Dollond, in the year 1757, discovered that, by making the object-glass double, one portion of the compound lens being composed of flint glass and the other of crown glass, the refractive powers of which are different, their mutual chromatic aberrations might be made to counteract each other, and a colourless image would be formed in the focus; while by grinding the lenses to different curvatures, the spherical aberration might also be reduced to a minimum, and there would result a perfectly definite, sharp, and colourless picture of the object viewed. Telescopes constructed on this principle are termed "*achromatic,*" or "without colour;" though the term "*aplanatic,*" or "without error," would be more appropriate; inasmuch as a good instrument has its errors of sphericity balanced equally with those of colour.

Achromatic telescopes adapted to astronomical observations are usually of 3½, 5, or 7 feet focal length. Of late years the celebrated Fraunhofer of Munich introduced certain improvements in the construction of achromatics, and made object-glasses of much greater diameter than ever had been known before. One of the largest and best achromatic telescopes in the world is in the possession of Sir James South; the diameter of the object-glass is twelve inches, and its focal length twenty feet. Another is under the management of Professor Struve of Dorpat; its focal length is fourteen feet, and diameter $9\frac{9}{10}$ inches: both of these gentlemen have turned them to good account in most valuable observations, especially on the fixed stars. But let not the amateur observer be discouraged by the supposition that such superior instruments are necessary either for viewing most of the wonders of the heavens, or for accurate observations. Some of the most valuable and trustworthy measurements of the positions of the double stars, which may be found in the records of the Royal Astronomical Society, are those executed by the Rev. W. R. Dawes, with a 5-feet achromatic by Dollond; and even a $3\frac{1}{2}$-feet achromatic will disclose several double stars, although there will still remain a great number which its space-penetrating power will never reach.

324. The following remarks will assist in judging of the character of a telescope: first, it must come to a focus sharply, *i.e.* the object ought not to appear the same when you draw the eye-tube in or out to a small extent on either side of the focal point; 2dly, there must be no colour around the image of any object viewed; 3dly, when directed to a fixed star, the image should be a small sharp round luminous point, free from the optical appendages of a "wig" or "wings," either of which would indicate imperfection in the form of the lenses. This last is a most severe test, and if on a favourable night the telescope will stand its scrutiny, it may be looked upon as approaching perfection.

"When about to buy my large object-glass,* at Paris, in 1829," says Sir James South, "I directed it to Aldebaran, viewed it in the telescope certainly not one minute, and paid for it the next." The planet Venus is a good test for a telescope, inasmuch as the great redundance of light about her will in an inferior glass be resolved into the prismatic colours; if she appears colourless and sharply defined, the glass does its work well, and may be implicitly relied on for fair representations of celestial objects.

325. *Reflecting telescopes* are of three kinds: those on the *Gregorian* construction, which are more generally to be met with out of observatories, have a hole pierced in the centre of the large mirror to receive the eye-piece; the rays from the object, falling on the large speculum, are reflected to its focus; they are then received by a small concave mirror whose focus coincides with that of the large one, and reflected through the aperture, where they are received and the image magnified by the eye-glass. The *Cassegrainian telescope* differs from the above only by the small mirror being made convex instead of concave. The *Newtonian telescope* has no aperture in the large speculum; but the rays it reflects are received on a plane speculum near the object-end of the tube, which is fixed at an angle of 45° with the axis, and by it are reflected to the side of the tube, where the rays are brought to a focus by the eye-glass. The comfort and ease of observation with telescopes of this construction have made them great favourites with many astronomers. Some of Sir W. Herschel's most valuable observations were made with a 7-feet Newtonian, with a

* The price of the object-glass alone was above £1000.

mirror seven inches in diameter; indeed, that illustrious man is said to have finished and made trial of no fewer than two hundred mirrors before he was perfectly satisfied with the finish and figure of the one he at last adopted for his favourite instrument.

The leviathan telescope lately completed by Lord Rosse, at Parsons-town in Ireland, at the expense of many thousand pounds, is on the Newtonian construction; its focal length is fifty-four feet, and the diameter of the large speculum six feet. Sir James South publicly announced, soon after its erection, that its finish was all that could be expected, and its performance most satisfactory, even when tested by the image it gives of a fixed star. "Regulus," says he, "being near the meridian, I placed the 6-feet telescope on it, and with the entire aperture and a magnifying power of 800, I saw with inexpressible delight the star free from wings, tails, or optical appendages." Too much cannot be said in honour of a nobleman who has brought to bear upon the construction of the largest telescope in the world, sound mathematical knowledge, a princely fortune, a persevering and undaunted energy, which will, no doubt, be crowned with the success they so richly deserve; for this telescope, we may fairly presume, is destined to disclose secrets of the remote regions of space, of which the most lively imagination has never dreamed. It is contemplated to change its construction into the Herschelian, in which the small mirror is dispensed with, and the image formed by the large is thrown a little out of the axis of the tube towards the edge, where it is viewed by the observer with his back to the object.

326. Messrs. Lassell and Nasmyth have also suc-

cessfully turned their attention to the construction of large reflectors, which have done good service to the science of Astronomy. Of these large reflectors, however, neither the author's experience nor the plan of his work will allow him to treat. The reflecting telescopes most likely to be used by amateurs are the 2, 3, and 4-feet Gregorian. A 2-feet Gregorian, with an aperture of four inches, is a convenient and portable instrument; nearly equal, on land objects, the planets, the sun and moon, to a 3½-feet achromatic, but decidedly inferior when turned on a fixed star, which is not represented, as it ought to be, as a lucid point; while many double stars, which the 3½-feet achromatic will easily separate, cannot be seen double by it. A good 4-feet Gregorian is a powerful instrument, nearly equal, with a 7-inch aperture, to a 7-feet Newtonian, and perhaps in magnifying power superior to a 5-feet achromatic; but this also suffers in comparison under the double stars, unless its mirrors be polished with such extreme care as to render its price greater than that usually received by opticians for instruments of this description.

The difficulties attending the use of reflectors, arising from adjustments—variations caused by the difference of temperature—the liability of the mirrors to tarnish from exposure to damp, and the tremor which frequently accompanies them, have rendered achromatics of late years greater favourites with amateurs, who have not always either time at their disposal, or manual dexterity at their command, for minute adjustments. The light, moreover, of reflecting telescopes is not so great as the diameter would lead one to suppose; a considerable portion of the rays is absorbed in each reflection; so that in a Gregorian or Newtonian telescope a large proportion of the incident rays from the object fail to enter the pupil of the eye; whereas in the transmission of light through an object-glass, only about $\frac{1}{20}$ is lost. A reflecting telescope is liable, moreover, to deteriorate in the course of time from the tarnish of the metal, and to require repolishing; whereas with fair usage an achromatic will always remain the same; indeed, if it has acquired a good character in skilful hands, its value is enhanced, because of its having been subject to severe tests and found equal to them all Still, it cannot be denied that a good reflector presents a most agreeable and colourless vision of the moon and planets, and on the Gregorian construction the image is not inverted, but viewed in its natural position.

327. We will suppose, then, an individual desirous of viewing the heavens is in possession of a telescope at all events not much inferior to some one of those described in the preceding paragraphs, mounted on a firm steady stand, with rack-work for giving slow movements in altitude and azimuth, without which no pleasure or comfort can attend the observation of the heavens: our object will now be to direct him what he is to look for, and how he is to find the object required.

Of course he will turn his telescope upon the sun, and watch for the appearance or change of spots on his surface; a moderate power will be found best for this purpose. The moon will also engage his attention; and as here there is no want of light, he may examine her disc with every power he can bring to bear; her features will repay constant and repeated watching, from the time she presents a fine crescent till she is full. Of course the higher the power of the instrument, the more varied and beautiful will be its disclosures of her craters, her valleys, her mountains, and her plains.

328. To find what planets are visible and where they are situated, take out their right ascension and declination from an ephemeris, and determine their position on the celestial globe (see § 257); rectify the globe for the latitude and time (see § 244), and the planets will be found in the heavens immediately above their place on the globe. In case a celestial globe is not at hand, ascertain from an ephemeris the time of a planet's southing, and judging of its altitude from its declination, it may thus be found.

Venus will be best seen between her inferior conjunction and her greatest elongation; the features of Jupiter described in § 103 will be disclosed without difficulty, except the shadow of any one of his moons when crossing his disc, which is a severe test of the excellency of a telescope. With one of Dollond's 5-ft. telescopes, I have not only observed this beautiful phenomenon, but have at the same time seen the satellite on the planet. Saturn's ring may be seen with either of the telescopes described; but the detail of this planet will enable an observer to judge whether or not he is in possession of a superior instrument.

In viewing Saturn, or indeed any other object where distinct vision is absolutely necessary, wait till he is within two hours of the meridian; here he will be near his greatest altitude, and most free of the clouds and vapours which float near the horizon. If he is to be seen to perfection, the night must be dark, the atmosphere clear and not dry, the wind must not be east—for from no quarter can it blow less auspicious to astronomers: the eye must have rested from viewing bright objects, such as the moon or an artificial light, for at least half an hour; when the excitement of the retina has ceased, turn the telescope on the planet; a $3\frac{1}{2}$-feet achromatic ought to give a fair image of the planet, of the shadow of the ring on the planet, the shadow of the planet on the ring, and of the belt across the body. One satellite may be seen with the $3\frac{1}{2}$-feet, but it will not divide the ring; for this to be seen double, a 5-feet achromatic or a 3 or 4-feet Gregorian is the lowest telescope we can use: the more powerful the telescope, the more satisfactory will be the view. It must not be supposed, however, that this all-repaying sight is one which can always be commanded, even by the same instrument. The author has known one of Dollond's best 5-feet achromatics fail to shew the division in the ring when not well mounted; proving that the performance of the telescope depends in a great measure upon the stand which carries it; but of this more hereafter.

329. The observer may now venture on the double stars, beginning with those which are easily separated, of which a list will shortly be given. He must find out their position from the celestial globe or maps of the stars; a $3\frac{1}{2}$-feet will shew the colours in γ Andromedæ, the double star Castor; the minute companion of Polaris may be perceived by it; α Lyræ will be beyond its power; but Polaris, in Dr. Kitchener's phraseology, "will give of it as good an idea as a kitten does of a cat." If the telescope be mounted only with vertical and horizontal movements, the nebulæ, invisible as they

are to the naked eye, will be pitched upon only by dint of labour and perseverance, even when the declination and right ascension are known. Practice in this case will in time enable an observer to fish them up. Mark, as in the case of the planets, their place on the globe; indeed, 18-inch globes give many of the most remarkable; observe the stars in their neighbourhood; put on the telescope the lowest power possible, which will always, be it remembered, have the largest field of view; catch the nearest star which is visible to the naked eye, and move the instrument in the direction in which the nebula required lies. After some time the probability is, that it will appear in the field of view, when the low power may be exchanged for the one most suited to display its character. Thus the annular nebula in Lyra lies about midway between β and γ of that constellation, and may be picked up by moving the telescope from one star to the other. It would facilitate the process much to have an eye-piece adapted to the telescope, which should magnify only about fifteen or twenty times. As such eye-pieces are useful in finding comets when their position is approximately known, they are termed "comet eye-glasses."

To resolve nebulæ into their component stars, light in abundance is requisite—hence the superiority for this purpose of large reflectors with mirrors of eighteen inches at least in diameter. Even large achromatics will resolve but a few. A 3½-feet will, however, shew enough of these faint objects to indicate their general character, and of some will give a very satisfactory view: the nebula in Orion, those in Andromeda and Hercules, and some few others hereafter mentioned, will be well worth inspection. A 5-feet achromatic will resolve a few, and only a few, of the nebulous clusters. Still a telescope with a motion only in altitude and azimuth is an unsatisfactory instrument ; the constant following of the object by jerks and starts, and the losing of it by the motion of the earth as soon as found, especially under the application of a high magnifying power—the time the instrument takes to become steady after vibrations constantly occurring from the movement, before the vision becomes distinct—all combine to put one out of sorts with this kind of mounting. The superiority of the equatorial mounting—the pleasure of following the object by simply turning the tangent-screw, and the facility with which an unseen object may be identified, will be appreciated by all who are acquainted with this mode of mounting a telescope for celestial observations.

SECTION XIV.

THE EQUATORIAL.

METHOD OF RECTIFYING THE INSTRUMENT—HOW TO FIND AN OBJECT BY ITS RIGHT ASCENSION AND DECLINATION—R.A. AND DECLINATION OF MANY REMARKABLE OBJECTS—THE AUTHOR'S OBSERVATORY—CONCLUSION.

330. If the construction of the universal dial (fig. 52, Plate VIII.), which was explained in § 281, be clearly understood, little remains to be said on the principle of the equatorial. The drawing in Plate IX. represents the German method of mounting a telescope equatorially, and that of the author's Observatory the

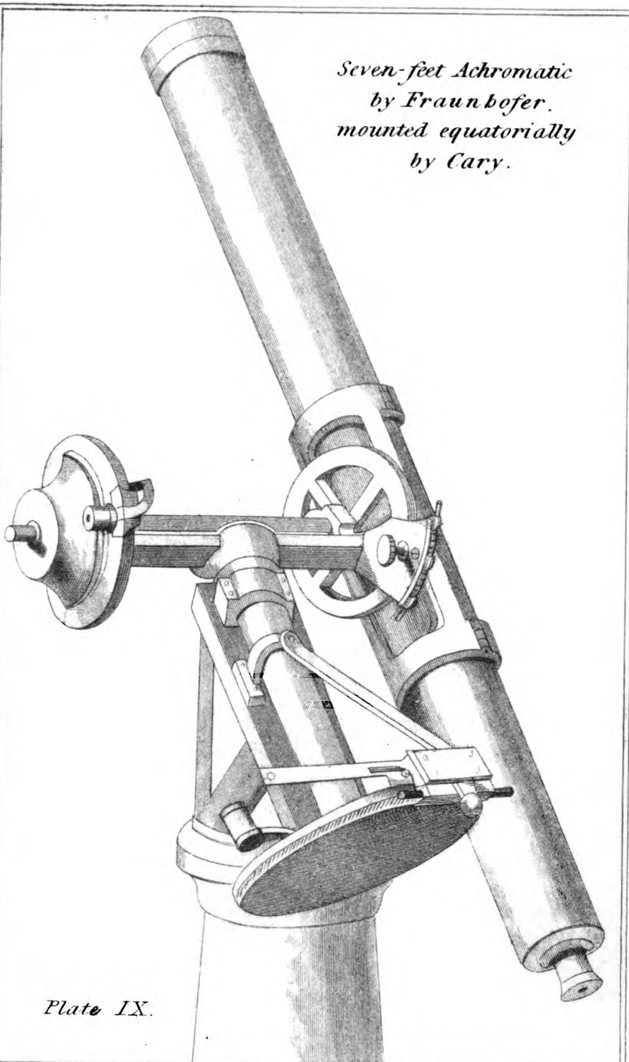

Seven-feet Achromatic
by Fraunhofer.
mounted equatorially
by Cary.

Plate IX.

English method; in either case the polar axis of the telescope must be placed parallel to the axis of the earth, or, which is the same thing, must be made to coincide with the axis of the heavens, by elevating it (when the vertical motion is in the plane of the meridian) as many degrees above the horizon as are equal to the latitude of the place. The circle which is at right angles to the axis will then coincide with the equator; this is divided into twenty-four equal parts for the hours, which commence at the meridian, and is subdivided at pleasure by the verniers.

The declination-circle is divided into degrees and minutes, from 0° to 90° north and south of zero; which commences at a point indicated by the index when the line of collimation of the telescope is parallel to the hour-circle, or in the plane of the equator: when the index of the hour-circle points to XII., and the polar axis is in the meridian and has an inclination equal to the latitude, the axis will coincide with the axis of the heavens, and the right ascension or hour-circle will be parallel with the equator. We have now only to set the declination-circle to the degrees and minutes of the declination of any heavenly body, as the sun, and we shall be able to follow it in its diurnal course by one motion; for since all the diurnal arcs are parallel to the equator, the movement of the telescope on its axis will trace out in the celestial sphere the circle described by the sun in the course of the day; while the index of the hour-circle will shew, when the sun is in the centre of the field of vision, the *hour-angle*, that is, the number of hours, minutes, and seconds he is from the meridian—in other words, will point out the apparent time (see § 318). A tangent-screw gives a slow movement to the telescope, by which a heavenly body may be followed when once found.

331. When the telescope follows a star with a uniform motion, the index of the hour-circle will indicate the hour-angle in hours, minutes, and seconds of sidereal time.

The drawing in Plate IX. exhibits the most generally approved construction of an equatorial mounting for a moderate-sized telescope, though many prefer the English plan of a long polar axis, supported at either end as shewn in the drawing of the author's Observatory. This stand is composed of brass coated with bronze; the declination-circle is nine inches in diameter, divided on palladium, a metal which does not oxidize, and read off by two verniers to 30″; the right ascension or hour-circle is of the same diameter, and read off by the verniers to two seconds of time: the mode of clamping and of giving motion to the circles is much superior to the common construction; while its solidity and firmness, united with the application of counterbalancing weights to every movable portion, renders the instrument perfectly steady in observation, at the same time that the telescope may be moved with ease in every direction, and will remain stationary in any position, even without the aid of the clamping apparatus.

Astronomical telescopes have usually a small telescope, called the finder, attached to the side, with a low magnifying power, and a proportionally large field of view; in its focus two wires cross each other at right angles. When the finder is properly adjusted, an object which has been brought to the intersection of the wires will be seen in the centre of the field of view of the large telescope; this will be the case when the axes of the two are exactly parallel; if this adjustment be nicely made, and the vertical wire brought perpendicular to the plane of the hour-circle, we may use the cross-wires of the finder in adjusting the equatorial, unless the larger telescope be furnished with a micrometer, or an eye-piece carrying a diaphragm with vertical and horizontal wires.

A general view of the equatorially mounted telescope having been given, the adjustments will be explained hereafter. The great beauty of the equatorial movement is, that we are enabled by its aid to identify and follow a star or planet in the day-time—a star, planet, comet, or nebula in the night, when the R.A. and dec. of the object are known.

Set the declination-arc to the declination of the object; bring the index of the hour-circle to the hours, minutes, and seconds of the hour-angle, allowing in each case for the index error, if there be any; and the star, planet, or nebula will appear not far from the centre of the field of view. By simply turning the tangent-screw of the hour-circle, it may be followed for any length of time. Of late years clock-work has been adapted to the equatorial, by means of which this latter motion is produced; the tangent-screw being turned by the wheel-work at a uniform rate, accommodated to the diurnal motion of the earth. The effect of this apparatus is most beautiful, being, in fact, equivalent to viewing a star in an immovable sky; while for micrometrical measurements, in which it is important to have both hands at liberty, it is almost indispensable. The steady regularity of the clock-work movement far exceeding, as it does, that produced by hand, renders it an invaluable acquisition. The equatorial shewn in Plate IX. is exactly adapted for clock-work, from its immovability, and from the facility with which the telescope may be turned in any direction, every part being counterbalanced by weights in every position. It is, in fact, upon the plan of the great Dorpat telescope, the performance of which, under the able management of Professor Struve, has fully equalled the expectations which were originally formed of it on its completion by Fraunhofer twenty-seven years ago.

332. It will often happen that an approximation to the hour-angle will be sufficient to identify the star, planet, or nebula: this may be obtained, in the case of a star, by finding its time of transit from the celestial globe, or by subtracting the sidereal time at mean noon (found in page II. of every month in the Nautical Almanac) from the R.A. of the object; this will give the time of southing nearly. The difference between this and the mean time of observation will give the hour-angle approximately. By setting the arc to the declination, and moving the instrument a little backward and forward on each side of its hour-angle thus found, the star or nebula will soon appear.

An agreeable proof of the correctness of the principles of astronomy, and of the adjustments, will be to turn the telescope upon the planets or large stars at mid-day. Jupiter and Venus are easily found: the phases of the latter are beautifully seen in the daytime; the larger stars will be readily discovered. The double star Castor may be seen as easily by daylight as in the darkest night.

The mass of the instrument just described and its counterbalancing weights is very considerable, and contributes to its stability; the head is fixed on a cone of cast iron filled with sand, by which all vibration is destroyed, and the vision rendered most distinct. With a seven-feet achromatic, similar to that in the drawing, furnished with clock-work movement and micrometer, a sidereal clock, an astronomical circle for altitudes and the time, an amateur may consider himself in a condition, not only to verify the principles of astronomy for himself, but to commence a series of observations on the double stars, which, carefully worked out, may be of use in establishing some important truths. Let not, however, the student whose means are far below the acquisition of these splendid instruments, be discouraged in the pursuit of the science. A little mechanical ingenuity well applied may construct, even of wood, an instrument similar in principle to the equatorial just described, able to carry a $2\frac{1}{2}$-feet achromatic, which may be obtained for a moderate price; and although this instrument will fail to do the work of larger telescopes, it will reveal to the novice many of the wonders of the heavens; while the use of a small instrument will give him a knowledge of the stars, facility in pitching upon them, and correctness of eye, which will be of great service when his means or inclination may place a superior in his hands.

333. The following table will give the right ascensions and declinations of all the remarkable objects described in this treatise, with some few others equally deserving inspection. They are arranged so that those

more easily descried are first in the list. More than one-half will be within the range of a 3½-feet achromatic; to be seen distinctly and clearly, many of them will, however, require a five-feet, with an aperture of 3¾ inches.

After the student of astronomy has made himself acquainted with them, should he wish to pursue the science, and inspect the most remarkable objects which the whole face of the heavens presents, he cannot do better than procure Captain W. H. Smyth's *Cycle of Celestial Objects*, which contains the places of 850 compound stars and nebulæ, with the angles of position of the former class of bodies, determined by late admeasurements. The *Bedford Catalogue*, as this is called, obtained a gold medal from the Royal Astronomical Society; it is enlivened by the most quaint and amusing extracts from old astronomical authors. The detail of the construction and furniture of Captain Smyth's observatory at Bedford will form a good guide to any one who contemplates a similar undertaking.

The following extract from Sir W. Herschel is distinguished by the same practical sense which marks all his writings, and will serve as a good introduction to a list of telescopic objects.

"I should observe, that since it will require no common stretch of power and distinctness to see these double stars, it will therefore not be amiss to go gradually through a few preparatory steps of vision, such as the following: When η Coronæ Borealis, one of the most remote double stars, is proposed to be viewed, let the telescope be some time before directed to α Geminorum, or, if not in view, to either of the following stars: ζ Aquarii, μ Draconis, ρ Herculis, α Piscium, or the curious double double star ε Lyræ.

"These should be kept in view for a considerable time, that the eye may acquire the habit of seeing such objects well and distinctly. The observer may next proceed to ξ Ursæ Majoris, and the beautiful double star in Monoceros's right fore-foot; after these to ι Boötis, which is a fine miniature of α Geminorum, to the star preceding α Orionis, and to n Orionis. By this time both the eye and the telescope will be prepared for a still finer picture, which is η Coronæ Borealis."

The attempt to view these delicate objects will be useless, except under favourable circumstances. The best evenings for astronomical observation are those in which the atmosphere is laden with moisture, which will be found invariably to settle on the object-glass in the form of dew, and render the image indistinct. The best method of guarding against this is to adapt to the object-end of the telescope a tin tube, called a dew-cap, about 18 inches long, bright on the outside and blackened within: this will be found effectually to prevent the annoyance, and do away with the necessity of wiping the object-glass, which should be avoided if possible.

The stars in the following list only noted as double, are, for the most part, of very different characters, the components, in some cases, being of equal size, in others exceedingly unequal: they are all worthy of attentive inspection.

DESIGNATION.	R.A.		DEC.		DESCRIPTION.
	h.	m.	°	′	
γ Delphini	20	39	15	33 N	double star.
ζ Aquarii	22	20	0	50 S	"
μ Draconis	17	2	54	41 N	"
ι Boötis	14	10	52	6 N	triple star.
ξ Boötis	14	44	19	46 N	double star.
θ Orionis	5	27	5	30 S	multiple and neb.
in Andromeda . . .	0	34	40	23 N	oval nebula.
in Hercules	16	35	36	46 N	globular cluster.
γ Andromedæ . . .	1	54	41	33 N	double, coloured.
in Libra	15	10	2	41 N	globular cluster.
in Can. Venat. . . .	13	35	29	10 N	"
Pleiades	3	36	23	30 N	group.
Coma Beren.	12	30	22	0 N	"
Præsepe	8	30	21	0 N	"
in Perseus	2	10	56	24 N	"
ξ Libræ	15	55	10	55 S	triple.
Castor	7	24	32	14 N	double.
ε Lyræ	18	39	39	30 N	double double.
Polaris	1	2	88	27 N	double.
55 Andromedæ . . .	1	44	39	56 N	nebulous star.
ε Orionis	5	28	1	18 S	"
ι ib.	5	28	6	1 S	triple star.
in Aquarius	20	55	11	59 S	planetary nebula.
in Ursa Major . . .	10	28	54	20 N	"
in Lyra	18	48	32	50 N	annular nebula.
in Andromeda . . .	2	13	41	36 N	"
α Herculis	17	7	14	34 N	double star.
ζ Cancri	8	3	18	7 N	triple star.
ξ Ursæ Majoris . . .	11	9	32	26 N	double.
γ Crateris	11	17	16	48 S	"
γ Leonis	10	11	20	39 N	"
γ Lyræ	18	53	32	28 N	"
ο Ceti	2	11	3	42 S	variable.
η Antinoï	18	41	6	5 S	double.
χ Cygni	19	40	33	20 N	"
δ Cephei	22	23	57	36 N	"
α Serpentis	15	36	6	56 N	"
δ ib.	15	27	11	5 N	"
in Cassiopeia	23	22	57	40 N	multiple star.
in Vulpec. et Ans. . .	19	52	22	16 N	dumb-bell nebula.
in Clyp. Sobieski . .	18	11	16	15 S	diffusive nebula.
in Libra	15	10	2	41 N	brilliant cluster.
η Coronæ	15	16	30	52 N	double.
Rigel	5	7	8	23 S	"
α Lyræ	18	31	38	38 N	"
in Antinoüs	18	43	6	27 S	crescent-like nebula.
ζ Persei	3	44	31	24 N	quadruple.
ε Boötis	14	38	27	45 N	double.
α Leonis	9	59	12	45 N	"
ι Cancri	8	37	29	20 N	"
η Cassiopeiæ	0	39	56	58 N	"
γ Virginis	12	33	0	34 S	"
σ Coronæ	16	8	34	16 N	triple.
36 Ophiuchi	17	5	26	21 S	multiple.
in Cygnus	21	26	47	43 N	nebula.
in Hercules	17	12	43	18 N	globular cluster.

334. One word on the micrometer before concluding. This is an instrument inserted in the eye-tube of the telescope, for the purpose, 1st, of measuring minute angles, such as seconds and parts of seconds: for this end we make use of two wires, one of which may be allowed to remain fixed, while the other, which is parallel to it, may be moved to or from the stationary wire. By making both of these tangents to the disc of a planet, and reading off the number of turns and parts of turns of the micrometer-screw, which have a certain known value, its diameter in seconds becomes known. 2dly. By the micrometer the angle of position of double stars may be measured. Suppose a fixed wire to be parallel with the hour-circle of the equatorial, and another wire to be capable of moving round an entire circle; if one of the components of a double star be brought to the point of intersection of the wires, and the movable wire made to bisect the other, the angle included between the two wires, which may be read off on a graduated circle, will give the angle of position of the stars. The detail of the management of this exceedingly delicate instrument must be learnt from inspection and actual practice with the micrometer itself.

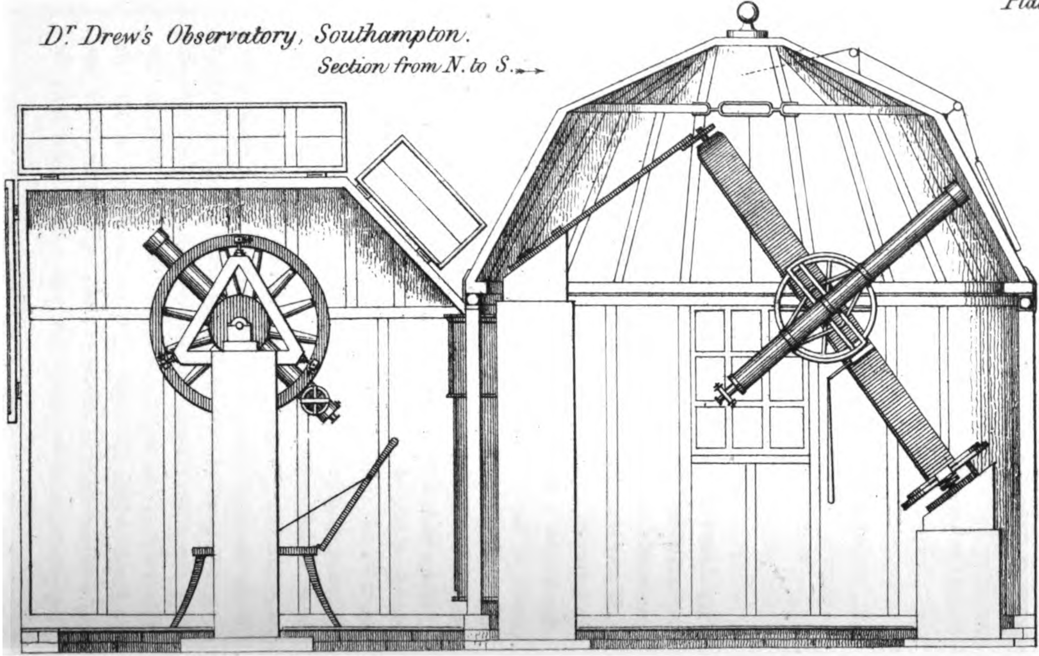
It is, indeed, in the measurement of the angle of position of the double stars that any thing new in the science of astronomy can be expected from extra-observatorial astronomers: to this it is recommended that amateur observers, who have time on their hands and good instruments at their command, should principally confine their labours, if they wish to advance the interests of the science. The number of compound stars already observed amounts to some thousands, and it is only by the increase of accurate observers that their periodic times can be ascertained, their changes of position registered, and this branch of astronomy be brought to perfection.

3dly. Suppose a comet or newly-discovered planet, whose place we require to note very particularly, has been observed so near a star, whose right ascension and declination are known, as to appear in the field of view of the telescope with it; its distance from the star in R.A. and dec. being accurately measured by the micrometer, its place is at once known with much greater certainty than it could be determined by one observation with any other instrument.

Plate 1.

Dr. Drew's Observatory, Southampton.

Section from N. to S.



THE AUTHOR'S OBSERVATORY.

THE drawing opposite represents a sectional view of the author's Observatory, Southampton, with the instruments *in situ*. It will be observed that the polar axis and transit-circle rest on stone supports; the floor is detached from these, so that the stability of the instruments is not affected by movements on it. The clock is fixed on the north side of the support of the higher end of the polar axis; a side view of it is presented in the drawing. The walls are of weather-boards ¾ of an inch thick, overlapping each other 1¼ inch, and the roof is covered, outside the boards which compose it, with canvass, which having received a thick coating of paint, and having been nailed on in a moist state, has been found impervious to rain; the method of opening the shutters of the transit-room will be apprehended from the drawing—they are counterpoised by weights on the opposite side of the building; the shutters of the dome are closed, but the counterpoise is shewn on the roof to the right. The position-wire micrometer is fixed on the telescope, and the handle giving motion in declination is attached to the tangent-screw. When the shutters of the dome are open, the dome may be turned round towards the object to be viewed, and may be made to follow it by an advance westward from time to time. The observing-chair may be remarked in the drawing—its position is between the two upright supports of the transit-circle.

The building consists of two compartments, the equatorial-room and the transit-room: the former is nine feet in diameter, in the form of a duodecagon, the roof is nearly circular; the shutters opening in the side increase from 9 inches to 2 feet 6 inches in width. The lower curb of the roof and the upper curb of the wall are fitted with cast-iron plates, between which are the four-inch cannon-balls which support the roof and enable it to revolve. The telescope is mounted with a polar axis having the usual adjustments: the right ascension and declination-circles are each fifteen inches in diameter, and read off, the one to four seconds of time, the other to one minute of space. The shutters of the transit-room run along the ridge of a sloping roof, which is held together by iron hoops extending across the slit; these admit of being turned round so as not to interfere with distinct vision.

Before the foundation was laid, the ground was excavated to the depth of 18 inches, and filled up with concrete; on this, brickwork was raised six inches above the ground. An oaken curb is laid on the brickwork, into which are inserted uprights of 2½ inches by 2, and 6 feet in height. These are united at the top to a corresponding curb, and outside of these are nailed the weather-boards forming the walls. Though simple in its arrangement, this Observatory was constructed after the pattern of some of the most approved private observatories in the kingdom, which the author inspected carefully before setting to work.

For a description of the instruments, for specimens of the mode of registering observations, and of the accuracy with which results may be obtained by the application of corrections for minute instrumental deviations, the paper at the end of the work may be advantageously consulted.

For the last five years a complete set of meteorological observations have been taken daily at the Observatory, the results of which have been published from time to time in the Registrar-General's Quarterly Reports.

To guide the judgment of such as may be disposed to establish an observatory of similar pretensions, the expense of the building and instruments is here given. Building, exclusive of the stone piers of the instruments, 50*l.*; transit-circle and two collimators, 210*l.*; 5-feet equatorially-mounted telescope by Dollond, 160*l*; clock, 40*l.*; micrometers, artificial horizon, &c., 25*l.*; meteorological instruments, 12*l.* 12*s.* These are the prices which would be charged by the best opticians in London, whose names would be a warrant that the instruments were excellent of their kind.

The author's humble, but he hopes not useless, labours have now been brought to a conclusion. He trusts that his time has not been misemployed in simplifying astronomical science—an object which has engaged the attention of such eminent men as the Astronomer Royal, Professor Arago of Paris, and M. Quetelet of Brussels, who have not disdained to write elementary treatises similar in their tendency to the present.

Adopting as his own the words of M. Quetelet, with them he would conclude:

"Les savans n'ignorent pas combien il est difficile de mettre à la portée des gens du monde les résultats d'une science essentiellement fondée sur le calcul; aussi j'ose compter sur leur indulgence, trop heureux si cet essai peut être de quelque utilité aux personnes qui, occupées d'autres études, voudraient s'initier aux secrets de l'astronomie, et acquérir des notions suffisantes pour lire les ouvrages d'un ordre plus élevé."

ON THE ADJUSTMENT OF THE TRANSIT CIRCLE AND EQUATORIAL.

(*Read before the Royal Astronomical Society, December* 1851, *and published with the sanction of the Council.*)

THE following paper on the adjustment of the transit circle and equatorial has been published under the impression that a succinct explanation of the methods adopted might not be without its use to those who have no immediate opportunities of consulting others skilled in practical astronomy, or who have not at hand the *Greenwich Observations*, or the volumes of the *Memoirs* of the Royal Astronomical Society; to which, in combination with the valuable papers of the Rev. R. Sheepshanks, and his readiness in obliging me with answers to my inquiries from time to time, I have been much indebted.

THE TRANSIT CIRCLE.

The transit circle in use at my Observatory is a very fine one, by Jones, late of Charing Cross. The telescope has an object-glass of $3\frac{1}{4}$-inches aperture, with a focal length of $3\frac{1}{2}$ feet, which will shew the companion of Polaris on the unillumined field. As the weight of the instrument is very great, and the transit room small, and as, moreover, the mounting of the micrometer microscopes interferes, I have not been able to reverse it, but have adopted such methods in its rectification as have, I apprehend, answered every purpose of that cumbrous process. The pivots of the axis (which is 30 inches across) rest on agate bearings carefully protected from dust; their supports are based on stone piers, and the three micrometer microscopes are attached to the western pier on a triangle of stone, the base of which is hewn out of the solid block which forms the pier, and the two sides from another. Though the circle had been made fifteen years before it came into my possession, it had never been unpacked, and some contrivance was necessary before I could conveniently put the parts together. I apprehend, however, that this method of mounting the microscopes is superior to metal arms, which are subject to varying expansion from change of temperature. Two small circles, three inches in diameter, at the eye-end of the telescope, serve for finding the object by its zenith-distance. In the focus of the object-glass are one fixed horizontal wire and five vertical wires; parallel to the fixed wire another is carried by a micrometer-screw, with a divided head. I have found the instrument preserve its adjustments steadily, and discharge its duties most faithfully, as the observations will shew.

As, from the enclosed position of my Observatory, I could not avail myself of any distant object of reference, I substituted a collimating telescope of 20 inches focal length, with an object-glass of 1·6 inch in diameter, which I have mounted on a solid pier of brickwork, 2 ft. 3 in. by 1 ft. 3 in., laid in cement. It is built outside of the Observatory to the north, and is carried down to the gravel four feet below the surface; being of such a height that, when the collimating telescope and that of the transit circle are both horizontal, their axes shall be in a straight line. It is protected from the weather by a movable covering, in which are two small shutters opening north and south: when the south shutter is down, and the north (which opens downward) is depressed so as to form an angle of 45° with the horizon, the inside of it, being whitened, reflects sufficient light from the sky to render the cross-wires of the collimator distinctly visible; at night they are easily illuminated.

I cannot say that the horizontal point ascertained by this collimator is trustworthy, although determined with a good level, sixteen inches in length, to the amount of several seconds; the value of the collimator, however, as a point of reference, is very great. The first use to which it was applied was in adjusting the central transit wire to the vertical plane. To facilitate this adjustment, the whole system of wires, including the eye-piece, has a small movement regulated by two antagonist-screws on the exterior of the instrument. By making the central wire coincide with the cross of the collimator throughout the whole field of view, after the axis had been carefully levelled, this adjustment was completed.

To determine the value of the run of the micrometer-screw carrying the movable horizontal wire in the focus, the wire was brought on the cross of the collimator, and the arc of the circle read off by the three micrometer microscopes; the wire was then moved through twenty revolutions, and again brought upon the cross-wires by the slow movement of the transit circle, and the reading again recorded. Consistent results were obtained on several occasions.

Sept. 1850	. 20	revolutions	=938″ ∴ 1	revolution	=46″·9
,,	. 20	,,	=933″ ∴ 1	,,	=46″·65
Sept. 1851	. 20	,,	=936″ ∴ 1	,,	=46″·8
,,	. 19	,,	=890″ ∴ 1	,,	=46″·84
		Mean of the whole	. . . . . .		=46″·8

To determine the distances of the wires, I make use of the wire-micrometer attached to a five-feet telescope. By bringing the axis of the telescope—which for that purpose must be dismounted—in a line with that of the transit telescope, I have a distinct view of the wires when the two object-glasses are directed towards each other: the value of the run of the micrometer being known, the distances are measured with ease and certainty. Thus: Oct. 1, 1851, calling the wires 1, 2, 3, 4, 5, advancing towards the illuminated end of the axis, or from west to east looking north, the following measures were taken, each revolution of the micrometer-screw being equal to 33″:

From 1 to 3=578″ 566=38s·5
,, 2 ,, 3=289″·41 =19s·29
,, 3 ,, 4=289″·41 =19s·29
,, 3 ,, 5=578″·82 =38s·58

By nine complete transits, and five incomplete, of δ Ursæ Minoris, the times of passing across the wires were,

1 to 2=324s·6; 2 to 3=325s·7; 3 to 4=326s·6; 4 to 5=326s·5,

which multiplied by the cosine of the star's declination give for the equatorial intervals of the wires,

1 to 2=19s·25; 2 to 3=19s·31; 3 to 4=19s·37.; 4 to 5=19s·37.

To ascertain the reduction to the central wire of the mean derived from the transits over the five wires :

By the Micrometer.		By δ Ursæ Minoris.	
−38·5	+19·29	−38·56	+19·37
−19·29	+38·58	−19·31	+38·74
−57·79	+57·87	−57·87	+58·11
	−57·79		−57·87

$\frac{\cdot 08}{5} = 0^{s}\cdot 016 = 0''\cdot 25$ $\qquad$ $\frac{\cdot 24}{5} = 0^{s}\cdot 048 = 0''\cdot 72$

As in neither case the difference amounts to a second of space, and as I put most confidence in the distances measured micrometrically, I have applied no correction to reduce the mean of all the wires to the central wire.

The telescope of the transit circle is provided with an eye-piece formed of a single lens; immediately underneath the lens is a perforated mirror, moving on an axis adjustable outside; an aperture at the side of the tube admits the light, which, being reflected down the axis of the telescope when in a vertical position, is again reflected from the surface of mercury: by this contrivance we see the direct image of the wires through the aperture in the mirror, and their reflected image in the mercury at the same time. A mirror outside of the tube is so adjusted as to reflect the light of the sky, which I much prefer to the lamp which the maker provided for the purpose of illumination. Now, on the supposition that the cross-level will indicate any deviation of the axis from horizontality, I have here the means of determining my collimation-error without reversion. I first level carefully, so as to insure no deviation. I find, now that the foundation of the piers which were erected three years since, is settled, that when once the axis is horizontal, it is not liable to derangement: thus, August 15th, 1851, the following level readings were taken:

West readings.	East readings.
19	34 direct
35	18 reversed
19	34 direct
33	19 reversed
19	33 direct
33	19 reversed
158	157

Now, $158 - 157 \div 12$, the number of readings, $= \frac{1}{12}$ of a division $= 0''\cdot 2$.

August 23d, the readings shewed no deviation:

35	21 direct
21	35 reversed

Nor did those of September 18th:

32·2	28 direct
28	32·2 reversed

Presuming now that the axis is horizontal, I have recourse to observation by reflection; and if the image of the central vertical wire does not coincide with the wire seen by direct vision, I move the wire by the collimating screw, and bring the wire, seen directly, over its image seen by reflection; thus, I apprehend, the error of collimation is corrected. This was done August 23d, 1851, and subsequent observations shewed the correctness of the result.

I have endeavoured to determine the collimation-error with two collimating telescopes placed horizontally, one north and the other south of the transit telescope, in the following manner. If the circle could be raised (after having bisected the cross of one collimator) so as for the crosses of the two collimators to intersect each other, we should have two points exactly 180° distant from each other, measured on the plane of the horizon. On restoring the instrument to the Y's, there would be no error of collimation should the central wire bisect the northern cross, and also, when the instrument was turned half-way round, the southern. As I cannot conveniently displace my circle, I removed the object-glass and eye-piece, after producing coincidence with the vertical wire and the cross of the northern collimator ; I then brought the crosses of the two collimators together, by adjusting the southern to the northern through the axis. Restoring the object-glass and eye-piece to their places, and bringing the central wire on the northern cross, I turned the instrument on the southern, and concluded that if it covered the bisection of the cross-wires, there would be no collimation-error ; and that if it did not, I must repeat the operation till this end was attained. In theory I believe I am right ; but I apprehend my failure must have arisen from the southern collimator having moved in the interval, as it was insecurely mounted : the plan I believe to be worth a trial with both collimators mounted on stone piers.

Now, on the supposition that the collimation-error has been eliminated (and the collimation-adjustment is not liable to derangement), I can always rectify my level error by reflection, as is practised at Greenwich : for if the direct and reflected images of the central wire do not on any occasion coincide, they may be made to do so by the inclination-screw.

As, however, it is of consequence to be able to ascertain the inclination of the axis, for the application of the correction for that error, should any be discovered after the completion of a series of observations, I have ascertained the value of the divisions of the cross-level, which, though professing to be seconds of arc, are not so in reality. For this purpose the level was strapped to the transit-circle, and the bubble moved through about forty divisions; the arc through which the circle had moved (noted by the cross-wires of the collimator) having been read off, supplied the proportion between those divisions and seconds of arc. Observations at various times have been consistent. The following were taken September 30th, 1851; temperature 56°.

38 divisions = 83″·66 ∴ 1 division = 2″·2
37 „ = 80″·37 ∴ 1 „ = 2″·17
42 „ = 90″·71 ∴ 1 „ = 2″·16

Now, suppose the level readings to be as they were June 5th, 1851—viz.

West.	East.
45	18
17	46
40	22
20	42
122	128
	122

Difference . . . = 6
No. of observations = 8

$$\frac{6}{8} = 0^{\text{div}}\cdot 75 \times 2''\cdot 2 = 1''\cdot 65,$$

they would indicate that the east end was higher than the west by 1″·65, and all the transits of that day must be corrected by multiplying the factor of inclination by 1″·65, and applying the product with the sign — above the pole, + below, to the times of observation. The factor of inclination is found by the formula

$$\frac{\textit{cos. zenith distance of star}}{15\ \textit{sin. north polar distance,}}$$

which multiplied by the seconds of arc of inclination will give the time at which the transit occurred over the true meridian, supposing the errors of collimation and azimuth to have been corrected.

The factors for collimation, inclination, and azimuth for the Greenwich stars, given in the *Greenwich Observations*, are calculated for the latitude 51° 28′ north, but will serve for any latitude not differing greatly from that. In the correction for collimation, the error is supposed to be east; for level, the west end of the axis is considered the higher, therefore the deviation is east; and the azimuthal deviation is assumed to be east looking south: if either of these errors is in the contrary direction, the sign must be changed. To use the table: having found the deviation in seconds of arc, multiply the tabular factor by it, and apply the result to the observed time of transit with its proper sign.

The only correction at this stage of proceeding, on which no satisfactory determination has been arrived at, is the relative sizes of the pivots of the axis; the agreement of the observations will shew whether an inequality exists to such an extent as to affect the results. It is true that this element may be determined, in the case of small instruments, by reversion; but, I apprehend, it admits of a question whether, after reversing an instrument weighing $1\frac{1}{2}$ cwt., it can be lowered into its place so gently as not to affect the inclination of the axis; yet, unless this important end can be completely insured, the same uncertainty will still exist.

The amount of the azimuthal variation now remains to be ascertained. If the clock has a fair rate, the transit of Polaris above, and again below the pole, will supply the requisite data.

On June 4th, 1851, at 8h. 30m. A.M., and in the evening of that day, the following transits were taken:

Wire.	Polaris. h. m. s.		Wire.	Polaris sub polo. h. m. s.	
1	0 44 55		5	12 44 55·5	
2	0 57 23		4	12 57 23·5	interpolated
3	1 9 46	interpolated	3	13 9 45	
4	1 22 11	interpolated	2	13 22 12	
5	1 34 28		1	13 24 24	
Mean	1 9 44·6		Mean	13 9 44	

Now the right ascension of Polaris had increased $0^s{\cdot}37$ in the interval; the time, therefore, between the first and second transit should have been $12^h\ 0^m\ 0^s\ {\cdot}37$; and the gain of the clock was $0^s{\cdot}5$. The last transit, corrected for clock-error, will therefore be:

	h.	m.	s.
	13	9	43·5
Subtract	1	9	44·6
Difference	11	59	58·9
Which should be	12	0	0·37
Error due to azimuthal deviation =	0	0	1·47

From this we observe, that the western portion of the star's diurnal arc was too small, or that the supposed meridian was west of the true (looking north). Let a = the amount in seconds of arc of the horizontal deviation; find the factors for azimuth of Polaris above and below the pole by the formula

$$\frac{\textit{sin. zenith distance}}{15 \textit{ sin. north polar distance}},$$

which, for Southampton, will be 1·564 and 1·668; then

$$a\,(1·56+1·67)=1^{s}·47, \text{ or } a=0''·45.$$

As Polaris, however, is not always to be thus conveniently taken, we must have recourse to other stars, such as δ Ursæ Minoris. Having eliminated the collimation-error, and levelled with care, on August 15th, 1851, the following transit of that star was taken with β Draconis and Capella sub polo:

Wire.	h. m. s.	β Draconis.		Capella s. p.
1 . .	18 9 12	25·5		9·2
2 . .	18 14 36	57		36·8
3 . .	18 20 2	28·5		4·6
4 . .	18 25 28	0·5		32·2
5 . .	18 30 52	31·2		59·4
Mean . .	18 20 2	17 26 28·54		17 4 4·44
Cor. for cl. er.	+ 37	17 27 5·53 N.A.	Az. 7″·9 × ·095	+ ·75
	18 20 39	−36·99		17 4 5·19
N.A.	18 20 33·8		N.A.	17 4 42·04
	+ 5·2 too late due to az. west of north.			−36·85

In this case the clock-error is found from β Draconis. The azimuthal factor, from the above formula, for δ Ursæ Minoris is equal to ·656. Putting a for azimuthal deviation in seconds of arc (·656 a = 5·2, or

$a = 7''\cdot 9$), the azimuthal factor for Capella is ·095, and its transit corrected for this error brings out a tolerably fair and consistent result.

The surest method, however, of detecting the azimuthal error, is to take the transit of δ Ursæ Minoris and of 51 Cephei, one above and the other below the pole, which I am able to accomplish over all the wires by passing from one star to the other. The following observations of September 22d, 1851, shew that the instrument, as a transit simply, is not far from correct adjustment, and reward me for hours of labour extending through many months:

	γ Draconis.	δ Ursæ Minoris.		51 Cephei S.P.
Wire.	h. m. s.	h. m. s.	Wire.	h. m. s.
1	13	10 33	5	16 53
2	44	15 57	4	23 39
3	15·1	21 23	3	30 23
4	46	26 46	2	37 2
5	17·2	32 18	1	43 46
Mean . . .	17 54 15·06	18 21 23·4		18 30 20·6
True place .	17 53 9·35	18 20 19		6 29 13
Clock-error	+ 1 5·71	+ 1 4·4		+ 1 7·6

Taking the clock-error from γ Draconis, which is in the zenith, it appears that δ Ursæ Minoris came too soon by $1^s\cdot 3$, and 51 Cephei too late by $1^s\cdot 9$; in either case an azimuthal deviation of $2''$ east of north is indicated. Applying this correction to the other transits taken the same evening, we have the following results:

Let a = azimuthal deviation in seconds of arc, then

for δ Ursæ Minoris $\cdot 646\, a = 1^s\cdot 3$, or $a = 2''$
for 51 Cephei . . . $\cdot 92\, a = 1^s\cdot 9$, or $a = 2''$

Wire.	β Lyræ. h. m. s.	ζ Aquilæ. h. m. s.	δ Aquilæ. h. m. s.	γ Aquilæ. h. m. s.	β Aquilæ. h. m. s.
1	55·5	1	27·8	38·7	28·3
2	18·7	20·8	47	58·5	47·5
3	41·6	40·5	6.2	18	7
4	4·8	0·5	25·2	37·4	26·5
5	28	20·5	44·8	57·4	46·2
Mean . .	18 45 41·72	18 59 40·66	19 18 6·20	19 40 18	19 48 7·1
Az. correc.	+·05	+·08	+·10	+·09	+·1
Obs. place	18 45 41·77	18 59 40·74	19 18 6·3	19 40 18·09	19 48 7·2
True place	18 44 36	18 58 35·10	19 17 0·68	19 39 12·20	19 47 1·35
Clock-err.	+ 1 5·77	+ 1 5·64	+ 1 5·62	+ 1 5·89	+ 1 5·85

Dividing the stars into two groups, one near the zenith and the other near the equator, we find the mean of the clock-error from γ Draconis and β Lyræ = $1^m\ 5^s \cdot 76$; from the Aquiline stars = $1^m\ 5^s \cdot 67$; which differs so little from the other as to shew that the adjustments of the instrument are not far from absolute correctness. Mean clock-error of the whole series due to 19 hours sidereal time + $1^m\ 5^s \cdot 71$; clock's rate + 2^s daily, or $1^s \cdot 6$ in 19 hours; hence, clock-error at $0^h\ 0^m\ 0^s$ sidereal time = + $1^m\ 4^s \cdot 11$.

For the adjustment of the micrometer microscopes two things are necessary at first setting out: 1, that they be at equal distances from the centre of the axis; 2, that they be at the three angles of an equilateral triangle inscribed in a circle concentric with the axis, whose circumference shall pass through the intersection of the cross-wires of each when at zero. To insure the first, I made a mark on a certain part of the arc at right angles to one of the divisions, and adjusted the cross-wires of each microscope to its intersection with the division; for the second, I brought the microscope marked A on 0, and made B read 120°; moving 0 to B, I made C read 120°; transferring 0 to C, I found 120° to extend beyond the zero 12″: this quantity, divided by 3, will give the difference between the distances of any two microscopes and that between 0° and 120°; and they were so adjusted that each microscope should be at 119° 59′ 56″ from the next on each side of it.

The nadir point of the circle was determined by producing coincidence between the direct and reflected images of the horizontal wire by daylight; and so accurately can this be done, that several independent observations will give invariably the same result. The reading of the nadir point $-180°$ gives the zenith point from which to reckon the series of zenith distances immediately following. I have so regulated the foci of the three microscopes, that the mean of five revolutions of the micrometer-screw of each measures exactly one division of the arc, or 5′; and I find this to be one of the most permanent adjustments.

September 18th, 1851, on that part of the arc numbered 329°, the spaces passed over by ten revolutions were:

at 329°	A = 9′ 58″	B = 10′ 7″	C = 9′ 54″	mean = 9′ 59″$\frac{2}{3}$
at 168°	A = 10′ 5″	B = 10′ 0″	C = 9′ 54″	mean = 9′ 59″$\frac{2}{3}$

OBSERVATIONS *to determine the Latitude of* DR. DREW'S *Observatory, by Stars north and south of the Zenith, the nadir-point having been determined by reflection, and the zenith-point by subtracting* 180° *from it, taken on two consecutive evenings.*

Date.	Object.	Deg.	Microscopes. A.	Microscopes. B.	Microscopes. C.	Concluded Circle-reading.	Zero, or Z. D. point.	Barometer.	Thermometer.	Refraction.	Wt.	Latitude deduced.
1851.		°	′ ″	′ ″	′ ″	° ′ ″	° ′ ″			″		° ′ ″
Sept. 22.	β Draconis	147	59 52	59 59	59 34	148 0 21	149 29 51·3	30·040	55·5	1·5	10	50 54 38·7
,,	γ Draconis	148	53 39	53 42	53 8	148 53 29·7	...	...	...	0	4	50 54 31·9
,,	β Lyræ	167	12 11	12 28	11 58	167 12 12·3	...	...	...	18·4	10	50 54 33·9
,,	51 Cephei	107	39 40	39 25	39 45	107 40 14	...	...	...	52	10	50 54 35·2
,,	ζ Aquilæ	186	44 39	45 2	44 22	186 44 41	...	...	...	42·6	10	50 54 34·3
Sept. 23.	51 Cephei	107	40 52	40 16	40 48	107 40 38.7	149 30 16	30·115	57·3	52	10	50 54 35·2
,,	γ Aquilæ	190	8 20	8 25	8 41	190 8 29	...	...	...	49·7	10	50 54 33·3
,,	β Aquilæ	194	21 5	21 8	21 38	194 21 17	...	...	...	57·8	10	50 54 32·3
,,	β Lyræ	167	12 28	12 35	12 50	167 12 21·7	...	...	...	18·4	6	50 54 34·6
											Mean of the series =	50 54 34·4
											Latitude by the Trigonometrical Survey =	50 54 34

To the circle-reading for β Draconis was applied $+\cdot 7 \times 46''\cdot 8$, or $32''\cdot 7$; and to the first observation of 51 Cephei $\cdot 8 \times 46''\cdot 8$ or $37''\cdot 4$, being the additional reading of the eye-piece micrometer.

These observations are given not because they are considered sufficient to give an independent determination of the latitude, but to shew the accuracy with which the nadir-point, and from that the zenith-point, may be determined by reflection. Their number could have been increased, and it might have been shewn that the mean of ten or more observations gives the latitude 50° 54′ 34″, within a small fraction of a second, which is that of my observatory, as determined from the latitude of the Ordnance Map Office, Southampton.

ADJUSTMENTS OF THE EQUATORIAL.

THE declination-circle of the equatorial, which carries a 5-feet telescope by Dollond, is read off by two verniers to minutes of space, and the hour-circle by two verniers to five seconds of time. I am compelled, therefore, to consider the instrument in adjustment when the errors of observation fall within these limits. The instrument was established in its present position about four years ago. The following observations were lately taken to ascertain how much it had deviated by the settlement of the piers and the foundation, or from other causes, during that interval.

1. *For the Collimation-error.*—To ascertain the errors with precision, I insert the position-wire micrometer, and bring the fixed wire to correspond with the plane of the circle of declination, which is readily accomplished by bringing it on a star not far from the equator, and causing it to be bisected during the time of its transit across the field of view near the meridian. One of the movable vertical wires is now brought as nearly as can be judged to the centre of the field. With the face of the declination-circle *east*, I note by the clock the time a star (not far distant either from the equator or meridian) crosses the wire, and I read off the hour-angle from the hour-circle; turning the instrument half-way round, with the face of the declination-circle *west*, I do the same. This star will be only affected by the error of collimation, and if the difference of the hour-angles, read off from the hour-circle, be equal to the difference of the times of observation, there is no collimation-error; but if these be not equal, an error

exists, which must be corrected before other observations can be taken.

October 11, 1851—α Aquilæ near the meridian.

	Clock-time.	Hour-angle.	
	h. m. s.	m. s.	
	19 50 50	+ 6 35	dec. circle east
	19 52 0	+ 7 40	„ „ west
Difference	0 1 10	1 5	

As the difference between these is five seconds, the collimation-error = $2^s{\cdot}5$, which, if great accuracy is required, must be multiplied by the cosine of the star's declination; as this, however, would only alter $2^s{\cdot}5$ to $2^s{\cdot}3$, it may be neglected.

$$2^s{\cdot}5 \times 15'' = 37''{\cdot}5$$

Knowing the value of the run of the micrometer-screw, I advanced the wire through $37''{\cdot}5$ in such a direction that the transit (circle east) should occur sooner, and consequently the transit (circle west) later, and then took the following observation:

	Clock-time.	Hour-angle.	
	h. m. s.	m. s.	
	19 59 53	+ 15 32	circle east
	20 1 25	+ 17 5	„ west
Difference	0 1 32	1 33	

These differences falling within the limits of the readings of the hour-circle, I now consider the collimation-error compensated.

This observation enables me to ascertain whether or not the hour-circle reads $0^h\ 0^m\ 0^s$ when a star is in the meridian.

	h. m. s.	h. m. s.
Clock-time	19 59 53	20 1 25
Correction for clock-error . .	−39	−39
True sidereal time	19 59 14	20 0 46
Right ascension of α Aquilæ .	19 43 32	19 43 32
True hour-angle	15 42	17 14
Instrumental hour-angle . . .	15 32	17 5

The star is west of the meridian, and its hour-angle is less than the true by 9 or 10 seconds; hence the zero of the hour-circle is west of the true meridian by that amount.

2. *For the Latitude.*—To ascertain whether the angle formed by the polar axis with the horizon is equal to the latitude of the place, measure the polar distance of a star on the meridian with the declination-circle east, and again with the circle west; the mean of these, corrected for refraction, should equal the polar distance of the star taken from the Nautical Almanac. If a star in the zenith be employed, no correction for refraction is requisite.

September 26, 1851.	β Draconis.		γ Draconis.
Declination-vernier A . .	52° 27′	circle east	51° 32′
" " B . .	52 28		51 36
" " A . .	52 15	circle west	51 20
" " B . .	52 15		51 20
Mean declination	52 21 15″		51 27
Instrumental polar distance .	37 38 45		38 33 0″
True polar distance	37 34 50		38 29
Difference	+3 55		+3 52

As the instrumental polar distance is greater than the true, the pole of the instrument is too low, or the inclination is too small by 3′ 54″. Having elevated the pole, the following observations were subsequently taken :

		α Aquilæ.		α Cygni.
Declination-vernier A	. .	8° 37′	circle east	44° 51′
" " B	. .	8 39		44 55
" " A	. .	8 21	circle west	44 35
" " B	. .	8 20		44 38
Mean declination	. . . .	8 29 15″		44 44 45″
Polar dist. = 90° − decl.	. =	81 30 45		45 15 15
Refraction	. . . . . .	+ 52		+ 7
Instrumental polar distance	.	81 31 37		45 15 22
True polar distance	. . .	81 31 0		45 14 33
Difference	. . . .	37		49

These differences falling within the limits of the divisions of the declination-circle, indicate that the instrument is adjusted to the nearest minute of latitude.

3. *To ascertain whether the Declination-Axis is at Right Angles to the Polar Axis.*—Having previously corrected the collimation-error, take the hour-angle of one of the Greenwich stars whose declination is considerable, near the meridian, and compare it with its true hour-angle, the error of the clock being known ; or its transit with the face of the declination-circle east, and again with the circle west, being noted by the clock, may be compared with the hour-angles read off from the hour-circle. The effect of this error somewhat resembles that of the level-error of the transit instrument, which is 0 at the horizon, and reaches its maximum at the zenith : so the effect of the inclination-error is 0 at the

equator, and reaches its maximum at the pole, varying, indeed, as the tangent of declination. And since tan. 45°=rad. or 1, it will be most convenient to select a star whose declination differs but little from 45°.

October 11th, 1851, the following observations of α Cygni were taken, the declination of the star being 44° 45′ 27″ north.

By the first method.

	h. m. s.		h. m. s.	
Clock-time	20 17 3	circ. east	20 18 13	circ. west
Correction for cl. error	−39		−39	
Sidereal time	20 16 24		20 17 34	
R.A. of α Cygni . . .	20 36 22		20 36 22	
True hour-angle . . .	−0 19 58		−0 18 48	
Instrumental hour ∠ .	−0 20 20		−0 18 30	
Difference .	+0 0 22		−0 0 18	

By the second method.

	h. m. s.		m. s.	
Clock-time	20 17 3	Hour ∠ −	20 20	circ. east
	20 18 13	−	18 30	„ west
Difference .	0 1 10		1 50	

An error of 40 s. is here indicated, which is double that due to the inclination of the declination-axis. With the declination-circle east, the star arrived at the wire too late; and with the circle west, too soon. Now, 20 s. × tan. 45° (or 1) × 15″ = 300″ = 5′, the difference between the inclination of the declination-axis to the polar axis and 90°. Having elevated the western extremity of the declination-axis one revolution of the adjusting-screw (the circle being east), I took the following observation:

	h. m. s.		m. s.	
Clock-time	20 30 10	Inst. hour ∠	−6 40	circ. east
	20 31 30		−5 55	„ west
Difference .	0 1 20		0 45	

The error now appears to be 35 s. in the opposite direction. Having turned the screw back half a turn, the two following observations shewed that the error was corrected, and, combined with the others, indicate that the value of one revolution of the adjusting-screw = 10′.

By the first method.

	h. m. s.		h. m. s.	
Clock-time	20 38 45	circ. east	20 40 4	circ. west
Correction for cl. error	−39		−39	
Sidereal time	20 38 6		20 39 25	
R.A. of α Cygni . . .	20 36 22		20 36 22	
True hour-angle . . .	+1 44		+3 3	
Instrumental hour ∠ .	+1 42		+3 0	
Difference .	0 0 2		0 0 3	

By the second method.

	h. m. s.		m. s.	
Clock-time	20 38 45	Inst. hour ∠	+1 42	circ. east
	20 40 4		+3 0	„ west
Difference .	0 1 19		1 18	

As the differences fall within the limits of the divisions of the hour-circle, the inclination-adjustment may now be considered completed.

4. *To ascertain the Azimuthal Deviation of the Polar Axis, the effect of which is to cause the Pole of the Equa-*

torial to point East or West of the Pole of the Heavens.— Measure the polar distance of a star six hours from the meridian, and compare it with the polar distance ascertained from the Nautical Almanac. The difference, if any, will be the amount of deviation, east or west, after the observation has been corrected for the effect of refraction; east, if the polar distance of a star west of the meridian be too great; west, if it be too little.

Oct. 25, 1851. β Ursæ Minoris, 5^h 20^m from the meridian.

	°	′	″		
Declination-vernier A . .	74	35		circle north	
„ „ B . .	74	38			
„ „ A . .	74	52		„	south
„ „ B . .	74	53			
Mean declination	74	44	30″		
Polar dist. = 90° − decl.	=15	15	30		
Refraction	+ 0	0	26		
Instrumental polar distance	15	15	56		
True polar distance . . .	15	14	8		
Difference		+1	48	=deviation.	

As the star is west of the meridian, and the polar distance measured is too great, I advanced the north pole of the instrument towards the west, by setting the verniers 2′ nearer the pole, and bringing the star on the wire by moving the adjusting-screw.

The following observations (October 27th) on β Ursæ Minoris six hours west of the meridian, and α Persei six hours east, shew that the azimuthal error has been reduced within 1′, the extent to which the divisions of the declination-circle are read

	β Ursæ Minoris.		α Persei.
	° ′		° ′
Declination-vernier A . .	74 36	circle north	49 14
„ „ B . .	74 40		49 13
„ „ A . .	74 53	„ south	49 28
„ „ B . .	74 55		49 28
Mean declination	74 46 0″		49 20 45″
Polar dist. = 90° − decl. .	= 15 14 0		40 39 15
Refraction	+ 0 0 19		+ 0 0 50
Instrumental polar distance.	15 14 19		40 40 5
True polar distance . . .	15 14 10		40 40 21
Difference . . .	+ 9		− 16

PROJECTION OF THE SPHERE ON THE PLANE OF THE HORIZON, ILLUSTRATING THE EFFECT OF REFRACTION IN NORTH POLAR DISTANCE AND THE HOUR-ANGLE.

In fig. 52, the primitive circle represents the horizon of London; Z is the zenith; P the pole; W P E the six-hour circle; *s* the true place of a star, *s′* its apparent place; then P *s* is the true polar distance, P *s′* the apparent; *e* P T the true hour-angle, *e′* P T the apparent; *s′* Z = apparent zenith distance; P Z = co-latitude; and *s s′* = refraction in altitude: let fall *s t* perpendicular to P *e′*. Now the angle *s s′ t* may be considered equal to P *s′* Z, which may be found in the spheric triangle P *s′* Z by the proportion sin. zenith dist. : cos. lat. : : sin. hour-angle : sin. P *s′* Z. Hence *s s′* × cos. *s s′ t* (or P *s′* Z) = *s′ t* = correction in polar distance, and *s s′* × sin. *s s′ t* = *s t*; which, divided by 15 sin. polar distance, will give the seconds of correction to be applied to the hour-angle with the positive sign. The hour-angle, any where out of the meridian, where the effect of refraction is 0, will always be lessened by refraction, reckoning from T (the point where the equator cuts the meridian)

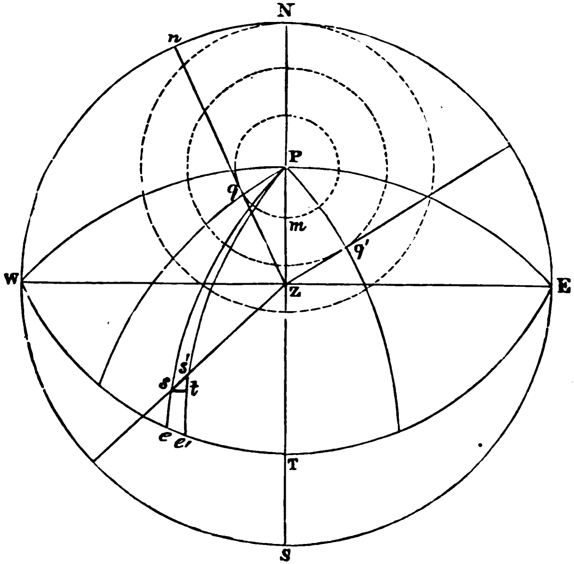


Fig. 52.

12 hours east or west; hence the sign of the correction will be positive. Whether the correction in polar distance is positive or negative, may be determined by the following considerations:

1. When the star is on the meridian, refraction will lessen polar distance by the whole amount between the south point of the horizon and the zenith; also between the north point and the pole; but will increase the polar distance between the pole and the zenith: hence, in the

former positions, to the correction must be applied the sign +, and in the latter —.

2. Any star which culminates south of the zenith, or whose polar distance is greater than the co-latitude, will have its polar distance diminished in every position; hence for such stars the correction will always have the positive sign.

3. Any star whose polar distance is less than the co-latitude, will have its polar distance differently affected according to its position.

Let Z *q n* be a vertical circle touching the parallel of declination of such star at the point *q*; at this point the correction for refraction in north polar distance will be 0. To find this point, we have, in the spheric triangle, P *q* Z; the angle P *q* Z=90°, P *q*=polar distance, and P Z the co-latitude; whence may be found the hour-angle Z P *q*. Any where between *q* and *m*, and as many degrees the other side of the meridian, the correction in polar distance will be negative; at the other portions of the diurnal arc it will be positive. This hour-angle will be less as the polar distance is greater; thus Z P *q'* is less than Z P *q*. It will never, however, be so great as 90°; hence, for six hours of distance from the meridian the correction will always be positive.

From the same triangle Z *q* P may be found Z *q*, which is the zenith-distance of the star; also, in any other part of the heavens, the zenith-distance may be ascertained without an additional observation. Thus, in the spheric triangle P *s'* Z, we have P Z=co-latitude, P *s'* = observed polar distance, Z P *s'* = the observed hour-angle; whence may be found Z *s'*, the zenith-distance of the star, for which the refraction must be taken from the table.

SYNOPTIC VIEW OF THE SOLAR SYSTEM.

Authority—Professor Piazzi Smyth, Astronomer Royal for Scotland.

Names of the Planets, &c.	Diameters in English miles.	Mean distances from the Sun in English miles.	Revolution round the Sun in mean solar days, or periodic time.	Earth Unity.		Rotation on their axes.	Mean apparent diameters as seen from the Earth.	Earth Unity.			Sun Unity.	Earth Unity.
				Mean distances.	Periodic times.	D. H. M.		Comparative density.	Comparative force of gravity at surface	Volume.	Mass.	Light and heat received from the Sun.
The Sun .	883,000	...	...	...	...	25 12 0	32′ 1·8″	0·25	28·36	1,407,124	1·0000000	...
Mercury .	3,140	37,000,000	87·97	0·38709	0·24084	1 0 5	6·7	2·94	1·15	0·06	0·0000005	6·656
Venus. . .	7,700	69,000,000	224·70	0·72333	0·61518	0 23 21	16 9	0·92	0·91	0·96	0·0000025	1·932
The Earth.	7,916	95,000,000	365·26	1·00000	1·00000	1 0 0	...	1·00	1·00	1·00	0·0000028	1·000
Mars . . .	4,100	144,000,000	686·98	1·52369	1·88079	1 0 39	5·8	0·95	0·50	0·14	0·0000004	0·436
Vesta . . .	250	224,000,000	1325·49	2·36148	3·62889	...	0·2	...	...	...	...	0·180
Juno . . .	79	253,000,000	1593·07	2·66946	4·36147	1 3 0	0·06	...	...	...	...	0·147
Ceres . . .	163	263,000,000	1684·74	2·77091	4·61244	...	0·1	...	...	...	...	0·130
Jupiter . .	90,000	494,000,000	4332·62	5·20277	11·86180	0 9 56	38·4	0·24	2·45	1,414·20	0·0009341	0·036
Saturn . .	76,068	906,000,000	10759·30	9·53885	29·45655	0 10 29	17·1	0·14	1·09	734·80	0·0002847	0·011
Uranus . .	34,500	1,822,000,000	30686·82	19·18239	84·01362	0 9 30	3·9	0·24	1·05	82·00	0·0000558	0·003
Neptune .	42,000	2,869,000,000	60624·63	30·20260	165·97660	...	2·8	0·23	1·20	150·00	0·0000890	0·001

Three only of the Asteroids are here given; a complete list of the entire number may be found under § 123.

THE KNOWN COMETS.

Authority—Sir J. F. W. Herschel.

	Halley's	Encke's	Biela's	Faye's	Brorsen's	De Vico's
Period in days	27866	1025	2393	2718	2042	1993
Semi-axis (Earth's unity)	17·98796	2·21640	3·50182	3·81179	3·15021	3·09946
Eccentricity	0·967391	0·847436	0·755471	0·555962	0·793629	0·617256
Inclination of orbit.	17° 45′	13° 7′	12° 34′	11° 22′	30° 55′	2° 55′
Motion	retrogrd.	direct	direct	direct	direct	direct

THE END.

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