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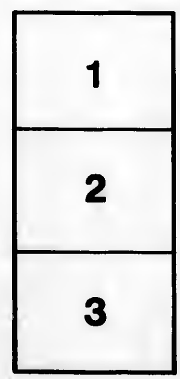
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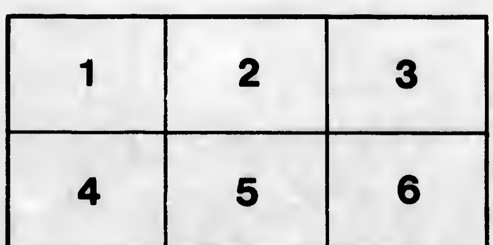
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PLATE XI.

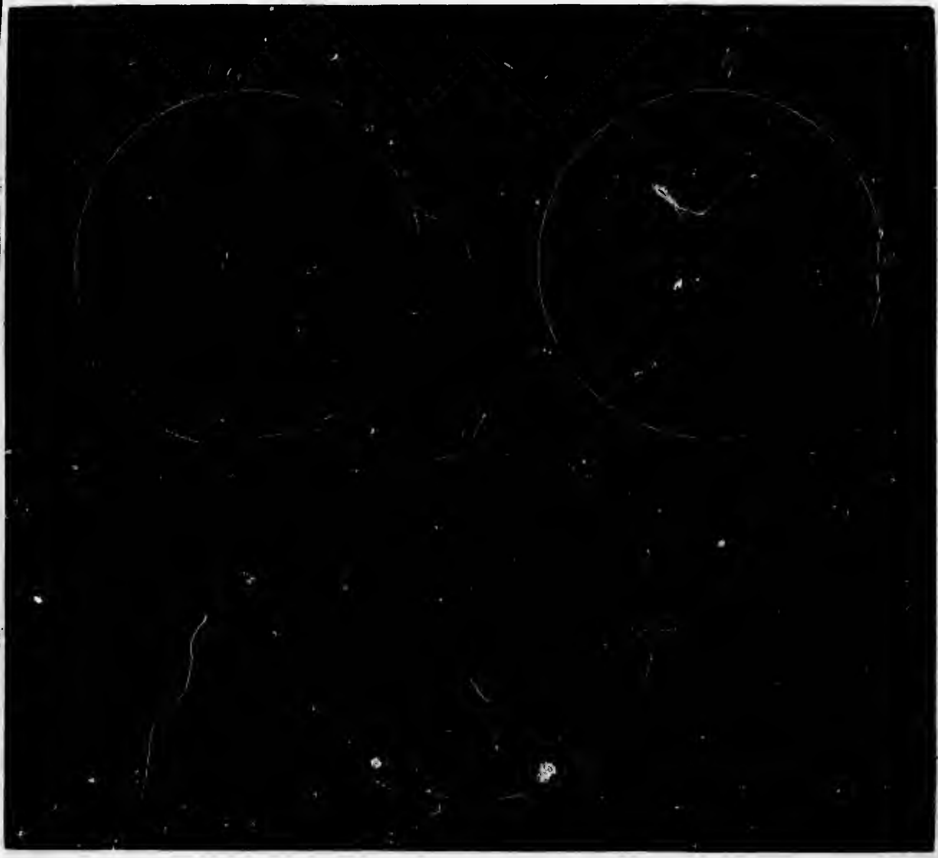
THE NOR

CIRCUMPOLA

THE NORTH
CIRCUMPOLAR STARS. (From Dick's Astronomy.

The position of the Planetary Axis relative to that of the Primary.

(a.) Parallel. (b.) Transverse. (d.) Perpendicular.



(a.) The general arrangement of the axis in the planets belonging to the solar system.

(d) The exceptional arrangement in the case of the planet Uranus.

(3.) CENTRIFUGAL FORCE & GRAVITATION.

THEORY

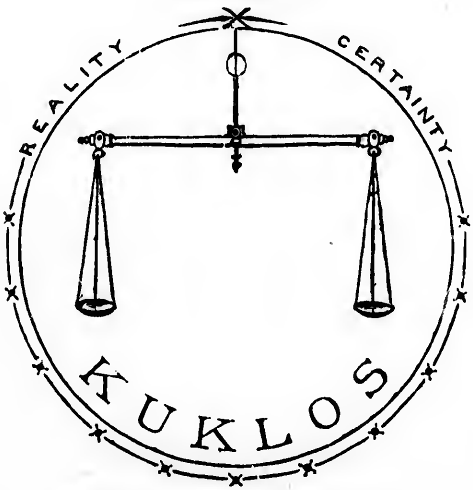
OF

THE STELLAR UNIVERSE.

AND

THE MIXED DOCTRINE OF PARALLAX AND ABERRATION.

BY
JOHN HARRIS.



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MAY. 1875.

INDEX.

INDEX OF PLATES.

CHAPTER I.

The Solar System and the General Arrangements of the Sidereal Universe.

INTRODUCTORY OBSERVATIONS.

(1) *The present state of Astronomical Science.*

If we go back to that epoch in human education which may be termed the childhood or early age of astronomical science and make comparison, we find the general apprehension of the relation existing between the particular stellar system to which we as terrestrial beings belong, and the sidereal universe, to be, at the present time, in some important respects, much more distinct and based in a more considerable degree upon a natural foundation of reality and certainty, but, in other respects, also very important, we find the ground occupied by doctrines not wholly consistent with those generalizations of experience and fact to which they pertain, and by theories some of which are as artificial and unreal in character as any, perhaps, of those taught at the earlier period.

It is true the fact has been now long known that the sun and not the earth occupies the centre of the solar system; much precise and accurate knowledge has been obtained as to the dynamical relations of the various members thereof to each other; much has been done in ascertaining and permanently recording the relative positions of the more distant celestial bodies; much progress has been made in the formal and rigorous (mathematical) application of the sciences of force and motion (Mechanics), of magnitude and form (Geometry), and of number and quantity (Algebra), to the observed phenomena of astronomy; great improvements have been effected in the instruments which enable or aid the astronomer to correctly observe those phenomena, and experience has made evident the importance of systematic observations by trained and practised observers to ensure correctness and accuracy in the general record of the observed facts belonging distinctively to astronomical science.

Notwithstanding, however, the great advance which has undoubtedly been made in these particulars, the present state of the astronomical department of general science may be considered an intermediate station between the old (artificial) system and a new (natural) system rather than as constituting in itself a complete, coherent, and intelligible system. Such as it is, it may, for reasons which we shall immediately proceed to explain, be distinguished by the appellation of.. 'the horizontal system.' It may be described as consisting in part of an imperfect *natural system—i. e.,* of a sound system based on reality and fact, and in part of the old artificial system which, although nominally and formally discarded, still retains its hold on a not inconsiderable portion of that domain of which it formerly held exclusive possession.

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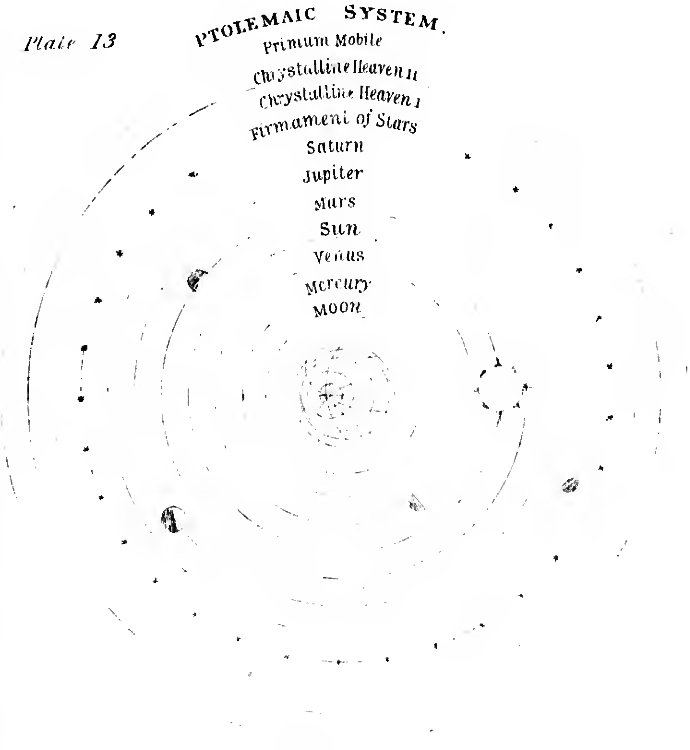
Plate 13



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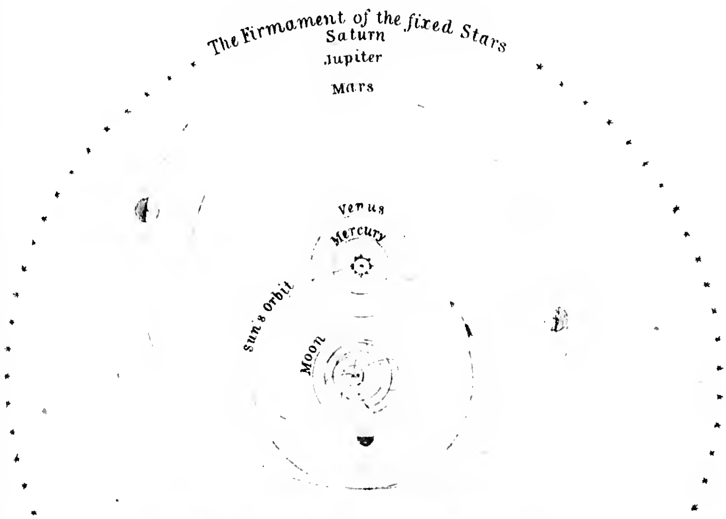
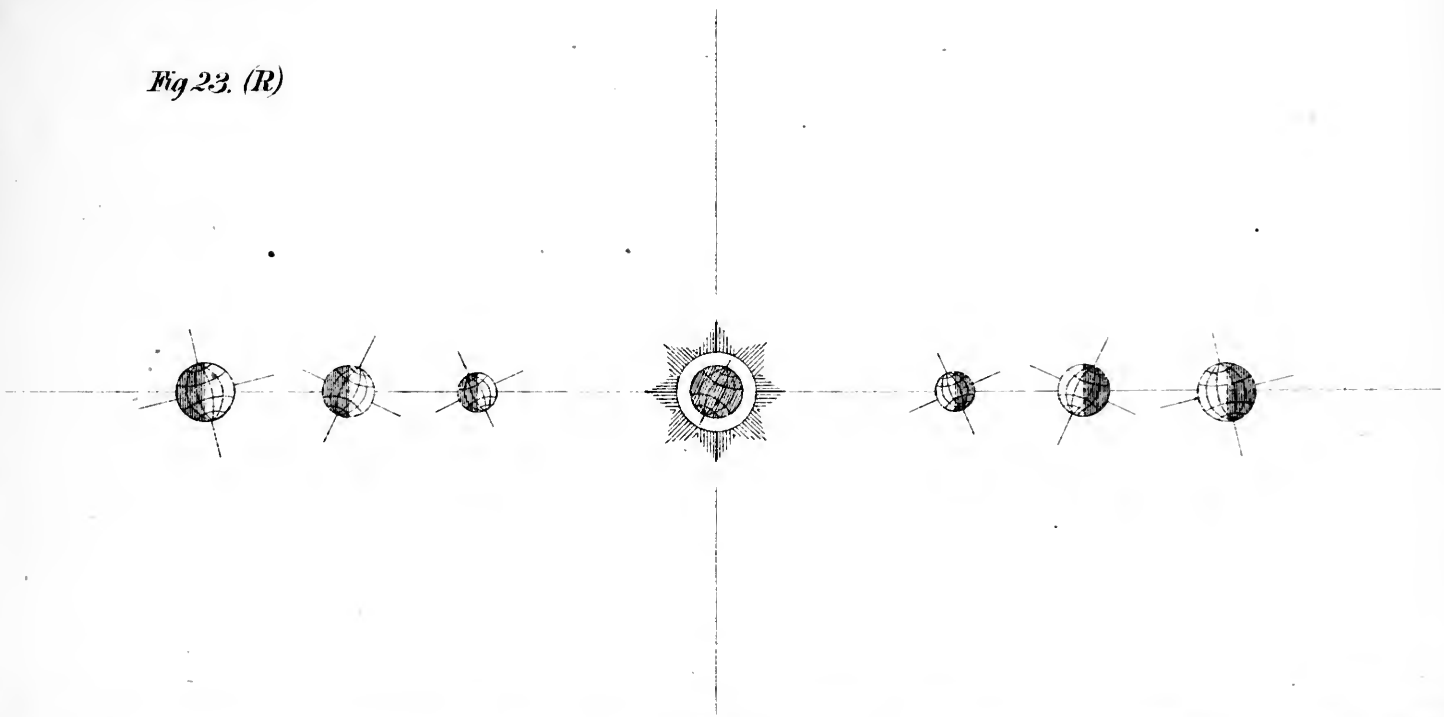


The System of Tycho Brahe A.D. 1580.

From Encyc. Britannica.

Fig 23. (R)



Hipparchus, of Rhodes (140 years B. C.), is, perhaps, entitled to rank as the last, as well as one of the greatest of the astronomers belonging to the older civilization; for Ptolemy (A. D. 130) was more a recorder of the progress already made and a connecting link between ancient and modern astronomy than himself an original observer or discoverer.

Now the ancient system, of which Hipparchus was the most advanced exponent, represented the various celestial bodies as revolving in concentric circles, within which the earth, already posited obliquely with the axis inclined to that of the sun, occupied the actual centre; *See Plate* 13. Amongst the later of the ancient mathematicians Plato, in particular, is supposed to have suggested the theoretical representation of the planetary orbits by circles in the same plane, and, the result appearing to harmonize well with the observed phenomena, the inference appears to have been at once adopted that the dynamical orbit of each planet or moving star, must be an undeviating horizontal plane, and this inference seems to have included the assumption that one uniform horizontal plane was common to all the planets of the solar (or terrestrial) system. *

* Whether in ancient astronomy any inference was arrived at as to the obliquity of the orbits of other planets, or as to the perpendicularity or inclination of their respective axes, does not appear; but in modern astronomy, even to the present time, the doctrine of the inclined axis leaves it open to the astronomical student to suppose all the planetary orbits to be confined to the one uniform horizontal plane of the ecliptic, (as shown in fig. 23 R, belonging to the preceding part of this series), the axis of the planet having, in each case, its own especial and distinctive inclination. It is true the practical astronomer, at the present time, would, if he carefully con-

So prominent a phenomenon as the undulating path of the sun in the heavens during its annual revolution could scarcely fail, however, to attract the notice and attention of astronomers at an earlier age than the comparatively advanced epoch of Plato and Hipparchus; we find it recorded, accordingly, that Thales, of Miletus (640 years B. C.), the founder of the Ionian school, either discovered for himself or obtained information * that the equatorial plane of the earth is cut obliquely by the ecliptic; but the assumption that the earth's axis of rotation was inclined to the axis of the sun appears to have been proposed and accepted as a satisfactory explanation at a very early date, and the prejudice that an oblique position of the earth combined with a revolution in a horizontal plane was equivalent to an oblique orbit † having established itself as a postulate or a (supposed) demonstrated theorem of astronomical science as then taught, became inherited and accepted as a part of modern astronomy, without suspicion.

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sidered the case without prejudice, at once know that such cannot be the actual arrangement, for, if it were true, eclipse, occultation, or transit would necessarily take place each time of conjunction between a planet revolving in the outer circle and an inferior planet; but, on the other hand, there is the obvious obliquity of the sun's apparent path as seen from the earth, and if that can be accounted for by supposing an inclined position of the earth revolving in a horizontal orbit, it is evident that the same explanation would apply to the case of each other planet supposed to revolve in a horizontal orbit.

* It is recorded that Thales, as Plato and others of the Greek astronomers subsequently did, travelled into Egypt expressly to obtain information from the Egyptian priests on scientific subjects.

† Observe that if the case were confined to the earth and sun only, and the position of the sun's axis be considered indeterminate or optional by the theorist, the obliquely posited earth and horizontal orbit would actually be equivalent to the oblique terrestrial orbit.

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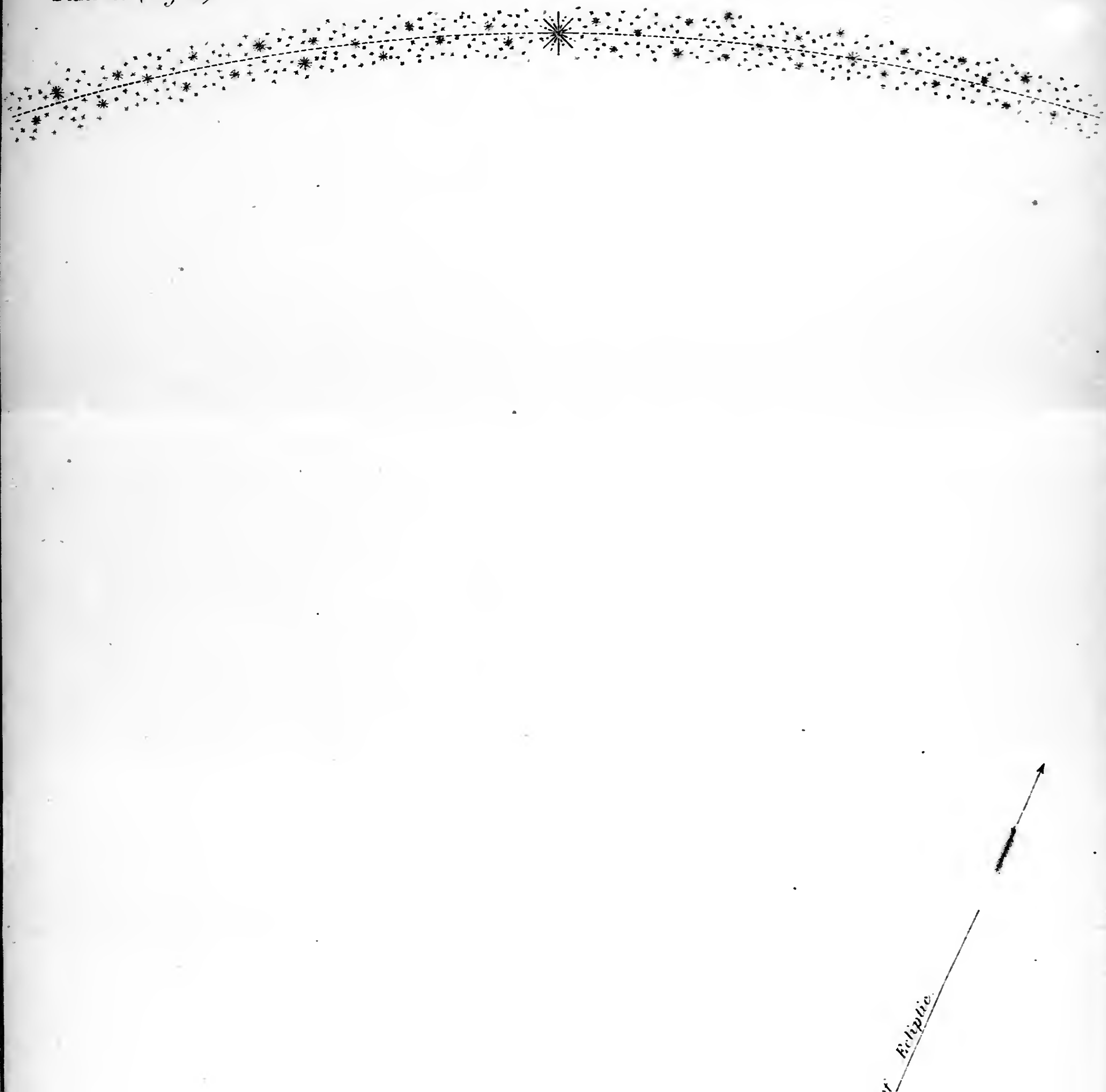
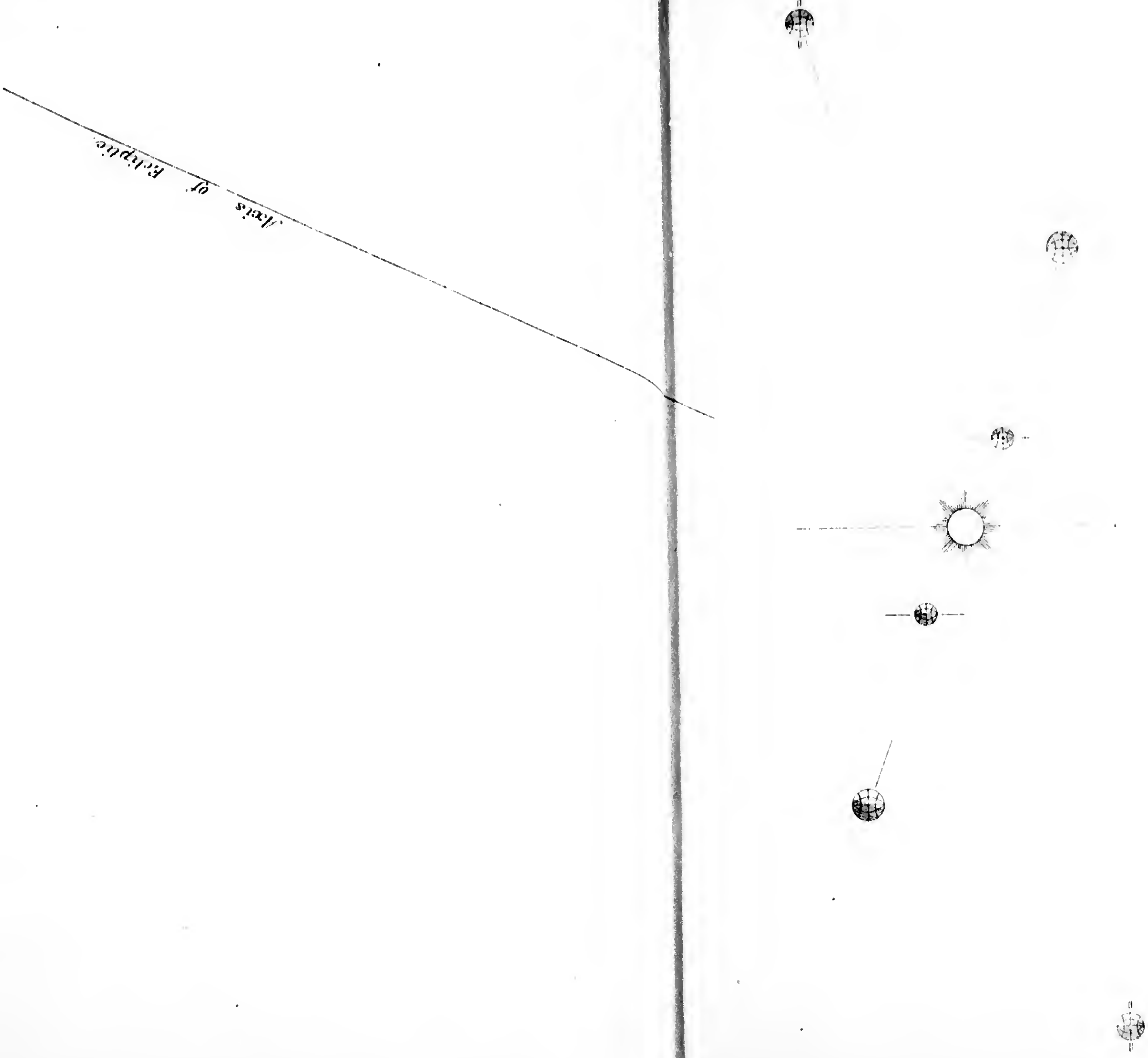
Plate 6. (Fig. 10.)




Axis of Ecliptic

(2.) *Stellar systems having their axes of revolution perpendicular to that of the solar system.*

The effect of a stellar system having its orbital plane perpendicular, or inclined at some considerable angle to the orbital plane of the solar system, does not seem to have been made the subject of especial study by astronomers. In our Fig. 10 (Pl. 6), illustrating the pole star and the solar system, the distance of the pole star from the sun as represented is less than twice the distance which the planet Uranus (if represented) would be from the sun. Therefore, if we suppose, for the purpose of illustration, the pole star to be the centre of gravitation of a system, having its central axis directly perpendicular to that of our solar system, and of which the orbit of one of the planets was about equal in diameter to the orbit of the planet Neptune, it is evident that the planet so circumstanced would approach more or less closely to our sun. In looking at such a representation as that shown at Fig. 10, and on a merely superficial consideration of the case, it would seem that such a vertical motion of a body at right angles to the path in which the earth is moving, if seen from the earth, could not be mistaken for or confounded with a motion in the same or nearly in the same plane as that of the earth's revolution. A closer and more attentive consideration of the actual conditions, however, will show that it might not be very difficult to fall into such an error. The planet would have descended, so to speak, more or less nearly to the horizontal plane before the light from our sun rendered it visible to an observer on the earth, it would then appear to approach the sun from or in an almost horizontal plane; and, if instead of the directly vertical, we substitute the supposition of a plane apparently deviating very considerably from the vertical, we shall then have a case wherein the compounded motions would be very likely to perplex and mislead an observer whose point of view was upon the earth; and such would be almost certainly the result, if the observer viewed the moving body with a prejudice or foregone conclusion that the body was revolving around our own sun in a plane either horizontal or not deviating very much from a horizontal plane. Let us consider some of the conditions under which a planet, belonging to a system having its axis perpendicular to a vertical plane passing through its centre and through the centre of the sun, would present itself to a terrestrial observer. In the first place, since the motion of the stranger planet would be at right angles to that of the earth, the actual orbital motion of the earth would in appearance be transferred to the planet, and would become an addition to the actual motion of the planet, thereby converting the vertical into an apparently oblique motion. If the stranger planet was of considerable size and approached sufficiently near to any of the planetary members of the solar system, it would perturb or cause a deviation in their orbital motion. If attended by satellites or moons, these would have an apparently oblique motion of revolution around their central planet in the opposite direction to the orbital motion of the earth. It is evident that —so long as the two systems retained the same relative positions, and the distance between the sun and the star remained the same—the stranger planet would periodically return in its orbit of revolution around its own centre of gravitation to the same relative place; and hence, particularly if the distance was very great, and observations required the medium of a powerful telescope, the stranger planet might be very easily mistaken for an additional member of the solar system. Entertaining the not improbable supposition that other stellar systems may be so arranged as to have their planes of revolution vertical to, or differing considerably from, that of the solar system; and that some of the members of one or more of these stellar systems may be, or become by the aid of very powerful telescopes, visible from the earth, let us consider the case of the two most distant planets which are now supposed to belong to the solar system. In doing so it will be most satisfactory to take the least distant of the two, as being the best observed and of which the apparent motion, for some considerable time past, has been recorded.

(3.) *The planets Uranus and Neptune, and the question of a neighbouring Stellar system.*

The Planet Uranus.—Subsequently to the discovery of this planet by Sir Wm. Herschel in 1781, it was found that observations of it had been recorded by preceding astronomers, and that its progress could be thereby traced back, with some degree of certainty, to the earliest period of such observations. This having been done, the result showed that the actual orbital path, through which the planet had (appeared to have) moved, differed greatly from the theoretical path which, considered as a member of the solar system, it should have followed. By attributing possible error to the earlier observations, and by theoretical suppositions of more or less ingenuity, the discrepancies were greatly reduced, and the motion of the planet was thus made to seemingly harmonize with that of the solar system until the year 1805, from which time till the year 1822 the departure of the planet from its supposed orbit became so marked as to suggest a search for some sufficient cause of such apparently unaccountable disturbance. The result of this search was the discovery of the planet Neptune. There can be no question as to the result being highly creditable to the perseverance and industry of those concerned in the investigation; but as to the precise nature of the result in a scientific sense, there is a great diversity of opinion —some considering it a great astronomical and mathematical achievement, because the planet was found in consequence of and very near to the actual place indicated by the calculation; but by others, viewed as being to a certain extent a merely fortuitous coincidence (a lucky chance), because when discovered and actually observed, the elements of the real planet were found to differ greatly (enormously) from those which had been assigned to it as the result of the hypothetical computation. The accompanying diagram, Fig. 4 (Pl. 1), copied from *Herschel's Outlines of Astronomy*, shows the discrepancy between the theoretical and observed path of the planet Uranus from the year 1690 to about 1845. (*See the Appendix.*)

The actual discovery of the planet Neptune having confirmed and apparently verified the conclusion that the motion of Uranus, in its departure from its supposed orbit, was to some extent effected by such source of local gravitating influence (*viz.* was perturbed by Neptune's attraction), seems to have occasioned a forgetfulness on the part of astronomers as to the previous lesser but yet very considerable discrepancy which had been partially reconciled by the ingenious but somewhat violent suppositions already mentioned. If, however, this partially reconciled discrepancy were the only remaining cause of doubt, it would not have been surprising that astronomers should, under the circumstances, consider the case, for the time, as satisfactorily explained, and rest satisfied accordingly; but there is another known (observed) circumstance belonging to this planet Uranus, so remarkable from its exceptional character as to forcibly suggest itself as an independent reason for the exercise of great caution in admitting the newly discovered planet (Uranus) to be a member of the solar system. The circumstance is that "the orbits of these satellites (the satellites of Uranus) offer remarkable and indeed quite unexpected and unexampled peculiarities. Contrary to the unbroken analogy of the whole planetary system—whether of primaries or secondaries—the planes of their orbits *are nearly perpendicular to the ecliptic*, being inclined no less than 78° 38′ to that plane, and in these orbits their motions *are retrograde;* that is to say, their positions, when projected on the ecliptic, instead of advancing *from west to east* round the centre of their primary, as is the case with every other planet and satellite, move in the opposite direction. Their orbits are nearly or quite circular, and they do not appear to have any sensible, or, at least, any rapid motion of nodes, or to have undergone any material change of inclination, in the course, at least, of half a revolution of their primary round the sun. When the earth is in the plane of their orbits, or nearly so, their apparent paths are straight lines or very elongated ellipses, in which case they become invisible, their feeble light being effaced by the superior light of the planet, long before they come up to its disc. So that the observations of any eclipses or occultation they may undergo is quite out of the question with our present telescopes." (*Herschel's Outlines of Astronomy*). The observed facts herein recorded, if the supposition that the planet Uranus belongs to the solar system is retained, appears even more remarkable and extraordinary, when the circumstances of the case are submitted to a particular examination; because the fact of the satellites or moons revolving around the planet in a plane perpendicular to the plane of the solar system, almost necessitates the inference that the planet itself must rotate on an axis parallel to the plane of the solar system, and thus, on the supposition that Uranus is a solar planet, we have a departure from what may be called the plan of the system, considerably greater than at first sight appears. Is mechanical science sufficiently advanced as yet to decide, by reference to experimental demonstration (*i. e.*, by the record of reliable and unobjectionable experiment), whether such arrangement would be mechanically admissible; that is to say, whether, according to the laws governing mechanical forces, such arrangement would have the necessary quality of stability?

The arrangement would admit of three forms; namely, the horizontal axis, on which the revolving planet rotates, might have (1) a position at right angles to a vertical plane joining the planet and the (centre of gravitation) central body of the system; or, (2) it might be situated obliquely to such a plane; or, (3) one extremity of the axis might point directly towards the central body.

Such three forms of the arrangement are indicated in Fig. 5. (NOTE. The axis of the central body of the system, supposing it to rotate, is understood to be perpendicular to the nodal plane of the planet's revolution.) We do not think the case can be authoritatively decided by reference to experiment, but we do not hesitate to express a strong opinion that neither of the forms of the arrangement would be permanently stable; the axis of rotation of the planet, in such a case, would more or less gradually assume a vertical position; that is to say, it would become perpendicular to the sun's equatorial plane. If, however, we admit the assumption that the planet

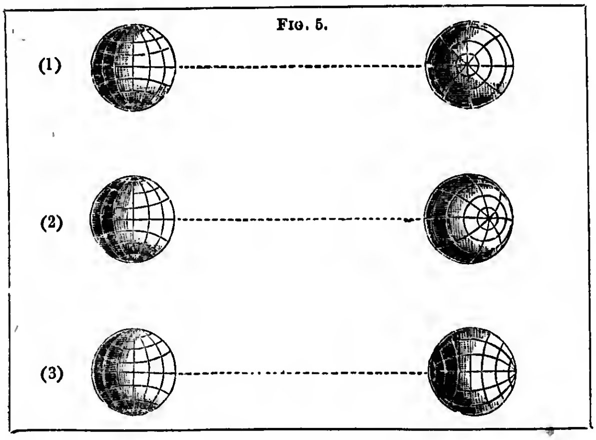


FIG. 5.

Uranus belongs to the solar system, we then have the form of the arrangement defined by the observed fact as recorded by Herschel* to be similar to that of (1) in the

*This is manifestly included in the statement of the (observation) already quoted. Owing to the great distance of Uranus from the sun, the line of vision from the earth, in any relative positions the moons can occupy, will be very nearly the same as if the planet was viewed from the sun: consequently the recorded observation necessitates the inference of the planet being posited as shown at (1) in the figure.

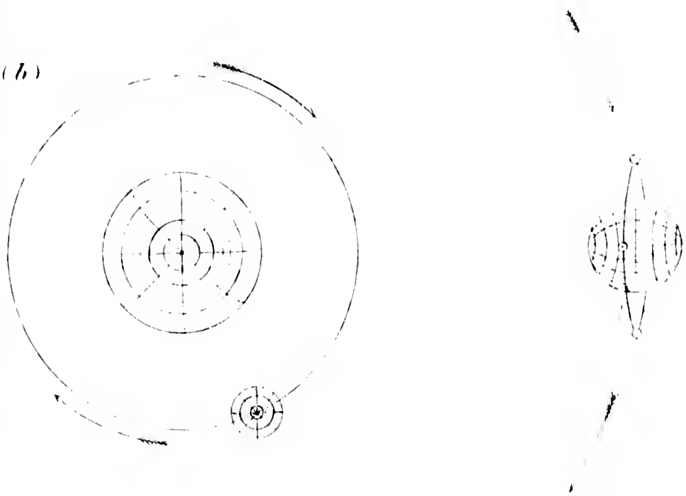
figure—namely, with the axis of the planet at right angles to a vertical plane joining the planet and the sun. The difficulty as to admitting the assumption is increased by taking into consideration the moons or satellites of the planet, as shown at (d) in Fig. 6 (Pl. 2); the angular orbital velocity of each moon would be greater than that of the planet when inside the orbital circle, and less when outside the planet's path; the difference would be very small, but there would necessarily be a *continual* and *active tendency* of the moons *towards the horizontal plane* of revolution. Now if we take the assumption that the planet Uranus belongs to a stellar system having its plane perpendicular to that of the solar system, the same very important and interesting fact observed and recorded by Herschel (quoted at page 17), will also serve to indicate, if not to define, the relative position of the central body of the neighbouring system, viz. the *star*, to that of our sun; because it is at once evident that the plane of the planet's orbit must coincide (or nearly so) with a vertical plane joining the *central star* and the sun; for if it does not, let it be supposed that the plane of the planet's revolution is at right angles to the vertical plane joining the *star* and the sun; then, observation would show the planet's moons revolving as at (*b*) Fig. 6 (Pl. 2), whereas the fact is recorded to be as at (*a*) in the same figure;* and similarly the supposition of more than a slight deviation (*i. e.*, a moderate degree of obliquity) from the plane join-

* The meaning intended, as to the relative positions, may be defined by stating that the vertical plane joining the sun and star coincides with the equatorial plane of the star.

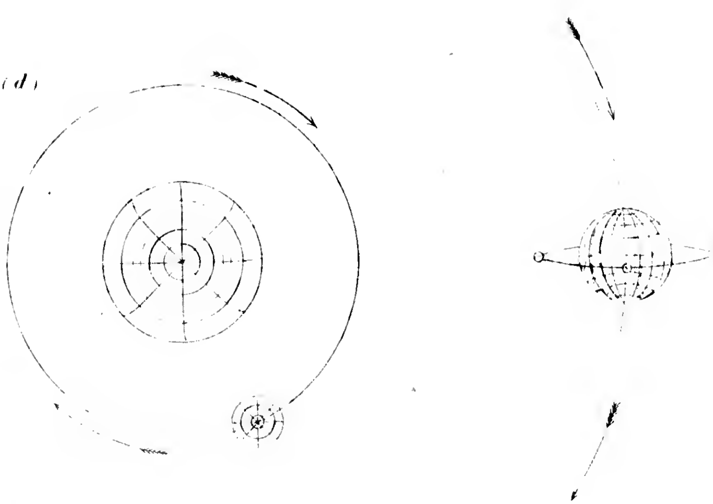
Plate Fig 6

Uranus considered as a Solar Planet.

(b)



(d)



Sun Earth Uranus

ing the *star* and the *sun*, may be at once negatived. The question is therefore reduced to (1) whether the place of the *star* is vertically above or beneath the polar axis of the sun; or, (2) whether it is above or below the equatorial plane of the sun; or (3) whether the place of the *star* is in the equatorial plane of the sun. The (1) case it is not necessary to consider, as such a supposition is clearly inadmissible; but to decide astronomically between the (2) and (3)—that is, whether the place of the *star* is above, below, or in the equatorial plane of the sun—will probably require further careful observation of the planet. The observations already recorded seem, however, to support the supposition that the place is considerably above the equatorial plane of the sun, as shown in the illustrations, plates 14 and 15; the conclusion that such is the true locality of the *star* will be somewhat strengthened by including the circumstances at present ascertained of the still more recently discovered and less known planet *Neptune*.

Taking the assumption that Uranus belongs to a neighbouring stellar system, the probability is at once suggested that Neptune is another member of the same system and at a less distance from the central body.* The few observations as yet recorded of this planet cannot be

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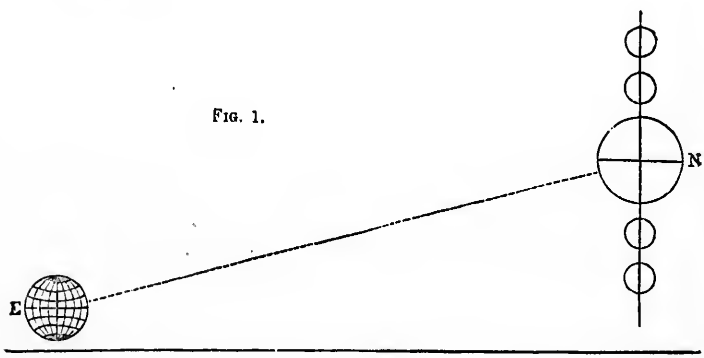
* On the assumption that *Uranus* and *Neptune* belong to the solar system, the orbital distance between *Mercury* and *Neptune* should be, according to Bode's law, twice that between *Mercury* and *Uranus*. It is now estimated from observation, only to exceed the latter by a little more than half the distance.

considered, on account of the great distance of the planet and difficulties of observing it, as very reliable; two moons are reported, of which one has "an orbit"—according to Mr. Otto Struve—"inclined to the ecliptic at the considerable angle of 35°; but whether, as in the case of the satellites of Uranus, the direction of its motion be retrograde, it is not possible to say until it shall have been longer observed." Now, an angle of 35° differs considerably from perpendicularity; but, even if admitting the correctness of the observation, we must remember it was made on an assumption (prejudice) that the earth and the planet were in the same or nearly in the same plane; whereas, if we assume Neptune to belong to the neighbouring stellar system, that planet would probably be considerably above the plane of the earth's orbit, and consequently (as before shown, with regard to the solar spots, in Part Second) an erroneous inference as to the obliquity of the satellites' plane of revolution would be occasioned. See the accompanying figure (Fig. 1), where the lower body E may be considered to represent the earth.

Fig. 1.



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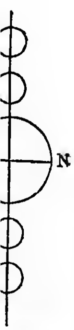
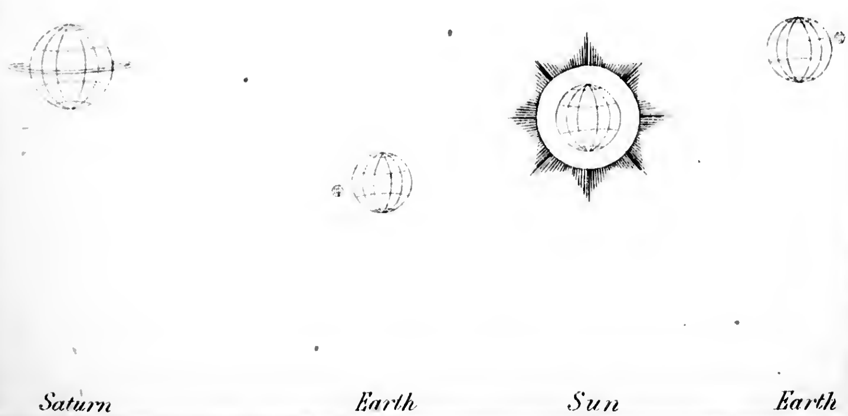


Plate 14

THE THEORY
OF
THE STELLAR UNIVERSE.

The Sun's Axis
being considered Vertical

The Solar System
Vertical axis



E.

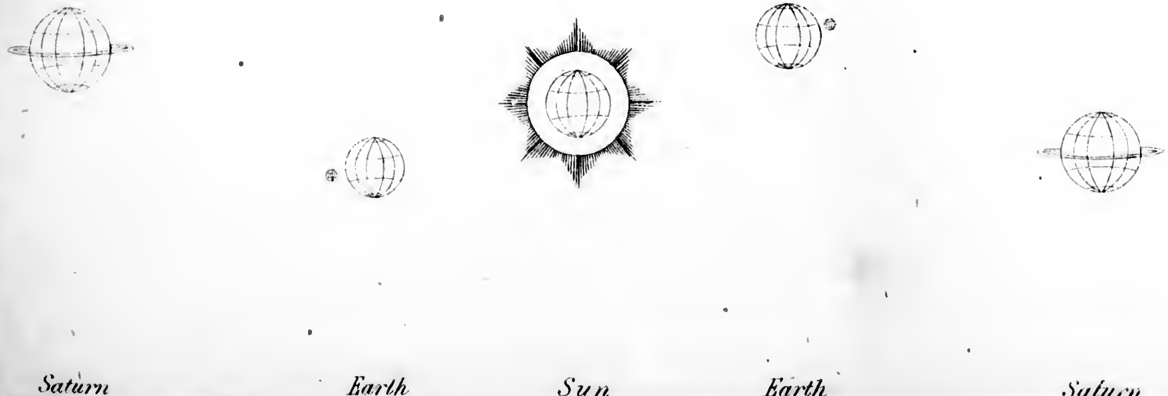
Earth

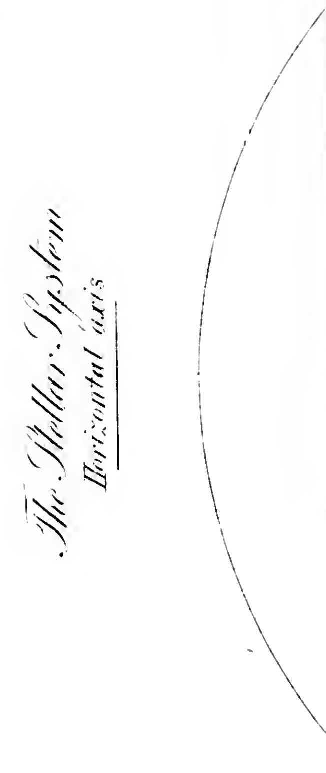
Plate 14

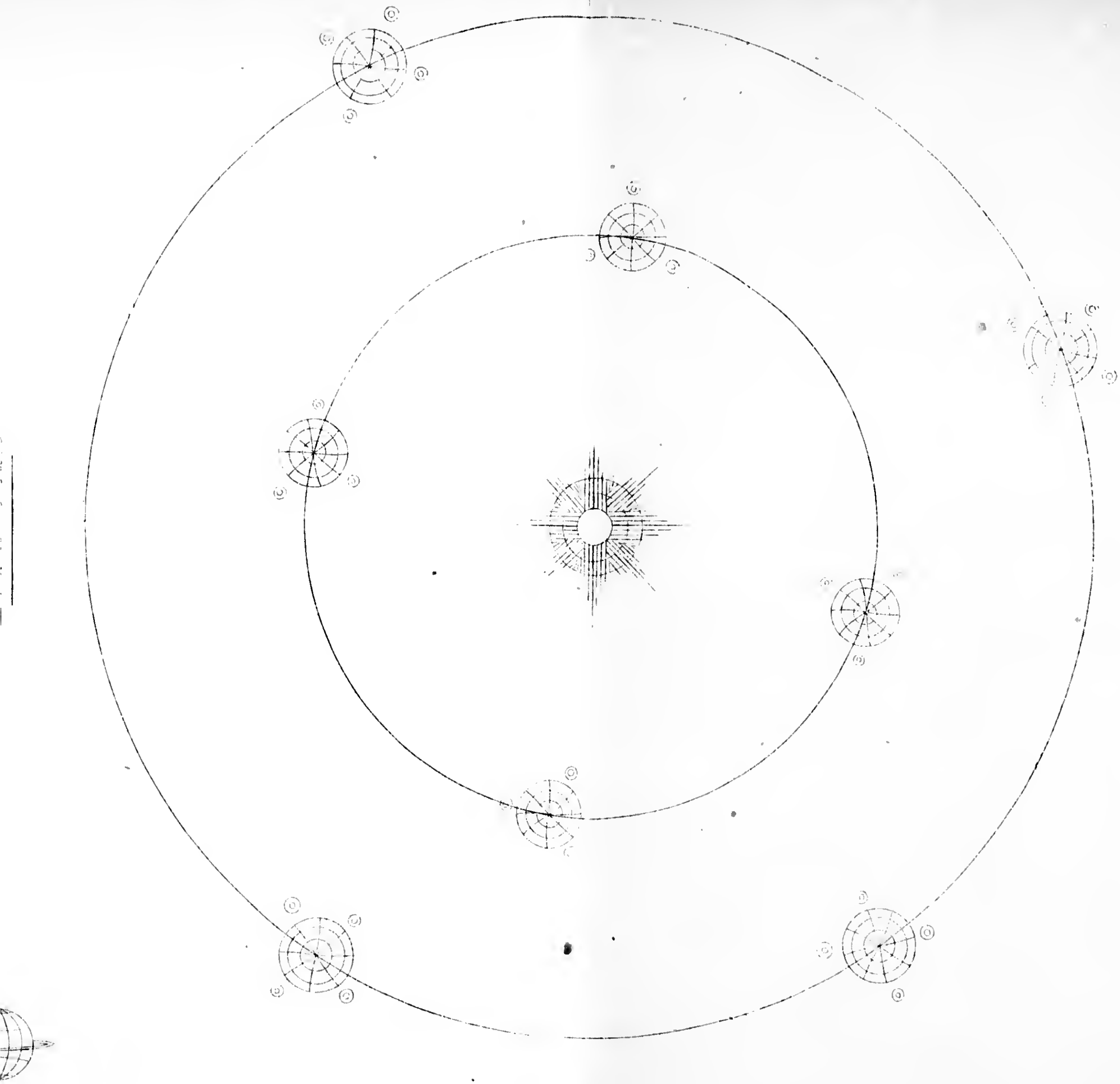
THE THEORY OF THE STELLAR UNIVERSE.

The Sun's Axis being considered Vertical

The Solar System
Vertical axis





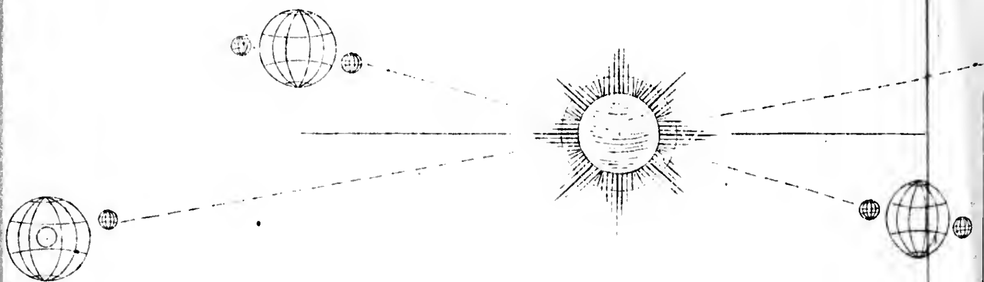


…urn *Uranus* *Neptune* *Uranus*

Plate 15

THE THEORY
OF
THE STELLAR UNIVERSE.

*The Sun's Axis
being considered Horizontal*



The Stellar System

Vertical axis

E.

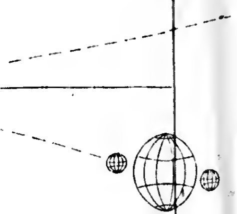
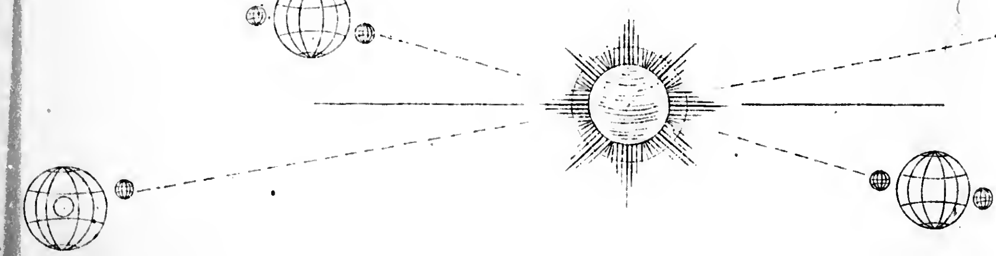


Plate 15

THE THEORY
OF
THE STELLAR UNIVERSE.

The Sun's Axis
being considered Horizontal

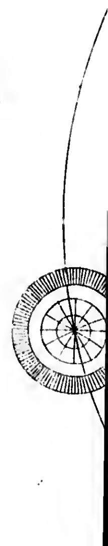


The Stellar System

Vertical axis

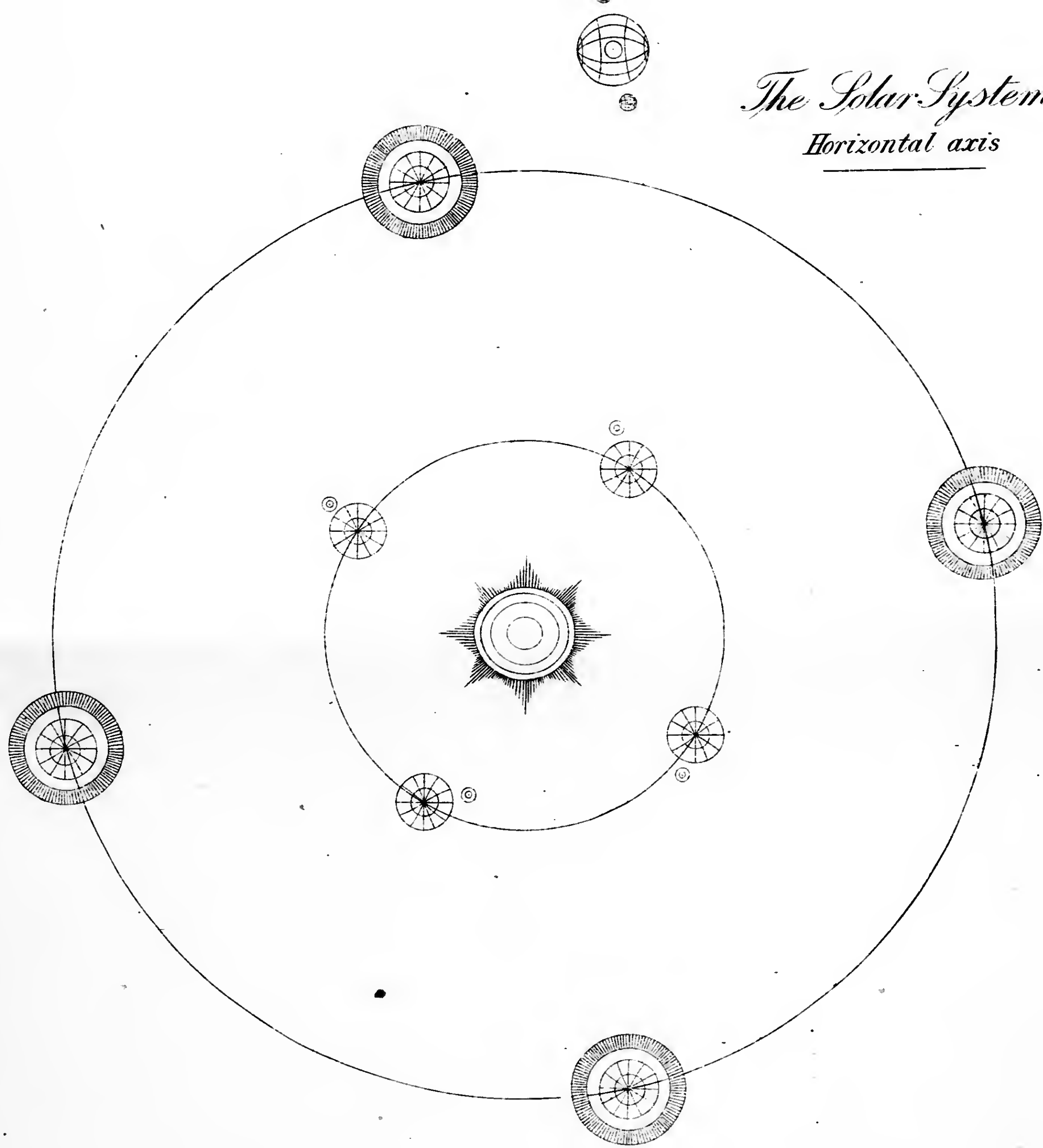
The Solar System

Horizontal axis



The Solar System

Horizontal axis



Summing up the consideration of the case, we conclude (1) that the planets *Uranus* and *Neptune* are not solar planets belonging to our system, but that they are stellar planets belonging to a neighbouring system which has its axis of revolution perpendicular to that of the solar system; (2) that the (central) *star* round which those planets revolve is very probably above the equatorial plane of our sun; and (3) that the distance of the *star* from the sun may be roughly estimated (by adding the distance of the planet Saturn to that of Uranus, 890 + 1800 = 2690 million miles) at about 3000 million miles.

(See Plates 14 and 15.)

NOTE.—The following apparently weighty or fatal objection to the opinion expressed above—that the planets Uranus and Neptune belong not to the solar but to a neighbouring stellar system—is very likely to suggest itself at once.—The planet Uranus has been for a considerable time, nearly a century, directly under astronomical observation, and occasional notices of its having been previously observed, and mistaken for a star, are on record. Now if evidence can be shown that the planet has been observed at successive places in its (alleged) solar orbit, and, so to speak, tracked throughout its orbit; or if, having been seen at one extremity of its supposed solar orbit, it has been subsequently observed at the opposite extremity, then the opinion stated by us cannot certainly be upheld. It is therefore to be understood that the strong and confident opinion stated includes the opinion on our part that no such evidence of an actual solar orbit can be shown.*

(4,) *Masses of aggregated matter and their relation to the laws of the material universe.*

The assumption that masses of matter, revolving around centres of gravitating influence in the neighbourhood of, but not belonging to the solar system, may approach sufficiently near to be visible from the earth, will perhaps enable us to understand and give a reasonable explanation of some of those observed facts of astronomy, which at present occupy the position of mechanical effects apparently governed and regulated by laws unknown to or unrecognized by mechanical science. We allude more particularly to those very various bodies at present grouped and classed together under the name *comet*. Plate 16 from the (*Encyc. Britannica*) is an example of the illustrations given at the present time in astronomical works, of the supposed orbital revolution of a comet around the sun. In some cases the orbital path is considered to be an ellipse of extreme eccentricity; in other cases, a parabola; or, a hyperbola. The objection to this teaching seems to have been overlooked that it is inadmissible in a scientific sense, because contrary to the law of gravitation; a law which is recognized both by astronomical

* Considered as solar planets, theory assigns 84 years as the period of Uranus, and about 165 years as that of Neptune.

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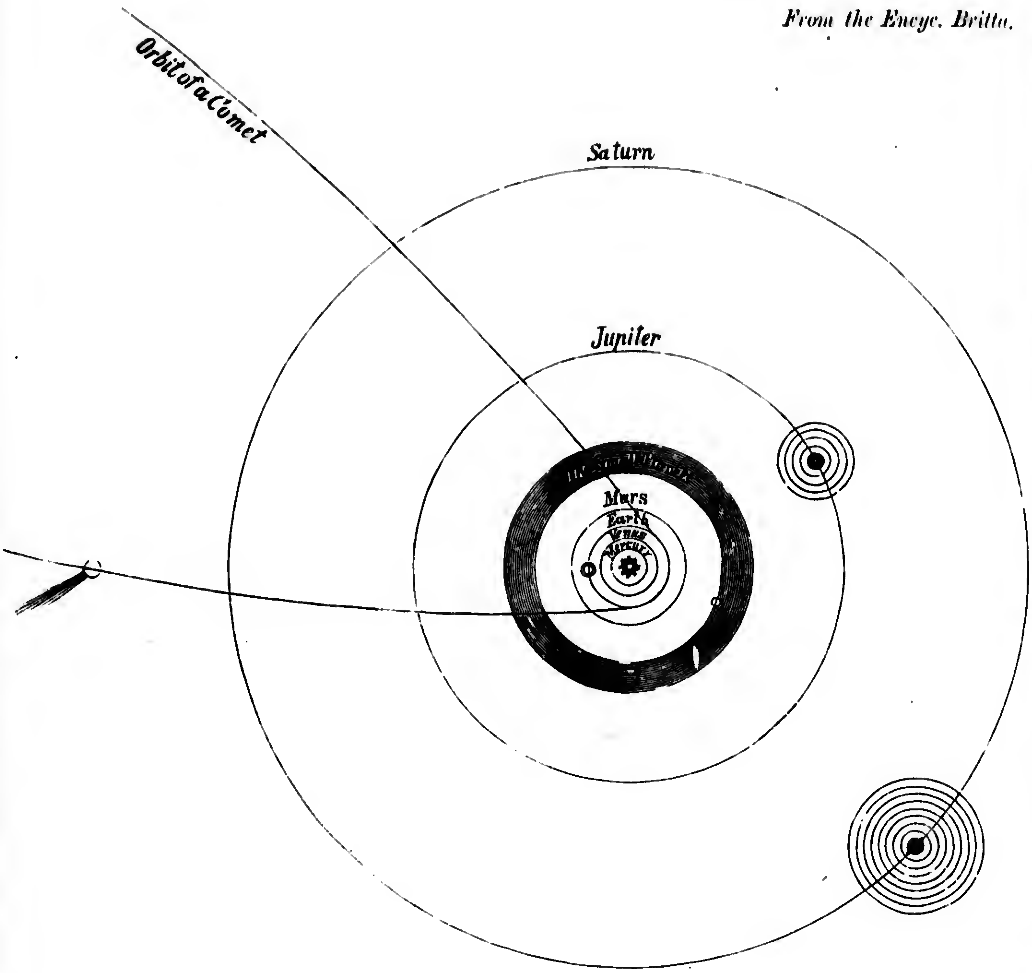
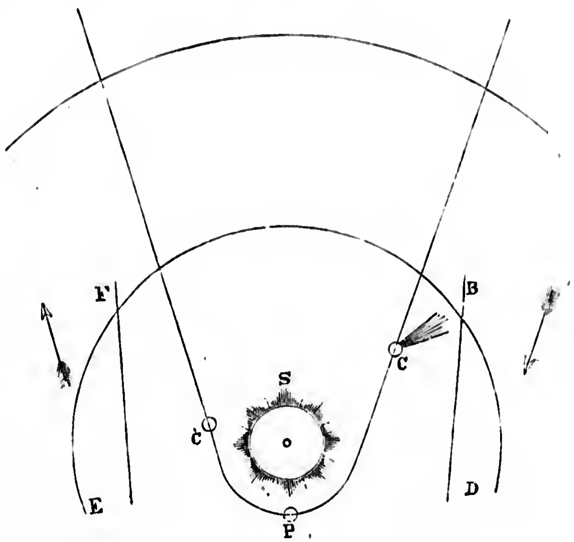
PLATE 6.

From the Encyc. Britta.



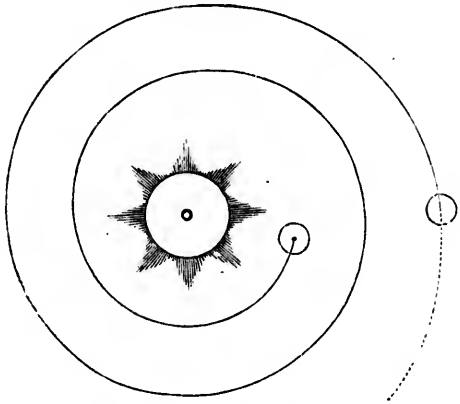
and mechanical science. In Fig. 2, the body C, to the north-east of the sun, is moving with an increasing velocity in the direction BD. The gravitating influence of the sun is supposed, at this place in the comet's orbit, to exceed the centrifugal force, causing it to gravitate towards and

FIG. 2.



approach the sun. Since the approach is very considerable in extent and rapid, so is the increase in the velocity proportionately great, and when the comet has arrived (*i.e.*, supposed to have arrived) at its perihelion P, it is moving with enormous velocity past the sun in the direction DE; for a certain short distance, it proceeds in a curve not differing very much from the arc of a circle, but then, notwithstanding that it is supposed to be comparatively very near the sun and under the influence of an enormous attractive force, it suddenly ceases altogether to obey this force, and proceeds in the direction EF, as shown in the figure, without any further regard to the central gravitating influence. If the body is material and subject to the known laws governing matter when moving from B towards D, and if, even after passing its perihelion, it still retains its material nature and recognizes the influence of gravitation until beyond E, how is it to be admitted that its subjection to the laws of matter can be suddenly abrogated? We cannot admit a supposition that any material mass, having once become subject to the sun as the central gravitating influence governing its motion, and thus belonging to the solar system, can suddenly throw off its allegiance and withdraw from the sun's controlling power into space, or to visit some other system in a similarly capricious manner. If we assume the body (comet) to have arrived at the place (P) shown in the figure, nearest the sun (without troubling ourselves to explain how it got there), and to be moving past the sun with such very great velocity that the centrifugal force developed is more than sufficient to counterbalance the enormous attractive force of the sun, at so short a distance; then the inference will be sound that the comet must recede from the sun; and further, the distance to which the comet will recede will be proportional to the excess in the centrifugal force over the gravitative force when nearest to the sun, as explained and demonstrated in Part First of this Series; but even in such case the recession could only take place in an orbit with a continually increasing radial distance from the sun, as shown in Fig. 3, and the path of the receding body would have the form of a spiral curve continually increasing outwards from the sun as its centre.

FIG. 3.



(5.) *The relative distance of the visible stars.*

Previously to explaining the real character of the cometary motions, it will be proper to examine the question as to the relative distances of the visible stars. In Plate 6 (Fig. 10), the illustration plainly shows, that assuming the pole star, for instance, to be at a much less distance than is attributed to it by astronomers at the present time, the orbital movement of the earth would not suffice to much alter the apparently relative place of the star. To an observer viewing it from the earth, it would appear almost directly over the pole—in whatever part of the orbit the earth's place might be at the time of the observation. And further, it will be found that if the assumed distance of the star be again diminished, and taken at (let us say) one half the distance shown in that illustration, the difference to the terrestrial observer would still be difficult to detect without some object having a relatively fixed position to compare with; for example (assuming the axes of the earth and sun to be both perpendicular to the plane of revolution), if the star was directly over the pole of the sun, it would be extremely difficult, even if the distance of the star was very much less than is supposed, to detect any difference; by careful and precise determination of the celestial sphere, however, and by comparison with a number of the (so called) fixed stars, a point could be found which would be relatively motionless and around which the earth's pole star would appear to revolve in a small circle—the direction of the earth's actual revolution being reversed in that of the apparent revolution of the star; and this effect would still be essentially the same even if the distance was very great, and indeed so long as the star remained visible; only that, the greater the distance of the star from the earth, the less would be the diameter of the circle in which the earth's pole star would appear to revolve around the point representing the pole of the celestial sphere; and if the distance was extremely great, so would the apparent circle of revolution be very small. The apparent motion or change in the apparent position of the pole star, since it would result from a change in the observer's actual position, would be astronomically termed the effect of "parallax;"*

* Parallax may be either geocentric or heliocentric; in the one, the diameter, or part of the diameter, of the earth; in the other, the diameter or part of the diameter of the orbital circle of the earth's revolution, is the measured base of the triangle. The general expression "parallax" is well defined, in *Lardner's Astronomy*, as "the apparent displacement of any object seen at a distance, due to a change of position (place) of the observer."

and as the distance of the earth from the sun is (approximately) known and therefore the diameter of the earth's orbit, the distance of the star from the sun (or earth) could be thus measured by parallax... Have the distances of the various stars been thus ascertained by parallax? The question will be answered by the following extracts from the Astronomical Record.

NOTE.—We will here again remind the reader that by the perpendicular axis theory such a parallax of the earth's polar-zenith (pole-star) can be only attainable by observations made when the earth is passing or repassing the sun's equatorial plane; if the observations be made at other times, the parallactic effect of the horizontal movement would be entirely masked or much interfered with by the effect of the vertical movement. And, again, should it appear that the earth is subject, as we have supposed, to a vibration on a horizontal axis transverse to a line joining the earth and sun.....this would constitute an independent interfering cause unless the observations were made at the nodal plane when the earth's position is strictly perpendicular

CHAPTER II.

The present mixed doctrine of Parallax and Aberration.

(6) Theory of Parallax.

Herschel's Outlines of Astronomy.

(800.) "The diameter of the earth has served us for the base of a triangle, in the *trigonometrical survey* of our system (art. 274), by which to calculate the distance of the sun; but the extreme minuteness of the sun's parallax (art. 275) is so delicate, that nothing but the fortunate combination of favourable circumstances afforded by the transits of Venus (art. 479) could render its results even tolerably worthy of reliance. But the earth's diameter is too small a base for direct triangulation to the verge even of our own system (art. 526), and we are, therefore, obliged to substitute the *annual parallax* for the diurnal, or, which comes to the same thing, to ground our calculation on the relative velocities of the earth and planets in their orbits (art. 486), when we would push our triangulation to that extent. It might be naturally enough expected that by this enlargement of our base to the vast diameter of the earth's orbit, the next step in our survey (art. 275) would be made at a great advantage;—that our change of station, from side to side of it, would produce a considerable and easily measurable amount of annual parallax in the stars, and that by its means we should come to a knowledge of their distance. But, after exhausting every refinement of observation, astronomers were, up to a very late period, unable to come to any positive and coincident conclusion upon this head; and the amount of such parallax, even for the nearest fixed star examined with the requisite attention, remained mixed up with and concealed among the errors incidental to all astronomical determinations. The nature of these errors "has been explained in the earlier part of this work, and we need not remind the reader of the difficulties which must necessarily attend the attempt to disentangle an element not exceeding a few tenths of a second, or at most a whole second, from the host of uncertainties entailed on the results of observations by them: none of them individually, perhaps, of great magnitude, but embarrassing by their number and fluctuating amount. Nevertheless, by successive refinements in instrument-making, and by constantly progressive approximation to the exact knowledge of the Uranographical corrections, that assurance had been obtained, even in the earlier years of the present century, viz., that no star visible in northern latitudes, to which attention had been directed, manifested an amount of parallax exceeding a single second of arc. It is worth while to pause for a moment to consider what conclusions would follow from the admission of a parallax to this amount."

(801.) "Radius is to the sine of 1″ as 206265 to 1. In this proportion then at least must the distance of the fixed stars from the sun exceed that of the sun from the earth. Again, the latter distance, as we have already seen (art. 357), exceeds the earth's radius in the proportion of 23984 to 1. Taking, therefore, the earth's radius for unity, a parallax of 1″ supposes a distance of 4947059760, or nearly five thousand millions of such units; and lastly, to descend to ordinary standards, since the earth's radius may be taken at 4000 of our miles, we find 19788239040000, or about twenty billions of miles for our resulting distance."

(802.) "In such numbers the imagination is lost. The only mode we have of conceiving such intervals at all is by the time which it would require for light to traverse them. (See note §, at the end of this chapter, for a more familiar illustration.) Light, as we know (art. 545), travels at the rate of a semidiameter of the earth's orbit in $8^{m.}\ 13^{s.}\cdot 3$. It would, therefore, occupy 206205 times this interval, or

"3 years and 83 days, to traverse the distance in question. Now, as this is an inferior limit which it is already ascertained that even the brightest and therefore probably the nearest stars exceed, what are we to allow for the distance of those innumerable stars of the smaller magnitudes which the telescope discloses to us! What for the dimensions of the galaxy in whose remoter regions, as we have seen, the united lustre of myriads of stars is perceptible only in powerful telescopes as a feeble nebulous gleam!"

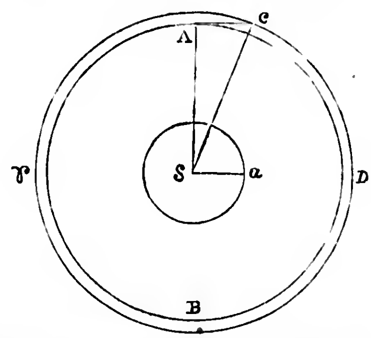
(803.) "The space-penetrating power of a telescope, or the comparative distance to which a given star would require to be removed in order that it may appear of the same brightness in the telescope as before to the naked eye, may be calculated from the aperture of the telescope compared with that of the pupil of the eye, and from its reflecting or transmiting power, *i.e.* the proportion of the incident light it conveys to the observer's eye. Thus it has been computed that the space-penetrating power of such a reflector as that used in the star-gauges above referred to is expressed by the number 75. A star, then, of the sixth magnitude removed to 75 times the distance would still be perceptible as a star with that instrument, and admitting such a star to have 100th part of the light of a standard star of the first magnitude, it will follow that such a standard star, if removed to 750 times its distance, would excite in the eye, when viewed through the gauging telescope, the same impression as a star of the sixth magnitude does to the naked eye. Among the infinite multitude of such stars in the remoter regions of the galaxy, it is but fair to conclude that innumerable individuals, equal in intrinsic brightness to those which immediately surround us, must exist. The light of such stars, then, must have occupied upwards of 2000 years in travelling over the distance which separates them from our own system. It follows, then, that when we observe the places and note the appearances of "such stars, we are only reading their history of two thousand years anterior date, thus wonderfully recorded. We cannot escape this conclusion but by adopting as an alternative an intrinsic inferiority of light in all the smaller stars of the galaxy. We shall be better able to estimate the probability of this alternative when we have made acquaintance with other sidereal systems whose existence the telescope discloses to us, and whose analogy will satisfy us that the view of the subject here taken is in perfect harmony with the general tenor of astronomical facts."

(804.) "Hitherto we have spoken of a parallax of 1″ as a mere limit below which that of any star yet examined assuredly, or at least very probably falls, and it is not without a certain convenience to regard this amount of parallax as a sort of unit of reference, which, connected in the reader's recollection with a parallactic unit of distance from our system of 20 billions of miles, and with a 3¼ years' journey of light, may save him the trouble of such calculations, and ourselves the necessity of covering our pages with such enormous numbers, when speaking of stars whose parallax has actually been ascertained with some approach to certainty, either by direct meridian observation or by more refined and delicate methods. These we shall proceed to explain, after first pointing out the theoretical peculiarities which enable us to separate and disentangle its effects from those of the Urano-graphical corrections, and from others causes of error which, being periodical in their nature add greatly to the difficulty of the subject. The effects of precession and proper motion (see art. 852), which are uniformly progressive from year to year, and that of nutation which runs through its period in nineteen years, it is obvious enough, separate themselves at once by these characters from that of parallax; and, being known with very great precision, and being certainly independent, as regards their causes, of any individual peculiarity in the "stars affected by them, whatever small uncertainty may remain respecting the numerical elements which enter into their computation (or in mathematical language their coefficients), can give rise to no embarrassment. With regard to aberration, the case is materially different. This correction affects the place of a star by a fluctuation, annual in its period, and therefore, so far, agreeing with parallax. It is also very similar in the law of its variation at different seasons of the year, parallax having for its apex (see art. 343, 344.) the apparent place of the sun in the ecliptic, and aberration, a point in the same great circle 90° behind that place, so that in fact the formulæ of calculation (the coefficients excepted) are the same for both, substituting only for the sun's longitude in the expression for the one, that longitude diminished by 90° for the other. Moreover, in the absence of *absolute certainty* respecting the nature of the propagation of light, astronomers have hitherto considered it necessary to assume at least as a possibility that the velocity of light may be to some slight amount dependent on individual peculiarities in the body emitting it."*

(805.) "If we suppose a line drawn from the star to the earth at all seasons of the year, it is evident that this line will sweep over the surface of an exceedingly acute, oblique cone, having for its axis the line joining the sun and star, and for its base the earth's annual orbit, which, for the present purpose, we may suppose circular. The star will therefore appear to describe each year about its mean place regarded as fixed, and in virtue of parallax alone, a minute ellipse, the section of this cone by the surface of the celestial sphere, perpendicular to the visual ray. But there is

* "In the actual state of astronomy and photology, this necessity can hardly be considered as still existing, and it is desirable, therefore, that the practice of astronomers of introducing an unknown correction for the constant of aberration into their equations of condition for the determination of parallax, should be disused, since it actually tends to introduce error into the final result."

"also another way in which the same fact may be represented. The apparent orbit of the star about its mean place, as a centre, will be precisely that which it would appear to describe if seen from the sun, supposing it really revolved about that place in a circle exactly equal to the earth's annual orbit, in a plane parallel to the ecliptic. This is evident from the equality and parallelism of the lines and directions concerned. Now, the effect of aberration (disregarding the slight variation of the earth's velocity in different parts of its orbit) is precisely similar in law, and differs only in amount, and in its bearing reference to a direction 90° different in longitude. Suppose, in order to fix our ideas, the maximum of parallax to be 1″ and that of aberration 20·5″, and let AB, *ab*, be two circles imagined to be described separately, as above, by the star about its mean place S, in virtue of these two causes respectively, S♈ being a line parallel to that of the line of equinoxes. Then if, in virtue of parallax alone, the star would be found



at *a*, in the smaller orbit, it would, in virtue of aberration alone, be found at A in the larger, the angle, *a* S A, being a right angle. Drawing then A C equal and parallel to S a, and joining S C, it will, in virtue of both simultaneously, be found in C—*i. e.* in the circumference of a circle whose radius is SC, and at a point in that circle in advance of A "the aberrational place, by the angle ASC. Now, since SA : AC : : 20·5 : 1, we find, for the angle ASC, 2° 47′ 35″; and for the length of the radius SC, of the circle representing the compound motion 20″.524. The difference (0″.024) between this and SC, the radius of the aberration circle, is quite imperceptible, and even supposing a quantity so minute to be capable of detection by a prolonged series of observations, it would remain a question whether it were produced by parallax or by a specific difference of aberration from the general average 20″.5 in the star itself. It is, therefore, to the difference of 2° 48′ between the angular situation of the displaced star in this hypothetical orbit, *i. e.* in the *argumenta* (as they are called) of the joint correction (♈SC) and that of abberration alone (♈SA), that we have to look for the resolution of the problem of parallax. The reader may easily figure to himself the delicacy of an enquiry which turns wholly (even when stripped of all its other difficulties) on the *precise* determination of a quantity of this nature, and of such very moderate magnitude."

The form of the figure illustrating the case defines the relative position which the observer's station is supposed to occupy, for, because *A.B.*, *a.b.* are circles described by the star about its mean place *S.*, a line passing through the star and through the earth must be perpendicular to the plane of the circles in every direction, or in other words, it must be a transverse axis to the circles passing perpendicularly through their common centre. Now parallax is an effect consequent upon an alteration in the observer's position, and parallax of the fixed stars is an effect consequent upon the constantly progressive change of the earth's place in its orbit. The parallactic circle of the star's apparent movement in the heavens is the representation, the inverted reflection, of the earth's actual movement in its orbital revolution. Therefore the parallactic displacement of the star through the semi-diameter of the circle, from *S* to *a* is consequent upon the (completed) motion of the earth through its second semi-orbit in the opposite direction, viz: correspondent to the semi-diameter *S*.♈. For if *a* be the extreme east of the star's parallactic circle, it is the apparent place of the star observed from the earth when at the western extremity of its orbit, and the star's apparent motion from *S.* to *a.* is the gradually increasing effect of the earth's motion from the central place of its orbit to the extreme west thereof. Aberration is an (hypothetical) effect consequent upon the motion of the person whose eye receives the light from the object, and aberration of the fixed stars is a (supposed) apparent effect consequent upon the actual motion of the earth in its orbit. The supposed aberrational circle of the star's apparent motion in the heavens is a representation or reflection of the *velocity* and the direction of the earth's orbital motion. Therefore the aberrational displacement of the star consequent upon the earth's orbital motion in the direction *D. S.* will be in the opposite direction, viz: from *A.* towards the west (*i. e.* the opposite direction to *A. c.*) For the aberrational displacement of the star to take effect in the direction *S. A*, the earth's orbital motion must evidently be in the direction opposite thereto, viz: in the direction *A. S.* or *A.B.*; but orbital motion of the earth in such direction cannot cause parallactic displacement in the direction *S. a*, nor yet in the direction *a.* S, because the displacement belonging to parallax as well as the supposed displacement due to aberration must be parallel to the motion or alteration in relative position of the observer's station, upon which each is dependent and of which both are consequents.

We are, therefore, quite unable to accept the statement, here made and defined by illustration, of an apparent theoretical motion by the star, compounded of an aberrational effect at right angles to the effect of parallax. In order that the reader may be able to fairly consider the evidence in this and other cases, we will presently give as fully and completely as our limits permit, Sir John Herschel's own statement and definition of the doctrine of *aberration.*

If *aberration* be indeed a reality, if it be anything more than a chimera of the imagination, some intelligible reason consistent with the theory to which it belongs can be shown why aberrational displacement should take effect in a direction at right angles to that of the displacement due to parallax.

Assuming, for a moment, the aberrational effect to be a reality in its application to the case here illustrated, that effect must be so related to that of parallax that the one is a deduction from the other, because when the one causes, or tends to cause, an effect in the one direction, the other causes, or tends to cause, an effect in the contrary direction, so that if the respective effects of the two causes should be exactly equal, the one must neutralize the other, and no apparent displacement of the star would take place.

The characteristic difference between the two effects is....that of parallax is consequent upon a completed movement from one place to another more or less distant from the first: in the case of the earth's orbital motion it is progressive from any given place in the orbit as a starting point until the entire diameter of the orbit has been completed. The quantity of apparent effect on the star, for any given distance moved through by the earth, is dependent upon the distance of the star; the result is quite independent of the velocity of the earth's motion (unless indirectly as effecting the distance moved through in a given time); whatever distance has been actually moved through by the earth there must be a proportional optical effect of parallax, *i. e.*, an apparent displacement, although if the distance moved through by the earth be comparatively small and the distance of the star very great, such effect may be too minute to be appreciable by the terrestrial observer, and it is indeed barely conceivable by the mind that the distance of a star might be so enormously great that the parallactic effect of the earth's motion, from one extremity of its orbit to the opposite, would be less than instrumental astronomy in its present state is able to take cognizance of.

According to the theory of aberration, the supposed effect thereof, which is wholly dynamical, is dependent upon the motion of the observer, whose eye receives the light, relatively to the observed object, and the amount of the effect dependent upon the velocity of that motion, consequently, if the earth be supposed to move from the extreme west to the extreme east of its orbit, the maximum aberrational displacement of the star towards the east will be attained at the time the earth passes the place in the orbit half distant between the east and west; but the displacement will be nearly as great for a considerable time before the earth arrives at the half-distance, and will begin to diminish so soon as the place of half distance has been passed; whereas the maximum of parallactic effect is only attained when the earth has arrived at the opposite extremity of the orbit, at which time the supposed aberrational effect due to the motion of the earth in that direction will have wholly ceased. It is true that by the theory of aberration there would be now a displacement, at right angles to the former, due to the earth's orbital motion from north to south, but this would be in the opposite direction to that shown in Herschel's illustration, and it would be counteracted by the parallactic effect also belonging to the earth's motion from north to south; and, be it observed, this last effect, even according to the aberration theory, could only take place in the case of a polar star (to which alone Herschel's illustration applies), for, in the case of an equatorial star, since the earth would be moving directly away from the star, no aberrational (or parallactic) effect whatever could take place as a consequent to the earth's motion in that direction, viz., from north to south.

The quotation from *Herschel's Outlines in Astronomy continued.*

(806.) "But these other difficulties themselves are of no trifling order. All astronomical instruments are affected by differences of temperature. Not only do the materials of which they are composed expand and contract, but the masonry and solid piers on which they are erected, nay even the very soil on which these are founded, participate in the general change from summer warmth to winter cold. Hence arise slow oscillatory movements of exceedingly minute amount, which levels and plumb lines afford but very inadequate means of detecting, and which, *being also annual in their period* (after rejecting whatever is casual and momentary), mix themselves intimately with the matter-

"of our enquiry. Refraction too, besides its casual variations from night to night, which a long series of observations would eliminate, depends for its theoretical expression on the constitution of the strata of our atmosphere, and the law of the distribution of heat and moisture at different elevations, which cannot be unaffected by difference of season. No wonder, then, that mere meridional observations should, almost up to the present time, have proved insufficient except in one very remarkable instance, to afford unquestionable evidence, and satisfactory quantitative measurement of the parallax of any fixed star."

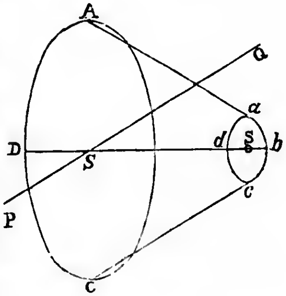
(807.) "The instance referred to is that of *a* Centauri, one of the brightest and, for many other reasons, one of the most remarkable of the southern stars. From a series of observations of this star, made at the Royal Observatory of the Cape of Good Hope in the years 1832 and 1833, by Professor Henderson, with the mural circle of that establishment, a parallax to the amount of an entire second was concluded on his reduction of the observations in question after his return to England. Subsequent observations by Mr. Maclear, partly with the same, and partly with a new and far more efficiently constructed instrument of the same description made in the years 1839 and 1840, have fully confirmed the reality of the parallax indicated by Professor Henderson's observations, though with a slight diminution in its concluded amount, which comes out equal to 0″·9128, or about $\frac{1}{1}\frac{0}{1}$ths of a second; *bright stars in its immediate neighbourhood being unaffected by a similar periodical displacement, and thus affording satisfactory proof that the displacement indicated in the case of the star in question is not merely a result of annual variations of temperature.* As it is impossible at present to answer for so minute a quantity as that by which this result differs from an exact second, we may consider the distance of this star as approximately "expressed by the parallactic unit of distance referred to in art. 804."

(808.) "A short time previous to the publication of this important result, the detection of a sensible and measurable amount of parallax in the star No. 61 Cygni of *Flamsteed's Catalogue of Stars*, was announced by the celebrated astronomer of Königsberg, the late M. Bessel. This is a small and inconspicuous star, hardly exceeding the sixth magnitude, but which had been pointed out for especial observation by the remarkable circumstance of its being affected by a *proper motion* (see art. 852), *i.e.* a regular and continually progressive annual displacement among the surrounding stars to the extent of more than 5″ per annum, a quantity so very much exceeding the average of similar minute annual displacements which many other stars exhibit, as to lead to a suspicion of its being actually nearer to our system. It is not a little remarkable that a similar presumption of proximity exists also in the case of α Centauri, whose unusually large proper motion of nearly 4″ per annum is stated by Professor Henderson to have been the motive which induced him to subject his observations of that star to that severe discussion which led to the detection of its parallax. M. Bessel's observations of 61 Cygni were commenced in August, 1837, immediately on the establishment at the Königsberg observatory of a magnificent heliometer, the workmanship of the celebrated optician Fraunhofer, of Munich, an instrument especially fitted for the system of observation adopted; which, being totally different from that of direct meridional observation, more refined in its conception, and susceptible of far greater accuracy in its practical application, we must now explain."

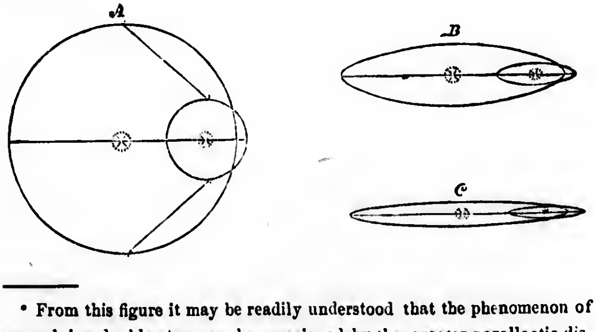
(809.) "Parallax, proper motion, and specific aberration (denoting by the latter phrase that part of the aberration of a star's light which may be supposed to arise from its individual peculiarities, and which we have every reason to "believe, at all events, an exceedingly minute fraction of the whole), are the only uranographical corrections which do not necessarily affect alike the apparent places of two stars situated in, or *very nearly in*, the same visual line. Supposing, then, two stars at an immense distance, the one behind the other, but otherwise so situated as to appear very nearly along the same visual line, they will constitute what is called a star *optically double*, to distinguish it from a star *physically double*, of which more hereafter. Aberration (that which is common to all stars), precession, nutation, *nay, even refraction, and instrumental causes of apparent displacement, will affect them alike*, or so very nearly alike (if the minute difference of their apparent places be taken into account), as to admit of the difference being neglected, or very accurately allowed for, by an easy calculation. If then, instead of attempting to determine by observation the place of the nearer of two *very unequal stars* (which will probably be the larger) by direct observation of its right ascension and polar distance, we content ourselves with referring its place to that of its remoter and smaller companion by *differential observation, i.e.* by measuring only its *difference* of situation from the latter, we are at once relieved of the necessity of making these corrections, and from all uncertainty as to their influence on the result. And for the very same reason, errors of adjustment (art. 736), of graduation, and a host of instrumental errors, which would, for this delicate purpose, fatally affect the absolute determination of either star's place, are harmless when only the difference of their places, each equally affected by such causes, is required to be known."

(810.) "Throwing aside, therefore, the consideration of all these errors and corrections, and disregarding for the present the minute effect of aberration and the uniformly progressive effect of proper motion, let us trace the effect of the differences of the parallaxes of two stars thus juxta-

"posed, or their apparent relative distance and position at various seasons of the year. Now, the parallax being inversely as the distance, the dimensions of the small ellipses apparently described (art. 805) by each star on the concave surface of the heavens by parallactic displacement will differ—the nearer star describing the larger ellipse. But both stars lying very nearly in the same direction from the sun, these ellipses will be similar and similarly situated. Suppose S and s to be the positions of the two stars as seen from the sun, and let ABCD, *a b c d*, be their parallactic ellipses; then, since they will be at all times similarly situated in these ellipses, when the one star is seen at A, the other will be seen at *a*. When the earth has made a quarter of a revolution in its orbit, their apparent places will be B*b*; when another, quarter, C*c*; and when another, D*d*. If then, we measure carefully, with micrometers adapted for the purposes, their apparent situation with respect to each other, at different times of the year, we should perceive a periodical change, both in the *direction* of the line joining them, and in the *distance* between their centres. For the lines A*a*, and Cc, cannot be parallel, nor the lines B*b*, and D*d*, equal, unless the ellipses be of equal dimensions, *i.e.* unless the two stars have the same parallax, or are equidistant from the earth."



In examining the case here illustrated we are in doubt as to the latitudinal place of the star represented in the figure and with respect to which no information appears to be given. It must be remembered that Herschel assigns to the earth an orbit horizontal to the axis of the celestial sphere; consequently, it seems to us that a parallactic ellipse, having its major axis perpendicular to the station of the terrestrial observer, as shown in the figure, could be only obtained by positing the celestial sphere horizontally. Let us suppose the double star under examination to be Polaris with a companion star actually at a much greater distance but apparently in close proximity. We then have Herschel's figure modified as in fig. *A*.. because the sum of the annual parallactic movements (displacements) of the two stars would be circles reflecting the orbital revolution of the earth, the greater circle belonging to the nearer star, the lesser to the more distant.* Now, if we suppose the star to be equatorial, or nearly so, we shall have the figure modified as shown at *C*... that is, the two stars would appear to shift their position almost linearly, having a reciprocating movement to and fro annually, in the same line, or in an extremely elongated ellipse. Again, if we suppose the double star to be located intermediately between the celestial pole and equator, we then have an ellipse such as shown at *B*.



* From this figure it may be readily understood that the phenomenon of a revolving double star may be occasioned by the greater parallactic displacement of the nearer of two polar stars which are nearly in the same

We have given reasons in the preceding part of this work why the earth's orbit should be considered to be compounded of vertical motion as well as of horizontal; adopting this theory (of the earth's perpendicular axis) we shall then have the parallactic effect on the equatorial star, illustrated by the fig. *B* instead of by the fig. *C*, and in the case of the intermediately located star the ellipse of the fig. *B* would be converted into an ellipse similar to that of Herschel's figure, but placed horizontally instead of upright.*

The quotation from *Herschel's Outlines of Astronomy* continued.

(811.) "Now, micrometers, properly mounted, enable us to measure very exactly both the distance between two objects which can be seen together in the same field of a telescope, and the position of the line joining them with respect to the horizon, or the meridian, or any other determinate direction in the heavens. The double image micrometer, and especially the heliometer (art. 200, 201), is peculiarly adapted for this purpose. The images of the two stars formed side by side, or in the same line prolonged, however momentarily displaced by temporary refraction or instrumental tremor, move together, preserving their relative situation, the judgment of which is in no way disturbed by such irregular movements. The heliometer also, taking

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visual line from the earth. That one of the two, which is much the nearer, appearing to revolve eccentrically once in the year around the more distant.

* The reader will understand the theoretical representation of the case belonging to each of the respective localities will be thus modified by the parallactic effect due to the vertical motion of the earth through 47° (or 45°) equalling about 74 million miles, and, therefore, not very much less than one half the horizontal diameter of the orbit.

in a greater range than ordinary micrometers, enables us to compare one large star with more than one adjacent small one, and to select such of the latter among many near it, as shall be most favourably situated for the detection of any motion of the large one, not participated in by its neighbour."

(812.) "The star examined by Bessel has two such neighbours both very minute, and therefore, probably, very distant, most favourably situated, the one (s) at a distance of 7′ 42″, the other (s′) at 11′ 46″ from the large star, and so situated, that their directions from that star make nearly a right angle with each other. The effect of parallax, therefore, would necessarily cause the two distances (Ss, and Ss′) to vary so as to attain their maximum and minimum values alternately at three-monthly intervals, and this is what was actually observed to take place, the one distance being always most rapidly on the increase or decrease when the other was stationary (the uniform effect of proper motion being understood, of course, to be always duly accounted for). This alternation, though so small in amount as to indicate, as a final result, a parallax, or rather a difference of parallaxes between the large and small stars, of hardly more than one-third of a second, was maintained with such regularity as to leave no room for reasonable doubt as to its cause; and having been confirmed by the further continuance of these observations, and quite recently by the exact coincidence between the result thus obtained and that deduced by M. Peters from observations of the same star at the observatory of Pulkova, is considered on all hands as fully established. The parallax of this star, finally resulting from Bessel's observation, is 0″.348, so that its distance from our system is very nearly three parallactic units (art. 804)."

(813.) "The bright star *a* Lyræ has also near it, at only 43″ distance (and, therefore, within reach of the parallel wire or ordinary double-image micrometer), a very minute star which has been subjected, since 1835, to a severe and assiduous scrutiny by M. Struve, on the same principle of differential observation. He has thus established the existence of a measurable amount of parallax in the large star, less indeed than that of 61 Cygni (being only about ¼ of a second), but yet sufficient (such was the delicacy of his measurements) to justify this excellent observer in announcing the result as at least highly probable, on the strength of only five nights' observation, in 1835 and 1836. This probability, the continuation of the measures to the end of 1838 and the corroborative, though not, in this case, precisely coincident result of Mr. Peters' investigations, have converted into a certainty. M. Struve has the merit of being the first to bring into practical application this method of observation, which, though proposed for the purpose, and its great advantages pointed out by Sir William Herschel so early as 1781, remained long unproductive of any result, owing partly to the imperfection of micrometers for the measurement of distance, and partly to a reason which we shall presently have occasion to refer to."

(814.) "If the component individuals S, *s* (fig. art. 810) be (as is often the case) very close to each other, the parallactic variation of their *angle of position*, or the extreme angle included between the lines A*a*, C*c*, may be very considerable, even for a small amount of difference of parallaxes between the large and small stars. For instance, in the case of two adjacent stars 15″ asunder, and otherwise favourably situated for observation, an annual fluctuation to and fro in the apparent direction of their line of junction to the extent of half a degree (a quantity which could not escape notice in the means of numerous and careful measurements), would correspond to a difference of parallax of only ⅛ of a second. A difference of 1″ between two stars apparently situated at 5″ distance might cause an oscillation in that line to the extent of no less than 11°, and if nearer, one proportionally still greater. This mode of observation has been applied to a considerable number of stars by Lord Wrottesley, and with such an amount of success, as to make its further application desirable. (*Phil. Trans.*, 1851.)" †

(815.) "The following are some of the principal fixed stars to which parallax has been, up to the present time, more or less probably assigned:

α *Centauri*..........	0″.976	(Henderson, corr'd by Peters.)
61 *Cygni*............	0″.348	(Bessel.)
21258 *Laland*...	0″.260	(Krüger.)
17415–6 *Oeltzen*.	0″.247	(Krüger.)
* α *Lyræ*.......... ..	0″.155	(W. Struve, corr. by O. Struve.)
Sirius..............	0″.150	(Henderson, corr. by Peters.)
70. p *Ophinchi*	0″.16	(Krüger.)
Ursæ Majoris...	0″.133	(Peters.)
Arcturus.........	0″.127	do
Polaris..........	0″.067	do
Capella...........	0″.046	do

* Qy. 0″.255 (see art. 813).

Although the extreme minuteness of the last four of these results deprives them of much numerical reliance, it is at least certain that the parallaxes by no means follow the order of magnitudes; and this is farther shown by the fact that α Cygni, one of M. Peters' stars, shows absolutely no indication of any measurable parallax whatever."

(7.) *The Theory of Aberration.*

Let us now examine the "theory of aberration, to which (as shown by the foregoing quotation) so great an importance is attached by astronomers.

† See Note on last page (page 89.)

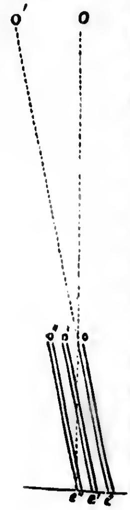
We will first take the explanation given by Dr. Lardner.

Handbook of Astronomy.

(2440.) "*Aberration of Light.*—Assuming, then, the velocity of light, and that the earth is in motion in an orbit round the sun with a velocity of about 19 miles per second, which must be its speed if it move at all, as will hereafter appear, an effect would be produced upon the apparent places of all celestial objects, by the combination of these two motions which we shall now explain.

"It has been stated that the apparent direction of a visible object is in the direction from which the visual ray enters the eye. Now, this direction will depend on the actual direction of the ray if the eye which receives it be quiescent; but if the eye be in motion, the same effect is produced upon the organ of sense, as if the ray, besides the motion which is proper to it, had another motion equal and contrary to that of the eye. Thus, if light moving from the north to the south with a velocity of 192,000 miles per second, be struck by an eye moving from west to east with the same velocity, the effect produced by the light upon the organ will be the same as if the eye, being at rest, were struck by the light having a motion compounded of two equal motions, one from north to south, and the other from east to west. The direction of this compound effect would, by the principles of the composition of motion (176), be equivalent to a motion from the direction of the north-east. The object from which the light comes would, therefore, be apparently displaced, and would be seen at a point beyond that which it really occupies in the direction in which the eye of the observer is moved. This displacement is called accordingly the ABERRATION OF LIGHT.

"This may be made still more evident by the following mode of illustration. Let O (Fig. 717) be the object from which light comes in the direction Ooe''. Let e be the place of the eye of the observer when the light is at o, and let the eye be supposed to move from e to e'', in the same time that the light moves from o to e''. Let a straight tube be imagined to be directed from the eye at e, to the light at o, so that the light shall be in the centre of its opening, while the tube moves with the eye from $o\,e$ to $o''e''$, maintaining constantly the same direction, and remaining parallel to itself: the light in moving from o to e'' will pass along its axis, and will arrive at e'' when the eye arrives at that point. Now it is evident that in this case the direction in which the object would be visible would be the direction of the axis of the tube, so that, instead of appearing in the direction oO which is its true direction, it would appear in the direction oO', advanced from o, in direction of the motion $e\,e''$, with which the observer is affected.



"The motion of light being at the rate of 192,000 miles per second, and that of the earth (if it move at all) at the rate of 19 miles per second (both these velocities will be established hereafter), it follows that the proportion of $o\,e''$ to $e\,e''$ must be 192,000 to 19, or 10,000 to 1.

"The angle of aberration $O\,o\,O'$ will vary with the obliquity of the direction $e\,e''$ of the observer's motion to that of the visual ray $o\,e''$. In all cases the ratio of $o\,e''$ to $e\,e''$ will be 10,000 to 1. If the direction of the earth's motion be at right angles to the direction $o\,e''$ of the object O, we shall have (2294) the aberration $a = \frac{206.265}{10.100} = 20''.42$. If the angle $o\,e''\,e$ be oblique, it will be necessary to reduce $e\,e''$ to its component at right angles to $o\,e''$, which is done by multiplying it by the trigonometrical sine of the obliquity $o\,e''\,e$ of "the direction of the object to that of the earth's motion. If this obliquity be expressed by O, we shall have for the aberrations in general $a = 20''.42 \times \sin. O$. According to this, the aberration would be greatest when the direction of the earth's motion is at right angles to that of the object, and would decrease as the angle O decreases, being nothing when the object is seen in the direction in which the earth is moving, or in exactly the contrary direction.

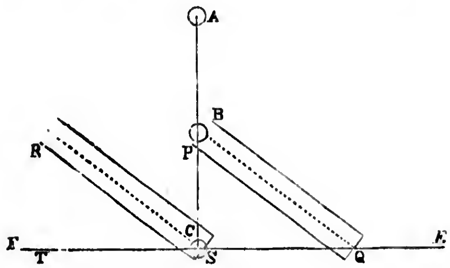
"The phenomena may also be imagined by considering that the earth, in revolving round the sun, constantly changes the direction of its motion; that direction making a complete revolution with the earth, it follows that the effect produced upon the apparent place of a distant object would be the same if that object really revolved once a year round its true place, in a circle whose plane would be parallel to that of the earth's orbit, and whose radius would subtend at the earth an angle of 20''.42, and the object would be always seen in such a circle 90° in advance of the earth's place in its orbit."

Since the subject is of great importance, we will also quote the explanation given by *Sir John Herschel.*

Outlines of Astronomy (page 210):

(328.) "Neither precession nor nutation change the apparent places of celestial objects *inter se.* We see them, so far as these causes go, *as they are,* though from a station more or less unstable, as we see distant land objects correctly formed, though appearing to rise and fall when viewed from the heaving deck of a ship in the act of pitching and rolling. But there is an optical cause, independent of refraction or of perspective, which displaces them *one among the other,* and causes us to view the heavens under an aspect always, to a certain extent, false; and whose influence must be estimated and allowed for before we can obtain a precise knowledge of the place of any object. This "cause is what is called the aberration of light; a singular and surprising effect arising from this, that we occupy a station not at rest, but in rapid motion; and that the apparent directions of the rays of light are not the same to a spectator in motion as to one at rest. As the estimation of its effect belongs to uranography, we must explain it here, though, in so doing, we must anticipate some of the results to be detailed in subsequent chapters."

(329.) "Suppose a shower of rain to fall perpendicularly in a dead calm; a person exposed to the shower, who should stand quite still and upright, would receive the drops on his hat, which would thus shelter him; but if he ran forward in any direction, they would strike him in the face. The effect would be the same as if he remained still, and a wind should arise of the same velocity, and drift them against him. Suppose a ball let fall from a point A, above



a horizontal line EF, and at B were placed to receive it the open mouth of an inclined hollow tube PQ; if the tube were held immoveable, the ball would strike on its lower side; but if the tube were carried forward in the direction EF, with a velocity properly adjusted at every instant to that of the ball, while *preserving its inclination* to the horizon, so that when the ball in its natural descent reached C, the tube should have been carried into the position RS, it is evident that the ball would, throughout its whole de-

"scent, be found in the axis of the tube; and a spectator referring to the tube the motion of the ball, and carried along with the former unconscious of its motion, would fancy that the ball had been moving in the inclined direction RS of the tube's axis."

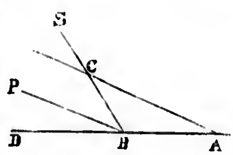
(330.). "Our eyes and telescopes are such tubes. In whatever manner we consider light, whether as an advancing wave in a motionless ether, or a shower of atoms traversing space (provided that in both cases we regard it as absolutely incapable of suffering resistance or corporeal obstruction from the particles of transparent media traversed by it*), if in the interval between the rays traversing the object glass of the one or the cornea of the other (*at which moment* they acquire that convergence which directs them to a certain point *in fixed space*), and their arrival at their focus, the cross wires of the one or the retina of the other be slipped aside, the point of convergence (which remains unchanged) will no longer correspond to the intersection of the wires or the central point of our visual area. The object then will *appear* displaced; and the amount of the displacement is *aberration*."

(331.) "The earth is moving through space with a velocity of about 19 miles per second, in an elliptic path round the sun, and is therefore changing the direction of its motion at every instant. Light travels with a velocity of 192,000 miles per second, which, although much greater than that of the earth, is yet not *infinitely so*. Time is occupied by

* "This condition is indispensable. Without it we fall into all those difficulties which M. Doppler has so well pointed out in his paper on Aberration. If light itself, or the luminiferous ether, be corporeal, the condition insisted on amounts to a formal surrender of the dogma, either of the extension or of the impenetrability of matter; at least in the sense in which those terms have been hitherto used by metaphysicians. At the point to which science is arrived, probably few will be found disposed to mention either the one or the other."

"it in traversing any space, and in that time the earth describes a space which is to the former as 19 to 192,000, or as the tangent of 20″.5 to radius. Suppose now APS, to represent a ray of light from a star at A, and let the tube PQ be that of a telescope so inclined forward that the focus *formed* by its object glass shall be received upon its cross wire, it is evident from what has been said, that the inclination of the tube must be such as to make PS: SQ: : velocity of light: velocity of the earth : : 1 : tan. 20″.5; and, therefore, the angle SPQ, or PSR, by which the axis of the telescope must deviate from the true direction of the stars, must be 20″.5."

(332.) "A similar reasoning will hold good when the direction of the earth's motion is not perpendicular to the visual ray. If SB be the true direction of the visual ray, and AC the position in which the telescope requires to be held in the apparent direction, we must still have the proportion BC: BA: : velocity of light: velocity of the earth : : radius: sine of 20″.5 (for in such small angles it matters not whether we use the sines or tangents). But we have also, by trigonometry, BC: BA: : sine of BAC: sine of ACB, or CBP, which last is the apparent displacement caused by aberration. Thus it appears that the sine of the aberration, or (since the angle is extremely small) the aberration itself, is proportional to the sine of the angle made by the earth's motion in space with the visual ray, and is, therefore, a maximum when the line of sight is perpendicular to the direction of the earth's motion."



(333.) "The uranographical effect of aberration, then is to distort the aspect of the heavens, causing all the stars to crowd, as it were, directly towards that point in the heavens which is the vanishing point of all lines parallel to that in "which the earth is for the moment moving. As the earth moves round the sun in the plane of the ecliptic, this point must lie in that plane, 90° in advance of the earth's longitude, or 90° *behind* the sun's, and shifts, of course, continually, describing the circumference of the ecliptic in a year. It is easy to demonstrate that the effect on each particular star will be to make it apparently describe a small ellipse in the heavens, having for its centre the point in which the star would be seen if the earth were at rest."

(334.) "Aberration, then, affects the apparent right ascensions and declinations of all the stars, and that by quantities easily calculable. The formulæ most convenient for that purpose, and which, systematically embracing at the same time the corrections for precession and nutation, enable the observer, with the utmost readiness, to disencumber his observations of right ascension and declination of their influence, have been constructed by Professor Bessel, and tabulated in the appendix to the first volume of the *Transactions of the Astronomical Society*, where they will be found accompanied with an extensive catalogue of the places, for 1830, of the principal fixed stars, one of the most useful and best arranged works of the kind which has ever appeared."

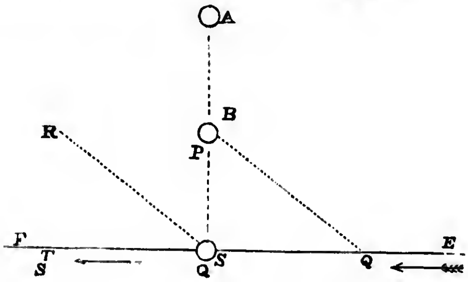
(335.) "When the body from which the visual ray emanates is itself in motion, an effect arises which is not, properly speaking, aberration, though it is usually treated under that head in astronomical books, and indeed confounded with it, to the production of some confusion in the mind of the student. The effect in question (which is independent of any theoretical views respecting the nature of light) may be explained as follows. The ray by which we see any object is not that which it emits at the moment we look at it, but that which it *did* emit some time before, viz., the time occupied by light in traversing the interval which separates it from us. The aberration of such a body then "arising from the earth's velocity must be applied as a correction, not to the line joining the earth's place at the moment of observation with that occupied by the body *at the same moment*, but at that antecedent instant when the ray quitted it. Hence it is easy to derive the rule given by ast· .omical writers for the case of a moving object. *From the known laws of its motion and the earth's calculate its apparent or relative angular motion in the time taken by light to traverse its distance from the earth. This is the total amount of its apparent misplacement.* Its effect is to displace the body observed in a direction contrary to its apparent motion in the heavens. And it is a compound of aggregate effect consisting of two parts, one of which is the aberration, properly so called, resulting from the composition of the earth's motion with that of light; the other being what is not inaptly termed the *equation of light*, being the allowance to be made for the *time* occupied by the light in traversing a variable space."

The last section brings in a division of the subject not immediately under consideration, but it is given here to complete the explanation by Herschel, and also as belonging to the general theory of (the so-called) aberration of light.

The explanation and illustration by Lardner are included in those of Herschel; it will, therefore, suffice to take the latter here for preliminary consideration. The definition of the meaning is by inference from analogy, and the first illustration is that of the shower of rain. The simple statement of fact, herein made, appeals to the experience of every individual, and, as it is not at once contradicted by that experience, it may be termed plausible; but upon more careful consideration, it will appear, in respect to the application to be made and the inference intended to be drawn from it, that the statement is not supported by fact. It is true that if a person runs rapidly in a shower of rain, a drop of the water may come in contact with his face, which would not have done so had he stood still; but it is surely evident that the angle at which the drop of water descended (or the angle at which it rains) cannot have been altered by the person's running, and *this* is the question at issue. A drop of rain will occupy a certain time in descending through a space equal to the distance from the upper part of a man's forehead to his chin; and if, during the time of that descent, a man running brings his face in contact with the drop, the effect is of the same kind as if the drop had been suspended at that height from the ground at which it comes in contact with his face. The additional supposition of the wind increasing the effect is, in regard to the rain only, not open to the same objection, because therein would be an actual cause operating to alter (increase or decrease) the angularity of the rain's descent; the effect of the wind's force would combine with that of the force of gravitation, and result in a compound effect; but in regard to the analogy, the supposition is entirely false and inapplicable, because there are no grounds for supposing that wind can divert or affect a ray of light; on the contrary, it is quite established that the fact is the reverse: the most violent hurricane does not cause a ray of light to deviate in the slightest degree from its direction or angle of incidence.

The illustration of the inclined tube, as shown, is not altogether incorrect, but as an analogy it is very imperfect and objectionable; and as an explanation, very likely to mislead the student. Taking the same figure, we will apply it, in the first instance, as follows (supposing the inclined tube to be left out of the figure): ESF represents a plane moving horizontally with a certain velocity in the direction EF. At P, in the perpendicular line APS, is a ball falling vertically from A, towards S; the propor-

Fig. 6.



tional velocity of the moving plane EF to that of the falling ball is such, that a place on the plane will move from Q to S, in the same time that the ball falls, from P to S; consequently, the ball P will fall upon the place Q. At the same time the place S will have moved towards F, and when P (the ball) arrives at S (or Q), S will have arrived at T; ST being equal to QS. The interposition of the tube, in fact, alters nothing; but it apparently complicates the otherwise simple case—which is, that the ball falls vertically and strikes the plane at right angles to its position and motion: just the same as if the plane had remained at rest, and the ball had been allowed to fall from a place at the same height vertically over Q.

The analogy of the falling ball to light emitted from a luminous body is very imperfect, because, whereas the ball can only fall vertically or in some one angular direction, the rays of light from the luminous body are emitted, in every angular direction, in radiant lines from the body as a centre. The conditions of the case are, therefore, essentially different from those of a ball falling vertically; whatever distance is assumed for A (supposing it a star), rays of light from it will be continually arriving at the earth in angular directions, dependent upon its situation relatively to the place upon which the ray is incident, and whenever the earth, moving in the direction EF, arrives at Q, it will evidently meet rays of light which have just arrived from the star.* By the illustration, the ball falls vertically upon the moving plane; now, supposing the ball is made to descend at a definite angle, as, for instance, through the tube PQ, it would strike or come in contact with the plane at its angle of descent (*i.e.* PQS), not, however, at the place Q; for, supposing the plane to be in motion, and Q to have been at the base of the tube when the ball commenced to descend, Q during the descent will have moved to S, and another place on the moving plane will receive the ball; but this does not alter the angle of incidence of the ball or of the light.

The correctness of this theory (aberration of light) may be tested by the illustration of the method of determining the sun's parallax (as given in *Herschel's Astronomy*, Fig. art. 355). We will suppose the earth to be moving in its orbit in the direction of the arrows; the effect of the aberration of light (if real) would be, as explained in the preceding quotations, to shift the apparent place of the sun from S to (some place) T. Consequently, if the

* We are here adopting, for the moment, the language of the theory, in order to meet the argument on its own ground: in a strictly scientific sense the expression is objectionable.

zeniths of the places of observation were determined independently of the sun's apparent place, the effect would be to give a different parallax for the two places; that of BTC being greater than ATC; but the zeniths of the two places of observation must be determined independently of the observed place of the sun, for otherwise there could be no parallax; the effect must be therefore to increase the actual parallax—*i.e.* the total apparent displacement—by the distortion due to

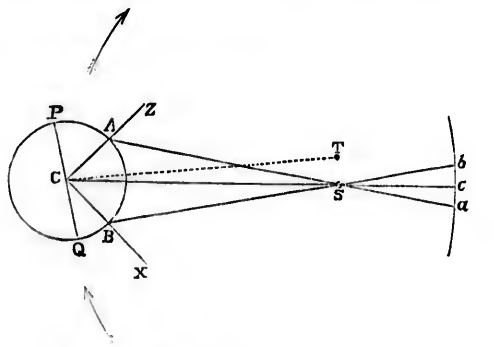


Fig. 7.

aberration. Now the parallax obtained by this geocentric method is 8″ 6; and the supposed displacement attributed to aberration is 20″.5.

If now, leaving the case for particular examination in the next chapter, we discard for the moment the supposed aberration of light as altogether imaginary; and, then, we assume those observed effects which have been attributed by astronomers to aberration of light to be really the effects of parallax, can we thus (from the total amount of parallax) obtain an approximate measure of the distance of the visible stars? The quotation already given from Herschel's work shows that the efforts of astronomers to obtain even such approximate measurement have been entirely unsuccessful. These attempts were made by heliocentric or annual parallax, in which the distance of the earth from the sun serves for the base line of the triangle. But this heliocentric parallax (as a trigonometrical process) differs essentially from the geocentric; nor is it anywhere explained how the apparently great, if not insurmountable, difficulty of thus directly obtaining the parallax of a star, even if the distance was less than the distance of the sun, has been overcome. It is evident that knowledge as to the distance of a body is obtained in the geocentric method by the two observations from places, at a definite and known distance from each other on the earth, being made at the same time; but to obtain parallax by the heliocentric method, it is impossible for two observers to be stationed at different and distant places in the earth's orbit at the same time, and therefore the method differs essentially from the geocentric. It is true an observation can be made from the earth at one extremity, or at any place in the orbit, and subsequently a second observation can be made from the opposite extremity or from some other distant place in the orbit; and the two observations may be compared; but does it follow, or is it to be expected that the same result as by the geocentric method, or, indeed, that any (reliable) result can be in this manner obtained? If some of the stars moved with a known velocity, and others were comparatively motionless, it is not difficult to understand that observations of them would have a differential value from which further knowledge might be obtained. But as all the stars are relatively (almost) motionless, it does not immediately appear where the standard of comparison is to be found, or whence the differential angle to be obtained upon which to base the computation. The apparent motion of all the stars (supposing the distance of them all to be very great) is necessarily nearly the same. An essentially distinct basis for the computation has, therefore, to be sought, and may be found in observing the relative positions of the sun and the star to that of the earth when the earth is at some definite place in its orbit, as for example, the central place equally distant from two definite extremities of the orbit; and then when the earth has arrived at a distant part of the orbit, observing the alteration in the relative angular position of the earth and sun, and the earth and star, respectively.

In this manner the helio-centric parallax of the star may be obtained; and, as we will presently show, by a modification of the same method two definite comparative angles may be obtained proportional to each other in the same ratio as the distance of the star from the sun is to the distance of the earth from the sun. Since the last is a known quantity, the distance of the star may be thus measured.

The collective parallactic result of the earth's progressive change of position throughout a complete revolution known by the term annual parallax is thus described by Dr. Lardner:—

Lardner's Handbook of Astronomy:

(2442.) "*Annual parallax.*—If the earth be admitted to move annually round the sun, as a stationary centre in a circle whose diameter must have the vast magnitude of 200 millions of miles, all observers placed upon the earth, seeing distant objects from points of view so extremely distant one from the other as are opposite extremities of the same diameter of such a circle, must necessarily, as might be supposed, see these objects in very different directions.

"To comprehend the effect which might be expected to be produced upon the apparent place of a distant object by such a motion, let $E\ \dot{E}\ \ddot{E}\ \dddot{E}$ (fig. 718) represent the earth's annual course round the sun as seen in perspective, and let O be any distant object visible from the earth. The extremity E of the line EO, which is the visual direction of the object, being carried with the earth round the circle $E\ \dot{E}\ \ddot{E}\ \dddot{E}$ will annually describe a cone of which the base is the path of the earth, and the vertex is the place of the object O. While the earth moves round the circle $E\ \ddot{E}$, the line of visual direction would, therefore, have a corresponding motion, and the apparent place of the object would be successively changed with the change of direction of this line. If the object be imagined to be projected by the eye upon the firmament, it would trace upon it a path $o\ o'\ o''\ o'''$, which would be circular or elliptical, according to the direction of the object. When the earth is at E, the object would be seen at o; and when the earth is at $\ddot{E}$, it would be seen at o''. The extent of this apparent displacement of

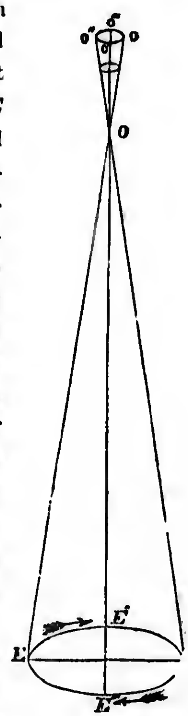


Fig. L. 718.

"the object would be measured by the angle $E\,O\,\ddot{E}$, which the diameter $E\,\ddot{E}$ of the earth's path or orbit would subtend at the object O. It has been stated that, in general, the apparent displacement of a distant visible object, produced by any change in the station from which it is viewed, is called *parallax*. That which is produced by the change of position due to the diurnal motion of the earth being called *diurnal parallax*, the corresponding displacement due to the annual motion of the earth is called *annual parallax*."

The general conclusion come to is the same as that expressed in the quotation previously given from Herschel's work: namely, that no parallax of any of the stars has been obtained in this way. On careful examination, however, it will appear that all the parallax observations in recent times have been made with a foregone conclusion that no parallax was attainable; or that, if any was attainable, it must necessarily be an extremely small amount, not exceeding, at the utmost, the sine of 1″. The consequence seems to have been that any quantity of parallax obtained exceeding this 1″ has been set down to aberration of light, or to error.

The *Encyclopedia Britannica*—art. *Astronomy:*

"Suppose, for example, we observe a star situated in the plane of the ecliptic. When the earth is at that point of its orbit, between the sun and the star, where the tangent to the orbit is perpendicular to the visual ray (which, on account that the star has no sensible parallax, always maintains a parallel direction), the apparent place of the star will be 20″.4 to the westward of the true place; so that it will appear to have an oscillatory motion on the ecliptic, the range of which is 40″.8, and the period exactly a year. Half way between these two points, the tangent of the orbit

"is parallel to the direction of the ray of light, and consequently there is no aberration. When the star is not situated in the ecliptic, it will suffer a displacement in latitude as well as in longitude. To render this more intelligible, let *E E E* (fig. 28) be the ecliptic; *E*, the earth; and *A*, the true place of a star situated at any altitude above the ecliptic. In the direction *EA*, take *Ea* to represent the velocity of light; *a b*, that of the earth, and in a parallel direction, that is, parallel to the tangent to the ecliptic at *E;* the line *Eb* will now be the apparent visual ray, and the star will seem to be situated at *B*. Suppose the earth to be placed at different points of its orbit; the lines *Ea* will be all parallel to each other, on account of the infinite distance of the star *A;* the lines *a b* will vary little in magnitude, because they are very small in comparison to *Ea*, but their directions will undergo every possible change, being parallel to the tangent at *E*. At the two points of the orbit where the tangent is parallel to *EA*, the two lines *Ea* and *a b* coincide, and consequently there is no aberration. Let us next suppose the star to be situated in the pole of the ecliptic. In this case the visual ray is constantly perpendicular to the direction of the earth's motion, so that the star will always appear at a distance of 20″.4 from its true place, or appear to describe a small circle about the pole of the ecliptic. In all other situations, out of the ecliptic, the star's apparent path will be an ellipse, the major axis of which, parallel to the plane of the ecliptic is always 40″.8, while the minor axis varies as the sine of the latitude."

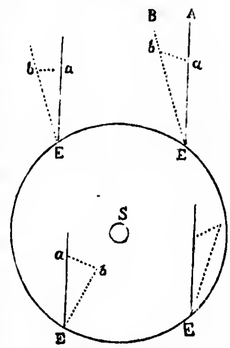


Fig. E. B. 28.

Lardner's Handbook of Astronomy, page 179:

(2447) "*Close resemblance of the effects of Parallax to Aberration.*—Now, it will be apparent that such phenomena bear a very close resemblance to those of aberration already described. In both the stars appear to move annually in small circles when situate 90° from the ecliptic; in both they appear to move in small ellipses between that position and the ecliptic; in both the eccentricities of the ellipses increase in approaching the ecliptic; and in both the ellipses flatten into their transverse axis when the object is actually in the ecliptic."

(2448. "Yet, aberration cannot arise from parallax.—Notwithstanding this close correspondence, the phenomena of aberration are utterly incompatible with the effects of annual parallax. The apparent displacement produced by aberration is always in the direction of the earth's motion; that is to say, in the direction of the tangent to the earth's orbit at the point where the earth happens to be placed. The apparent displacement due to parallax would, on the contrary, be in the direction of the line joining the earth and sun. The apparent axis of the ellipse or diameter of the circle of aberration is exactly the same, that is 20″.42,* for all the stars; while the apparent axis of the ellipse or

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* In the preceding quotation from the *Encyc. Britann.*, this quantity is correctly stated as 40″.8; the writer of the art. therein realizes that the supposed effect would, in the case of an equatorial star, manifest itself not as an ellipse, but as a linear displacement; the star appearing to have a reciprocating motion backwards and forwards through 40″.8. Surely the fundamental fallacy in the theory becomes here very evident, namely, that such an optical effect cannot take place unless there be an angular alteration in the relative position of the star and the observer; whereas, if there be any such alteration in their relative positions, the effect is due to parallax and not to aberration.

diameter of the circle, due to annual parallax, would be different for stars at different distances, and would vary, in fact, in the inverse ratio of the distance of the star, and could not, therefore, be the same for all stars whatever, except on the supposition that all stars are at the same distance from the solar system, a supposition that cannot be entertained."

But the illustration *L*, Fig. 718 of page 64, taken from Lardner's own work, will show that the observed effect of aberration, as described in the Encyclopedia, amounting to 20″.4, is precisely of that kind which would be occasioned by parallax.

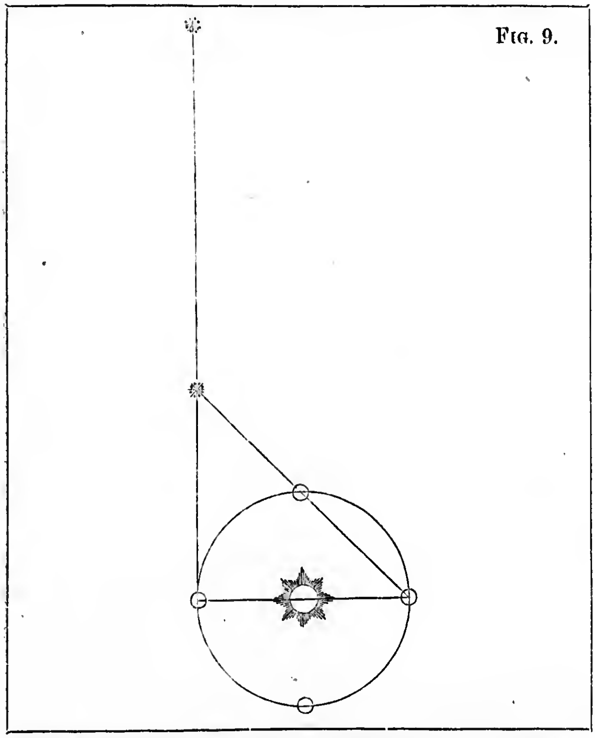
(8) *A Direct Method of obtaining Parallax of the Distant Stars.*

Let us now, resuming the assumption, tentatively, that the theory of the aberration of light is not based on fact and consequently untenable, consider the amount 20″.4, attributed to aberration, as an approximation to the average or mean parallax of a great number of the visible stars; and, with this suppositious quantity as datum, compute, by the direct method of heliocentric parallax, the average distance of those stars from the sun. The modification of the method which appears to us the most simple and advantageous is illustrated in fig. 9. Supposing the star to be in the equatorial plane of the sun at a distance from the earth equal to the diameter of the earth's orbit, the lines of junction would evidently form an angle of 45 degrees (the earth having moved from one extremity of the orbit to the other).

We obtain, therefrom, the proportion:—

As 45° : 20″.4 : : distance of the star: 190 million miles. Consequently 90,529,518 million miles, or about 953,000 times the distance of the sun from the earth, is the quantity which, subject to the supposition, thus represents the average or mean distance of the stars.

Fig. 9.



Note.—If the star be vertically above the earth, the same method will apply; but in that case, for correct application thereof, the successive observations of the relative angular position of the star must be made *only at each of the nodes...* that is, when the earth, in its ascent and descent, is passing and repassing through the equatorial plane of the sun.

CHAPTER III.

THE ABERRATION-OF-LIGHT THEORY.

We have already in the preceding chapter, page 50 to 57, put before the reader the particulars of the theory of aberration as stated and explained in the works of Dr. Lardner and Sir John Herschel. We have also in the same chapter stated certain preliminary objections to the theory.

It is, in the first place, desirable to show, as far as can be done, that the theory (of aberration) *on its own ground* is irreconcileable with the observed facts of astronomy. But, now, the very circumstance which should, as we think, have prevented the adoption of this theory, constitutes a difficulty in the way of demonstrating its unreality.

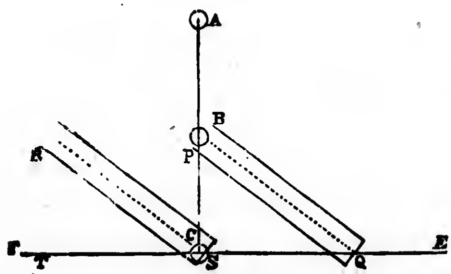
(9.) *The Conditions and Requisitions of the Theory.*

That circumstance is the absence of any actual fact or evidence upon which the theory is even presumably based. The theory is wholly suppositious. It is an inference from a supposed analogy; and is applied to cases which in the great majority of instances cannot be brought to the direct test of fact. Some instances, however, where such a practical test can be applied, we shall presently bring under consideration. Before doing so, in order that the reader may have the conditions of the theory distinctly in mind we will briefly take again the exposition and illustration of the theory, already quoted in Chapter II., (page 39), from *Herschel's Outlines of Astronomy :*

"This cause is what is called the aberration of light; a singular and surprising effect arising from this, that we "occupy a station not at rest, but in rapid motion, and that the apparent directions of the rays of light are not the same to a spectator in motion as to one at rest."

"Suppose a shower of rain to fall perpendicularly in a dead calm; a person exposed to the shower, who should stand quite still and upright, would receive the drops on his hat which would thus shelter him; but if he ran forward in any direction, they would strike him in the face. The effect would be the same if he remained still, and a wind should arise of the same velocity, and drift them against him."

Suppose a ball let fall from a point A, above a horizontal line E F, and at B, were placed to receive it the open mouth of an inclined hollow tube P Q; if the tube were held immoveable, the ball would strike on its lower side; but if the tube were carried forward in the direc-



tion E F, with a velocity properly adjusted at every instant to that of the ball, while *preserving its inclination* to the horizon, so that when the ball in its natural descent reached C, the tube should have been carried into the position R S, it is evident, that the ball would throughout its whole descent be found in the axis of the tube; and a spectator referring to the tube the motion of the ball, and carried along with the former unconscious of its motion, would fancy that the ball had been moving in the inclined direction R S of the tube's axis."

(10.) *Practical Application of the Theory.*

Let us now, taking this explanation, test it by application to the actual phenomena of the stellar universe. Fig. 11 shows the sun occupying the central place, the earth's orbit and four stars named respectively Alpha, Beta, Gamma, and Delta, which belong to the distant constellations and are in the plane of the sun's equator; and which are so situated, relatively to each other, that a line passing through the centre of the sun and joining either two of those opposite to each other, is at right angles to a line passing also through the centre of the sun and joining the other two. The actual places of the four stars are denoted by the letters a, a', a'', a'''. We will suppose the earth to be at m, at the eastern extremity of its orbit, and to proceed in its orbital path around the sun. An astronomer, on or near the earth's equator (the earth being at the place m in its orbit,) observes each of the four stars and compares their apparent places relatively to each other.* Now their *actual* places are, as already stated, those denoted by the letters a, a', a'', a'''; but where will their *apparent* places be, according to the theory of aberration as explained in the foregoing quotation from Herschel's Outlines? The observer first looks towards Alpha.... Since he is moving directly

* Evidently he could not observe these stars all at the same time of the day, although he could do so at different times of the same day. It is meant that he determine the longitude of each star successively, when the earth is at or near the place indicated.

towards that star, there is, by the theory, no aberration, and he sees it in its actual place at *a*. He next observes Beta. . . .Since the earth's motion (of about 19 miles a second) is at right angles to a line joining that star and the sun, the aberration is, according to the theory, here effective to the fullest extent; and, instead of seeing Beta at *a'*, he sees it at *c'*. He next turns to Gamma. . . .And since he is moving directly away from that star, he sees it in its true place at *a''*. Lastly, he looks at the star Delta,. . . .here again aberration is fully effective, and he sees Delta not at *a'''*, but at *b'''*. We now suppose the earth to have proceeded to the northern extremity of its orbit, at *n*; and the astronomer repeats his observations of the four stars successively. By the theory of aberration (Herschel's foregoing explanation) he will find that each one of the four stars has moved to another place; for he is now passing Alpha at right angles to a line joining that star and the sun, and therefore, by the theory, he sees Alpha at *b*. And he is moving directly towards Beta, which he now sees in its true place at *a'* . . . .Similarly Gamma has moved its apparent place from *a''*, to *c''*, and Delta has retired to its true place at *a'''*. The earth proceeds, and arrives at the western extremity of its orbit at *o*. The astronomer renews his observations. . . .The aberration theory tells us where he will find each of the four stars—namely, Alpha will have gone back to *a*. . . .Beta, which was at the time of the first observation at *c'* and at the second observation had moved to *a'*, will now be found at *b'* . . . And similarly of the others, Gamma will be found at *a''* and Delta which was first at *b'''* and then at *a'''* is now at *c'''*. Lastly, the earth having arrived at the southern extremity of the orbit, the observer finds that each star has again shifted its place . . . Alpha must now be seen at *c*; Beta at '*a*; Gamma has gone to *b*″; and Delta back again to *a*‴.

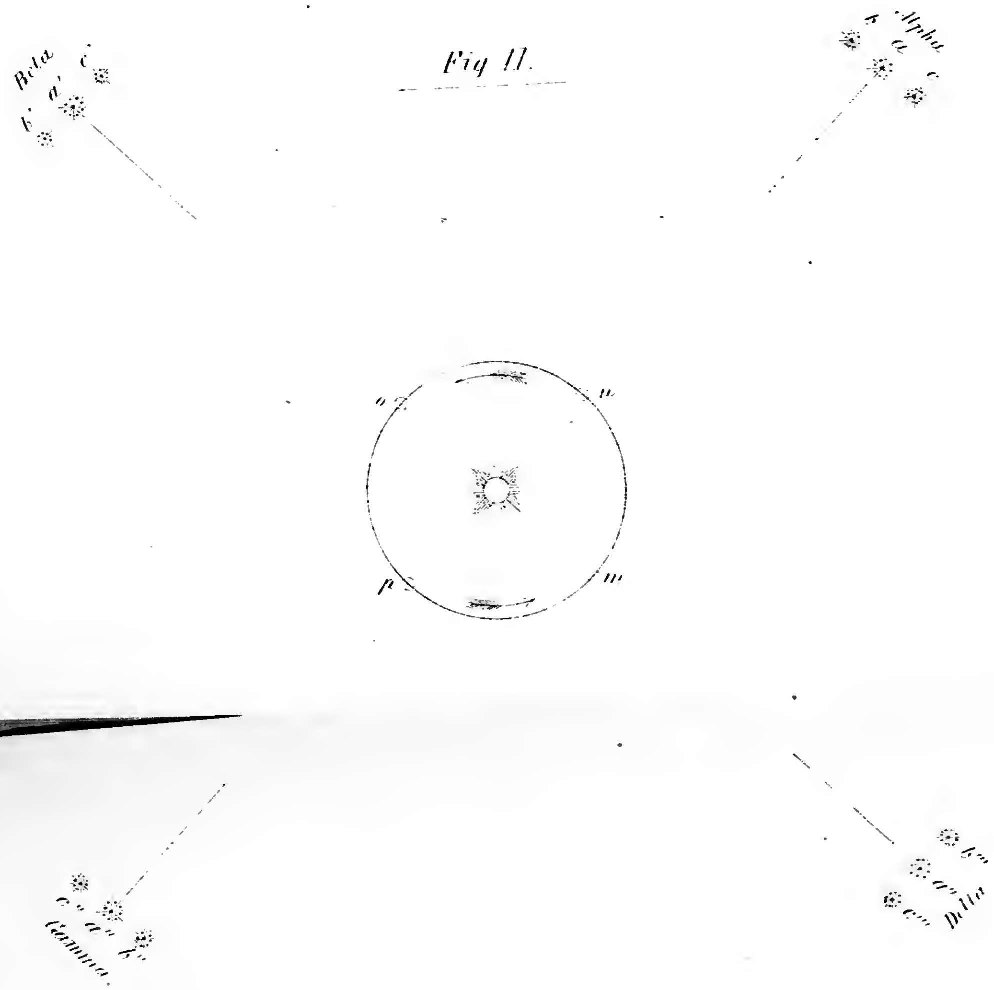
Here then is the statement of a case as to which the practical astronomer may be called upon for evidence. How stand the facts of observation? for this is simply a question as to the places at which the observer sees the stars. Do the facts of observation support the aberration-theory? Do the constellations in or near to the solar equatorial plane thus continually, independently of any parallax (which is quite distinct from the question here at issue,) shift their positions backwards and forwards relatively to each other, as the earth progresses in its orbit; at one time approaching nearer to each other, and again receding from each other; each of them shifting its place throughout an arc * of 40″. Let the practical astronomer give evidence in the case. Take four constellations situated, relatively to each other, as we have supposed; such, for example, as Gemini, Pisces, Sagittarius, and Virgo. Any one star in each of these four constellations may be chosen to try the case. Cannot the question be decided by positive evidence, whether the imperative requisition of the aberration-theory (as stated by Herschel) is in this particular case fulfilled or not?

There is a corollary to the aberration-theory, or, at least, what, as it seems to us, must be a corollary if the theory has any substantiality or definite consistency in itself, which, if stated distinctly and directly, can scarcely fail to startle the practical optician. It is. . .that the angles

* The angle of aberration is 20″ 5, which has to be doubled because it is at first fully effective in the one direction and afterwards in the reverse.

Aberration
of Light

Fig 11.



of incidence and reflection are not always equal. For the angle of vision, or the angle under which the eye perceives the luminiferous body, cannot be otherwise than equal to the angle of reflection, and this angle of vision is not, according to the aberration-theory, the true angle of incidence if the station of the observer have a progressive motion in such a direction as to form with the direction of the luminiferous body an angle not much less or greater than a right angle. Therefore the angle of reflection from the earth of the solar-light must always differ from the true angle of incidence ?

(11) *The Nature of Light as assumed by the Theory.*

But the statement of this corollary brings again under notice the anomalous character and, indeed, contradictory nature of the qualities which are attributed to 'Light' accordingly as the exigencies of the one or the other of the three theories—the velocity, the aberration, and the undulatory, theories—require a decidedly material nature subject to the laws of matter, or a semi-material nature subject to some of those laws and exempt from others, to be assigned to the atoms or waves of 'light.'* It is, perhaps, in the exposition of the aberration-theory that the want of a definite and real foundation becomes most immediately manifest. Referring again to Sir John Herschel's explanation, we have the

* The meaning of the expression 'Light' has now become, in some measure, involved in the vague and indefinite meanings which belong in common to these theories. It sometimes means luminous particles or atoms of luminous matter travelling with incredible velocity....sometimes means the particles of a purely suppositious fluid, called Ether, vibrating with inconceivable rapidity...sometimes means an effect produced by impact of the luminous matter on the eye.........

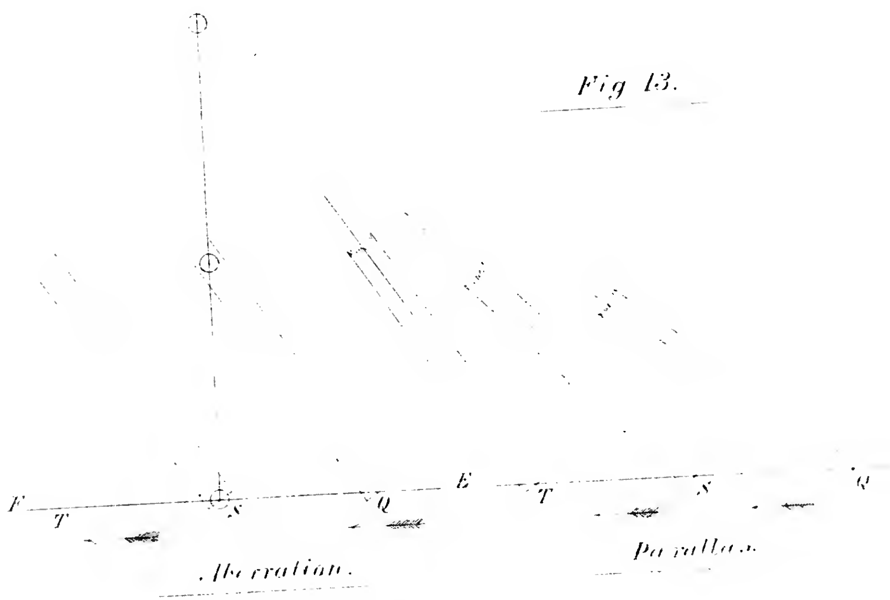
analogy of light to the shower of rain and to the falling ball, that is..to matter in the liquid and in the solid condition. Something called 'light' has motion and velocity, just as the earth moves in its orbit with a definite velocity....it enters the advanced end of the telescope tube, which is moving rapidly forwards, it is in the tube, moves through the tube, and, emerging from the posterior end, comes in contact with the eye of an observer, or with the ground; or, again, the observer, who is moving forward with the earth upon which he is stationed, strikes his eye against the descending ray of light, just as the person who running forward strikes his face against the falling rain..there is impact; the person whose eye receives the shock, which is a compounded result of the motion of the ray and of his own motion, infers the position of the luminiferous body from the compounded direction in which that shock is received, and hence is in a measure deceived or misled. The supposed analogy is here to *another form or kind of matter in motion.* The fundamental theory of light to which it belongs, appears to be the corpuscular theory of Sir Isaac Newton, in which extremely small particles of luminous matter are ejected from the luminiferous body and move in right lines with enormous velocity, rather than the undulatory theory. At last we find men the most experienced, eminent and distinguished in the sciences of astronomy and optics, as Sir John Herschel, in order to reconcile these theories of light with the actual and known facts of the phenomena, endeavouring to suppose the existence of a description of matter from which all the properties and qualities of matter are absent. The note to the 'Outlines of Astronomy,' in which Herschel adopts and endorses the doctrine of M. Doppler on this subjecct, and which we have already quoted (page 54), will serve to exemplify this strange hypothesis of an immaterial description of matter. "This condition is indispensable. Without it we fall into all those difficulties which M. Doppler has so well pointed out in his paper on Aberration. If light itself, or the luminiferous ether, be corporeal, the condition insisted on amounts to a formal surrender of the dogma, either of the extension or the impenetrability of matter; at least in the sense in which these terms have been hitherto used by metaphysicians. At the point to which science is probably arrived, few will be found disposed to mention either the one or the other."

This supposition of matter without any of the properties of matter seems to be precisely equivalent to supposing an animal without head, body, limbs, bones, flesh, or, in short, without any of those things which especially pertain to an animal. It is true there is, in the foregoing, a sort of saving proviso by Herschel, 'if light be corporeal,'—but then, if it be not corporeal, what becomes of the undulatory theory, what of the theory of aberration, and what of the velocity-theory of light? all of which are upheld by Herschel.

(12) *Aberration a Dynamical Theory.*

Let us return again to the astronomical theory; and submit to the astronomer the following case: We will suppose that the areal (absolute) velocities of the three planets, Venus, Earth, and Mars, are exactly equal, and that their angular velocities relatively to the Sun are so proportioned (by their respective distances from the Sun) that whilst the Earth is moving through an arc of six degrees, Venus moves through ten degrees, and Mars through only four. Now, taking the maximum angle of aberration at 20″ for the terrestrial observer, what will be the angle of aberration for the inhabitant of Venus and of Mars respectively? From Herschel's illustration of the inclined tube and falling ball, the angular velocity is that which must determine the angle of aberration; for, if the distance of the plane E. F., upon which the ball falls, from the starting point A. be doubled, and the plane, move with twice the linear velocity relatively to the point A., the same inclination from the perpendicular would still be given to the tube. To appreciate the whole case, it must be remembered that this illustration of the tube and ball illustrates the artificial idea upon which the aberration-theory is based only, and does not illustrate the case of an eye or of a telescope directed towards a body outside the Earth: if, for instance, a stationary object be supposed a few miles from the Earth which is moving, it is evident that the angular position of a telescope constantly directed towards the object would require to be constantly changed. Now in Herschel's illustration of tube and moving plane, the same inclination of the tube is preserved throughout the movement; therefore the illustration is defective, and it is also deceptive, because the theory of aberration itself and Herschel's own exposition of it, each expressly supposes (*see Fig.* 13) such an appreciable alteration in the relative position of the recipient body *which moves*, and the luminiferous body which *remains stationary*. The tube or telescope is always supposed to advance relatively to a perpendicular drawn vertically or horizontally, as the case may be, from the object to the plane beneath it; for the effect claimed, as stated by Herschel, is dependent upon and arises out of this motion of the plane relatively to the object at rest.

Fig 13.



Now, if the consideration of the case in this manner be pursued with attention, it will become evident that the theory of aberration *breaks down altogether;* because if the body move relatively to the perpendicular drawn from the object to the plane, the angular position of the telescope must be changed, for if it be not changed the successive rays of light cannot enter the tube; and, if the body has no such relative movement, there can be no effect such as claimed..but, if the angular position of the telescope requires to be changed, whether it be to increase or decrease the inclination* of the telescope, any optical effect necessitating such a change must belong to parallax. The especial point to which the attention should be directed, is that, if there be no appreciable alteration in the relative positions of the luminiferous body and the eye, so that the telescope having the same inclination, constantly receives light from the object at the same angle throughout the movement of the plane, there can be no appreciable aberration even if the possibility of the theory be admitted in other respects. And, if there be an appreciable alteration in the relative position, the effect must be parallax and in the reverse direction to that claimed for aberration. When the whole case is correctly apprehended, the utterly unreasonable character of the general result supposed becomes apparent; for, if a movement of the earth through only nineteen miles of orbit produces aberration, some proportional alteration in the relative angular position of the object and the

* As the telescope approaches or passes the perpendicular drawn from the object to the moving plane upon which the observer is stationed, parallax will require the inclination of the tube to be altered in the opposite direction to that which aberration would require.

eye must manifestly take place; and if the one effect be appreciable so must the other effect be also appreciable; but what, if instead of the plane moving nineteen miles, it move nineteen hundred or nineteen thousand, nay, nineteen million and even, a distance several times greater than nineteen million miles, and yet without any appreciable alteration in the relative angular position of the eye and the object? A claim of 1″ aberration for every 1″ angular alteration of position (parallax) might appear to be primarily reasonable until shown to be otherwise, but a claim of 20″ aberration and no appreciable alteration in the relative angular position is manifestly inadmissible. Even Herschel's own illustration evidences negatively that there cannot be any such effect; hence..

Note (a.) The theory of aberration is a dynamical theory in which the very meaning of the term motion, as a relative expression, seems to be imperfectly appreciated or misapprehended. One body moves relatively to another. A body moves with a certain velocity relatively to a standard of velocity. There is angular and linear velocity, and each of these is relative. It may be shown that if the earth relatively to the distant stars has no appreciable motion and no velocity such as contemplated by the theory, not even a suppositious case of aberration has been made out in respect to those stars.

(13) *Distrust in the Gift of Sight required by the Aberration Theory.*

Before leaving the theory of aberration—let us, referring to either of the illustrations we have given of the eclipses and occultations of Jupiter's satellites, once more briefly note what the student of astronomy is imperatively required by that theory to understand in respect to those phenomena.* It is..that he is not to suppose what he *appears to see* is actually taking place when and as he sees it, but that it is merely certain reflections of light, and interruptions and interferences with light, which have been occasioned by something which has happened about 35 minutes or 50 minutes previously, according to the place of the earth in its orbit at the moment of observation: for example, if he appears to see the satellite just entering the shadow, he is to believe that the satellite has really entered the shadow some forty or fifty minutes earlier, and, if it be the satellite nearest the planet, is already almost at the middle of the eclipse (or occultation.) But the shadowy messengers of light, belonging to the aberration-theory, have occupied all that time in bringing him the intelligence of what formerly happened; indeed, however, he has not yet sufficiently distrusted his eye-sight—this is only a general distortion and displacement of everything, which belongs of right to the velocity-of-light theory, aberration proper has not yet come into play, it has its functions to perform, and, seizing the shadowy record of the past event just as it reaches his eye, distorts it afresh by the angle of aberration proper, making it appear that the event, of which intelligence has at length arrived, happened at some place other than that at which it actually occurred.

We think the student, who has apprehended that this is the demand made upon his faith by these theories, which say to him..'put your confidence in us, distrust your eye-sight and beware lest it deceive you,' and who,

* This refers to our *Part Fifth* which has for its subject the undulatory and velocity theories of light.

then taking his telescope, reads *apparently*, not the record of the past event, but the event itself actually occurring as he watches the clear definition of each successive phase, will act reasonably if he listen attentively to the counter-claim made from within 'to put confidence in his eye-sight, to distrust the theories and beware lest *they* deceive him.'

Note (*b.*)—We suggest that an advantageous means of practically testing the truth of the Aberration-theory may be found in the observation of one of the lesser of Jupiter's Satellites.

Let the Earth be supposed (preferably) at a place in its orbit near to opposition; let the (apparent) moment of the satellite passing the centre of the planet during occultation be carefully determined from the ingress and egress: then, let the moment of passing the centre of the planet at the opposite extremity of the Satellite's orbit, namely, the central point of the transit; and, then, the central moment of the succeeding occultation be determined.

If there be truth in the theory of aberration there must necessarily be a distinct (apparent) difference between the two semi-revolutions; for, at the occultation both the Earth and the planet's satellite are moving in the same direction and there will be virtually no aberration; but at the transit, the Earth moving in one direction, the satellite moves in the reverse; and, consequently, the effect of aberration must be increased and should considerably exceed the 20″.5.

As the angle of aberration would be an addition to the one side and a deduction from the other, the difference between the two semi-revolutions would be more than 1′.

NOTE (c).—*On the question..whether a luminiferous and calcriferous body, in the absence of a recipient (or reciprocating) body, radiates light and heat continuously into space....**

How has it been ascertained that the sun radiates light into space, and in every direction alike? Gravitation is also an influence which is communicated from the sun to the planet, or is intercommunicated between them; and it may also be said to be emitted by the sun. Is, then, the sun supposed to emit or radiate gravitation into space? Or, is it only emitted in the direction in which there is an aggregated mass of matter, to receive and reciprocate that influence? If the latter, then, supposing we dismiss all foregone conclusion and prejudice, does it appear so certain that the influence which causes light may not be in the same case?"

We wish now, without introducing the case into our main argument, to point out that both the theories, of Aberration and Velocity of Light, are also dependent upon the assumption of the continuous radiation of light into space by the sun or other luminiferous body. We do not mean that the assumption affords any evidence or basis to support the theories but the theories require and are dependent upon the assumption. For, if the assumption be not true in fact, it will follow that, since, by each of the theories, the communication of light requires time (*i. e.* light has velocity) a star of which the distance from the earth exceeds a certain limited amount must be invisible from the earth. The earth travels in its orbit with a velocity (more than 1000 miles a minute) which will in about 8 minutes remove its entire bulk out of the space which it occupied at the commencement

* This question will come under consideration in our Part Fifth.

of that time. If, therefore, the luminiferous body be at such distance from the earth, that light (being assumed to have velocity) requires more than about 8 minutes to reach the earth, the body, during a great part of the earth's orbital revolution, would be invisible, because the rays if emitted towards the earth would be too late to arrive and would be projected into space or vacancy. But notwithstanding the enormous and incredible velocity assigned to light by the theory, a quarter of an hour would not nearly suffice for light to reach the earth from the very great majority of those stars which are *in fact visible*. In many cases the earth would have ample time, not only to get out of the way of the luminous matter, but to make one or more complete revolutions in its orbit, and might thus occasionally and accidentally (so to speak) return to its former place just when the rays were arriving.*

Now, is the assumption of continuous radiation into space established on certainty? Is it quite reliable, unassailable, and not open to any doubt whatever? Or is it itself an unproven theory, plausible, certainly, at a time when the known facts belonging to the subjects of light and radiant heat were comparatively few, but subject now to grave objection and doubt? Such grave objection and doubt respecting the assumption we, for ourselves, entertain. We remember the very reasonable objection taken by Sir D. Brewster to the undulatory theory of light † (*against the form* of which objection as irrever-

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* Sir John Herschel estimates the time, required by the light from some of the most distant (visible) stars to reach the earth at about 2000 years.

† Part Fifth (of this series).

ent we felt called upon to protest); an objection of the same character seems to us to apply with equal force to the case now under consideration. It does not seem reasonable, bearing in mind the properties and qualities of light and radiant heat, their great importance, and the grand and invaluable services rendered by them in the economy of nature...we say, it does not seem reasonable to suppose that a large proportion of the light and heat radiated goes to waste...is radiated and lost; yet such is the meaning of radiation into space. If there be a recipient, it is not difficult to understand that there need not be loss, the heat or light is received and (reciprocated) returned in the same or in some other (mode) condition of force. But radiation into space or vacancy means no return.*

There is besides, as noticed before, the kindred and analogous force of gravitation. Do masses of aggregated matter gravitate into space? No...... then why should it be positively concluded that they radiate into space?

(14) *Direct Heliocentric methods of obtaining Parallax of the distant Stars.*

Referring to the illustration in the preceding chapter, a correct method of computing the distance of the stars, ...we are strongly of opinion that the method there

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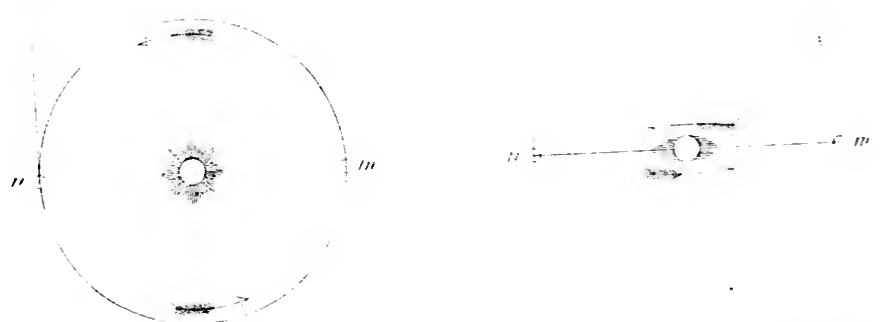
† We are mindful of Dr. Wells' theory of dew, but acceptance of this philosophical and felicitous explanation of the phenomena does not necessitate the supposition of radiation of heat into space from the surface of the earth......there are the stars in sufficient number to serve on a clear night as recipients, although we incline to the opinion that the escape of electricity, in some condition of force other than that of free caloric, into the atmosphere, causes that reduction of temperature on the surface of the earth which condenses the watery vapour.

indicated of ascertaining the parallax is not only practicable but is also the most simple and direct method.

Repeating the illustration of page 69, on the larger scale of Fig. 12 (A.).. The Earth may be supposed at any definite place *m.* in its orbit, at which place it is found by careful observation that a certain star in, or not far from, the solar equatorial plane, is so situated with respect to the sun that the vertical plane, joining the centre of the earth and sun, is at right angles to the vertical plane joining the centre of the earth and star. From the time of that observation, the Earth having made an orbital semi-revolution (exactly), the angle contained by the vertical planes is again determined by careful observation, and the difference between the two, *i.e.* the difference between the last angle and a right angle, is the parallax.

For ourselves, we are quite sure that aberration of light is a mere phantom of the imagination, but even those, who for the present are persuaded that human sight is deceived in that manner, will allow that aberration could not interfere with parallax ascertained by the method here proposed, for the earth would be at the time of the one observation directly receding from, and at the time of the other, directly approaching the star (or *vice versa)* and, therefore, by the theory there would be no aberration. Or, again, supposing the north polar zenith of the earth, when passing through the sun's equatorial plane, be accurately determined, and at the completion of a semi-orbital revolution of the earth the same place be found, the difference from a right angle with the sun's equatorial plane will be the parallax of the Pole-star; from which the approximate distance of the star

(A) (B)

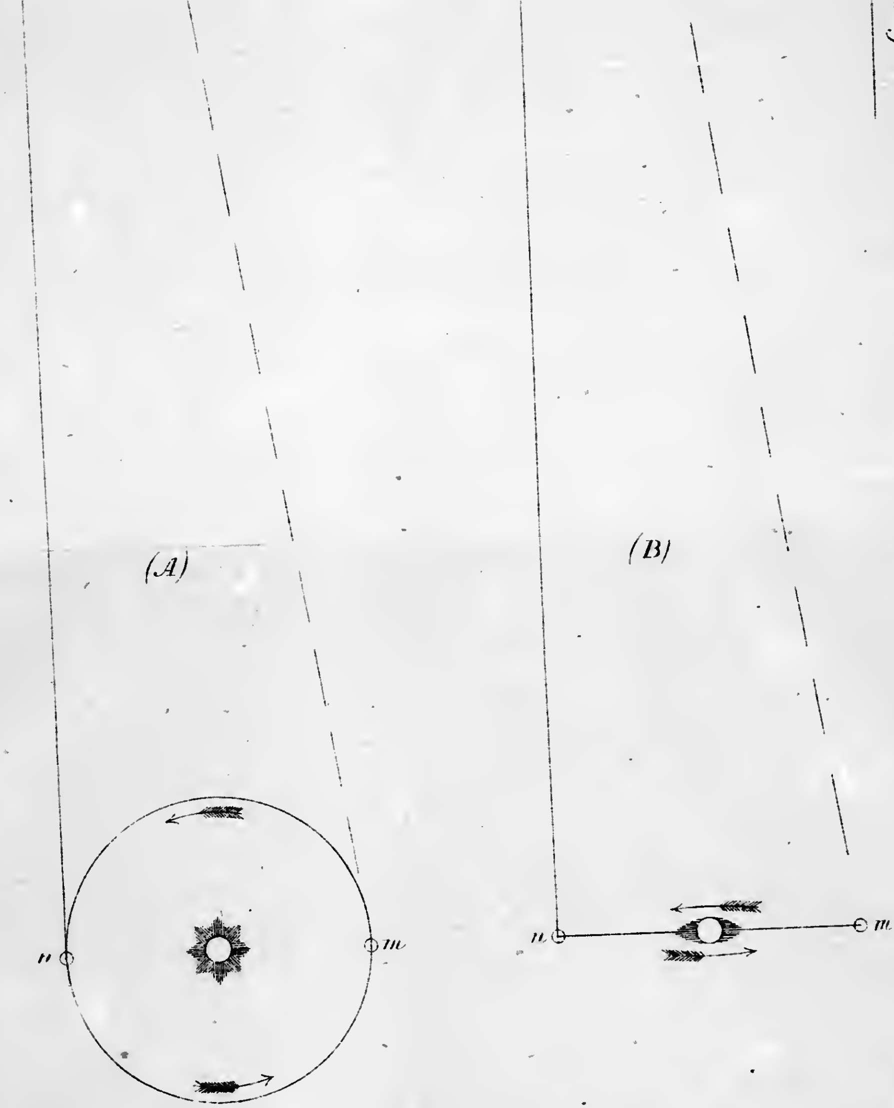


(A) The Star in the Plane of the Equator of the Heavens.

(B) The Star on the vertical Plane above the Earth's Pole

Parallax. — Fig 12.

Fig 12.



(A) The Star in the Plane of the Equator of the Heavens.

(B) The Star in the vertical Plane above the Earth's Pole.

would be readily obtainable by the simple computation shown at page 69.... *See Fig.* 12 (*B.*) In this case also, 'aberration' could not interfere; for by that theory its effect would be to shift the star's place backwards *in the vertical plane* joining the star and the earth, but it would not affect the angle formed by that plane and the solar equatorial plane. Whereas the parallax would be the deviation of the plane from a right angle in consequence of the removal of the earth to the opposite extremity of the orbit.*

(*Note.*—We have taken the right angle to render the illustration more clear, but, if the angle differed from a right angle, the difference between the first and second observation would still give the parallax; if, however, in the angle first observed the inclination be towards the sun, the star might be a truly solar pole-star, and in that case no parallax would be thus obtained because the angle would be the same from the opposite sides of the earth's orbit.)†

Another method, by which we opine the approximate parallax of the stars may be obtained, is by the comparison with each other of stars situated 90 degrees apart on or near to the celestial equator. Fig. 11 may serve well to illustrate this method. Suppose the station of the terrestrial observer to be at *p.* and let him note the actual and relative localities of the stars Delta and Alpha. At the expiration of six months his station having arrived at *n.* let him note again the actual and relative localities of the same two stars. Parallax will

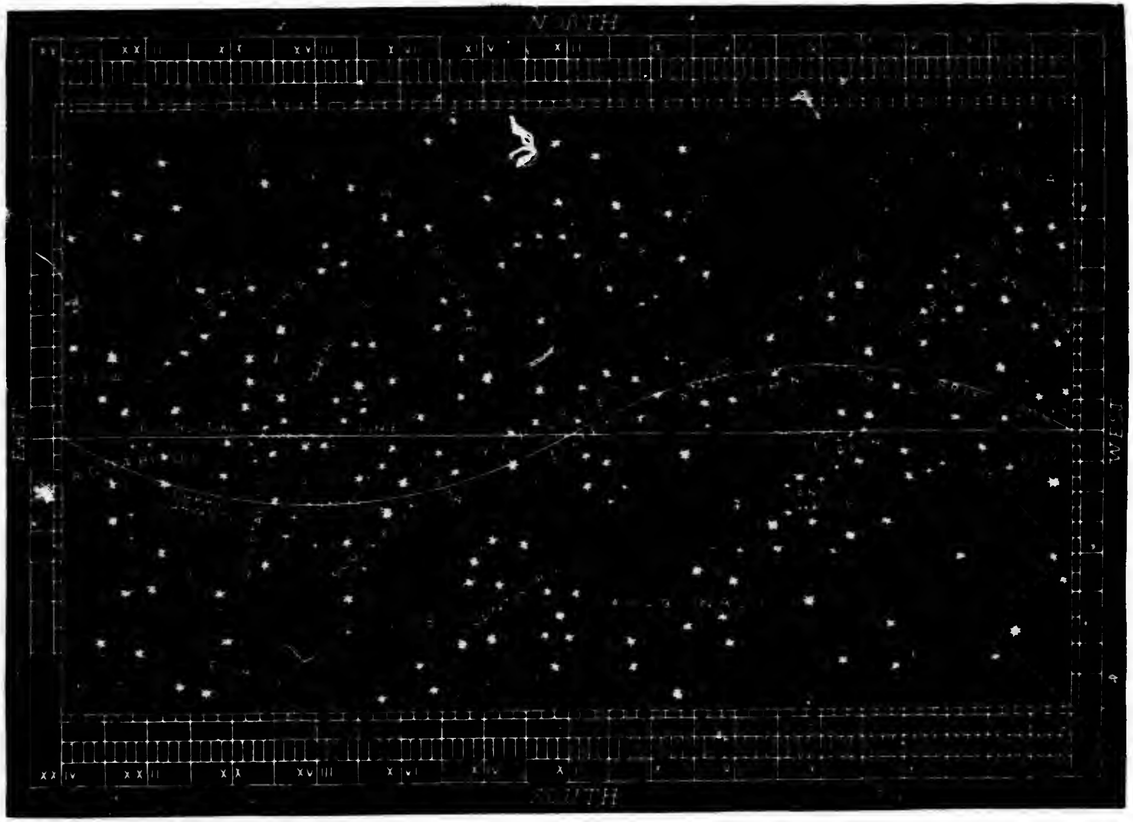
* Evidently the absolute right angle is not indispensable. Take Polaris, and, determining the exact deviation from a right angle with the equatorial plane when the earth is at the one node, then determine the increase or decrease in that deviation when the earth has arrived at the other node.

† We are in this example assuming that our demonstration of the perpendicular terrestrial axis of rotation, parallel to the solar axis, will necessarily be admitted, but, even otherwise, the method admits of modification accordingly.

have shifted the apparent place of Delta from b''' to c'' but the place of Alpha will have undergone no change, for the observer, on both occasions, sees Alpha at its actual place, viz., at *a*.

For many astronomical observations an observatory situated at one of the poles would be advantageous, and for the one observer to directly note the position of the two equatorial stars (Delta and Alpha) at the same time a station so situated would be necessary; indirectly, however, the one astronomer could, we opine, observe the locality of the star in the opposite longitude to his station (which station we suppose to be in the northern hemisphere) with perfect or almost perfect precision. It would be necessary to obtain the exact locality of the pole of the celestial sphere according to the perpendicular-axis theory; having obtained this he would observe the star Gamma when exactly on the meridian of his station, and then continuing the meridianal line through the place of the celestial pole, he would note one or more stars on the produced meridian which would be within the visible hemisphere when his station arrives in the opposite quarter (*i. e.*, when his station has revolved through $180''$). Evidently he might thus find the place of a star in the exactly opposite longitude to and in the same latitude as that of the star Gamma, which would be the place of Alpha. Supposing this method not to admit of sufficient precision in practice, the earth's diurnal rotation can be taken advantage of to observe the four stars successively, namely four stars, respectively situated in or near to the relative position we have indicated, are to be observed successively at each of the six hours; these observations being repeated on the second day would

PLATE XII. *Miniature Map of the Heavens, shewing the Milky Way.* (*From Dick's Astronomy.*)



furnish the data whereby the precise relative place (longitude) which each of the four stars would apparently occupy, if viewed simultaneously, could be determined.*

Our computation (at the conclusion of Chapter II,) shows for a parallax of 20″.5, a distance of the star proportionally about twice as great as the estimate given by Herschel for a parallax of 1″ only. † We will conclude these observations with the decided expression of opinion that, when correctly ascertained, the parallax for the nearer stars will be found to considerably exceed 20″. ‡

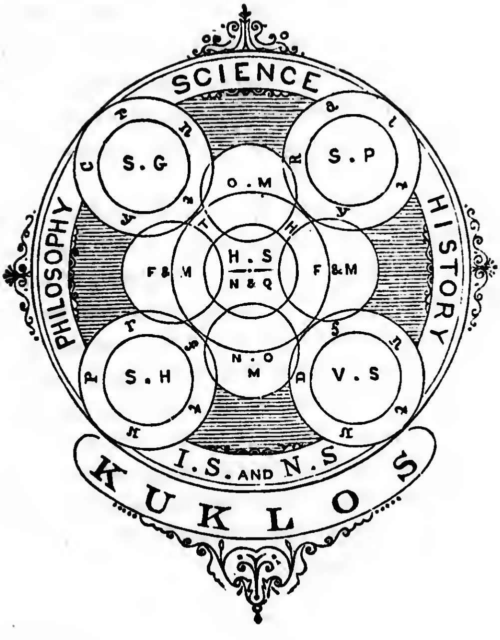
Note.—Referring to page 49—§ (814) of quotation from *Herschel's Outlines of Astronomy.*

" The paper on parallax by Lord Wrottesley, in Phil. Trans. for 1851, here referred to, furnishes, as it seems to us, very strong indirect evidence of the soundness of the perpendicular-axis theory. In consequence, according to our view, of the non-recognition of the earth's vertical motion, Lord Wrottesley finds unaccountable variations and apparent discrepancies in observations of the same stars made with great care at different times. Eventually he concludes to relinquish the attempt to obtain a decided parallax. . grounding his resolution to do so, if we apprehend aright, mainly on the apparently irregular and unsatisfactory character of the results actually obtained.

* This last is the method we have already supposed to be made use of in experimentally testing the reality of aberration by tri-monthly comparisons of the four equatorial stars.

† See quotation page 31, § (801).

‡ A helio-centric parallax of 1′ would be (of course) equivalent to about one-third of the distance represented by 20″.4, and, according to our computation, to about 600 times the distance of the planet Saturn from the Sun.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V.S
I.S. AND N.S
KUKLOS

SUPPLEMENTARY NOTE.

HELIOCENTRIC PARALLAX OF THE EARTH AND PLANETS.

The apparent path of the sun as it travels around the celestial sphere in the undulatory path of the ecliptic, may be considered as the effect of heliocentric parallax upon the sun itself (the parallax belonging to the horizontal motion of the earth being, in this instance, compounded with that belonging to its vertical motion: thus causing the oblique position of the circle of the sun's apparent path). For illustration of this refer to Plate 12, *Page* 88; or, to Plate, Fig. 20, of Part Second.

The earth being on the eastern side of its orbit and moving towards the west, the sun is seen on the western side of the celestial sphere and appears to move towards the east; the earth having moved to the southern side of its orbit, the sun is seen to the north; the earth having arrived at the western side of its orbit, the sun is seen on the eastern side of the celestial sphere. The sun thus appears to the terrestrial observer to move in the heavens from west to east, or from east to west, and so on.

Now if we suppose the distance of the sun from the earth to be increased 100 times or 1000 times, the parallactic angle would be thereby proportionally diminished, or, in other words, the apparent motion of the sun for the same actual movement of the earth would be reduced in proportion to the increase in the distance. We cannot, however, obtain directly by observation the parallax of the sun resulting from the movement of the earth through the diameter of its orbit, because, since the earth moves around the sun, the effect is thereby greatly increased and becomes continuous, manifesting itself as an apparent semi-revolution of the sun around the earth. But the geocentric parallax of the sun having been correctly ascertained and the magnitudinal relation of the diameter of the earth's orbit to the diameter of the earth itself being known, we possess the means of readily determining by calculatation the heliocentric parallax . . . 1st. of the Earth itself; 2nd. of each of the other planets; 3rd of any star at a definite known distance from the sun.

To do this we only require to imagine that the earth occupies at the same time two distinct places in its orbit, from one of which the terrestrial observer views the earth itself at a distance of 90°. The accompanying figure (Fig. 14) will make perfectly clear this hypothetical supposition, which as furnishing a basis for the comparison of the relative angles is not, we opine, open to objection.

* As 4000 : 190 *millions* : : 8″.6 : *tang. of* 45° ; therefore 45° is the h. c. parallax of the earth.

(This result is obvious because the semi-diameter of the earth's orbit equals the distance of the Sun, and the tangent of 45° equals the radius.)

° The geocentric parallax of the sun and the distance of the sun from the earth are immediately dependent each upon the other...... so that if the distance of the sun has been correctly ascertained to be a little more than 95 millions, it is certain that the geocentric parallax of the sun is 8″.6, and *vice versa.*

† By this method, therefore, we find that a star of which the parallax is ascertained to be 20″.4 would have a theoretical distance from the sun of about 1000 times the distance of Saturn, instead of 600 times, at which we have stated the estimate in the foot note to page 69.

Hence, since the relative distances of the planets from the sun are approximately known, we may at once derive the theoretical h. c. parallax of each planet from that of the earth, Thus: Taking †

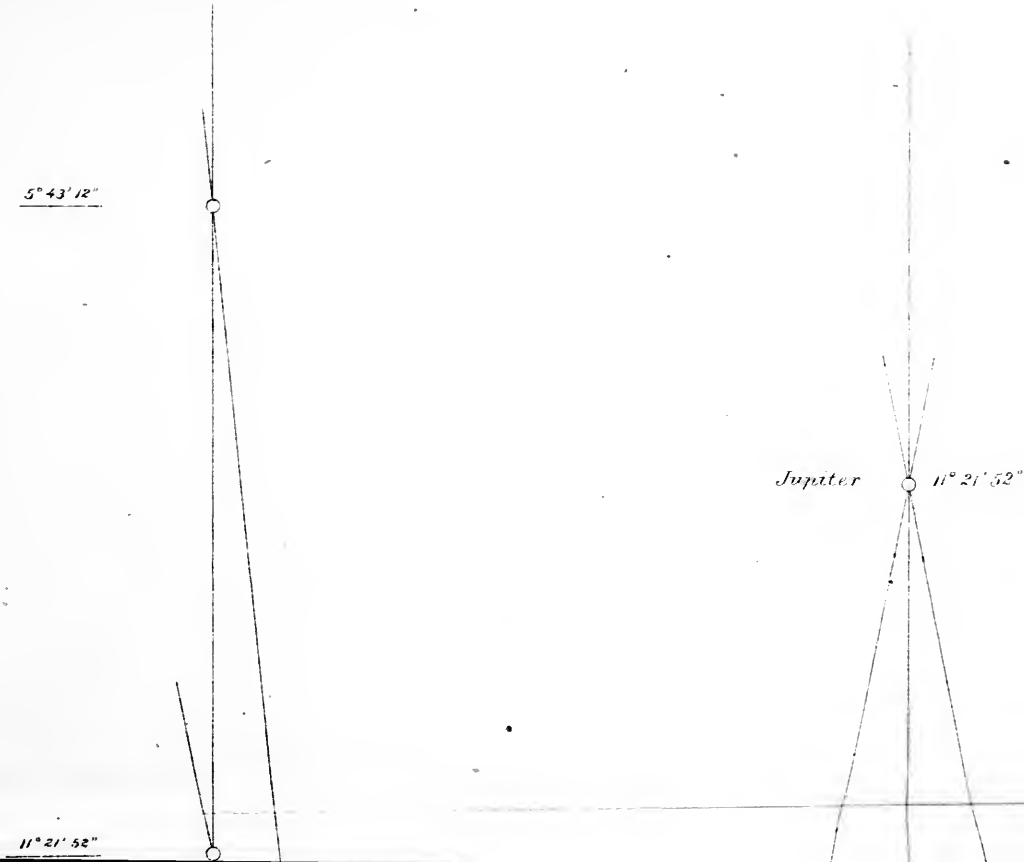
The Sun's distance at 95 million miles, the h. c. parallax of the Earth	45° 0′ 0
" Venus' distance at one-half that of the Sun, the h. c. parallax of Venus	63° 26′ 30″
" Mars' distance at twice that of the Sun the h. c. parallax of Mars.	27° 9′ 36″
Jupiter's distance at 5 times that of the Sun, the h. c. parallax of Jupiter.	11° 21′ 52″
" Saturn's at 10 times that of the Sun, the h. c. parallax of Saturn......	5° 43′ 12″
" The distance of a Star at 10 times that of Saturn, the h. c. parallax of the Star	34′ 23″
" of a Star at 100 times that of Saturn, the h. c. parallax of the Star ...	3′ 26″
" of a Star at 1000 times that of Saturn, h. c. parallax of the Star	20″.6
" of a Star at 2000 times that of Saturn, h. c. parallax of the Star	10″.3
" of a Star at 2,500 times that of Saturn, the h. c. parallax of the Star ...	about 8″.2

Now in this last quantity we obtain a convenient means of testing and checking these distances by computation based on an independent fact, because 8″.2 almost coincides with the geocentric parallax of the Sun, which is 8″.6 Therefore:—As the semi-diameter of earth : semi-diameter of earth's orbit : : semi-diameter of earth's orbit : the distance of that Star of which the h. c. parallax coincides with the g. c. parallax of the Sun; and accordingly . . .

As 4000 : 95 millions : : 95 millions : 2375 times the distance of Saturn (or 23750 times the distance of the Sun;) which result is in close agreement with the preceding.*

We would suggest that parallactic observations of the planets with the theoretical quantity in each case as a guide and a check on the apparent results, might be found a very useful and desirable preparation for parallactic observations of the stars.

* The diameter of the parallactic circle or the major axis of the parallactic ellipse would be (of course) twice as great as the respective quantities here given. The Star for example having 3·26″ h. c. parallax, should have an extreme apparent motion, to and fro, of 6·52.″


5° 43' 12"
Jupiter
11° 21' 52"
11° 21' 52"

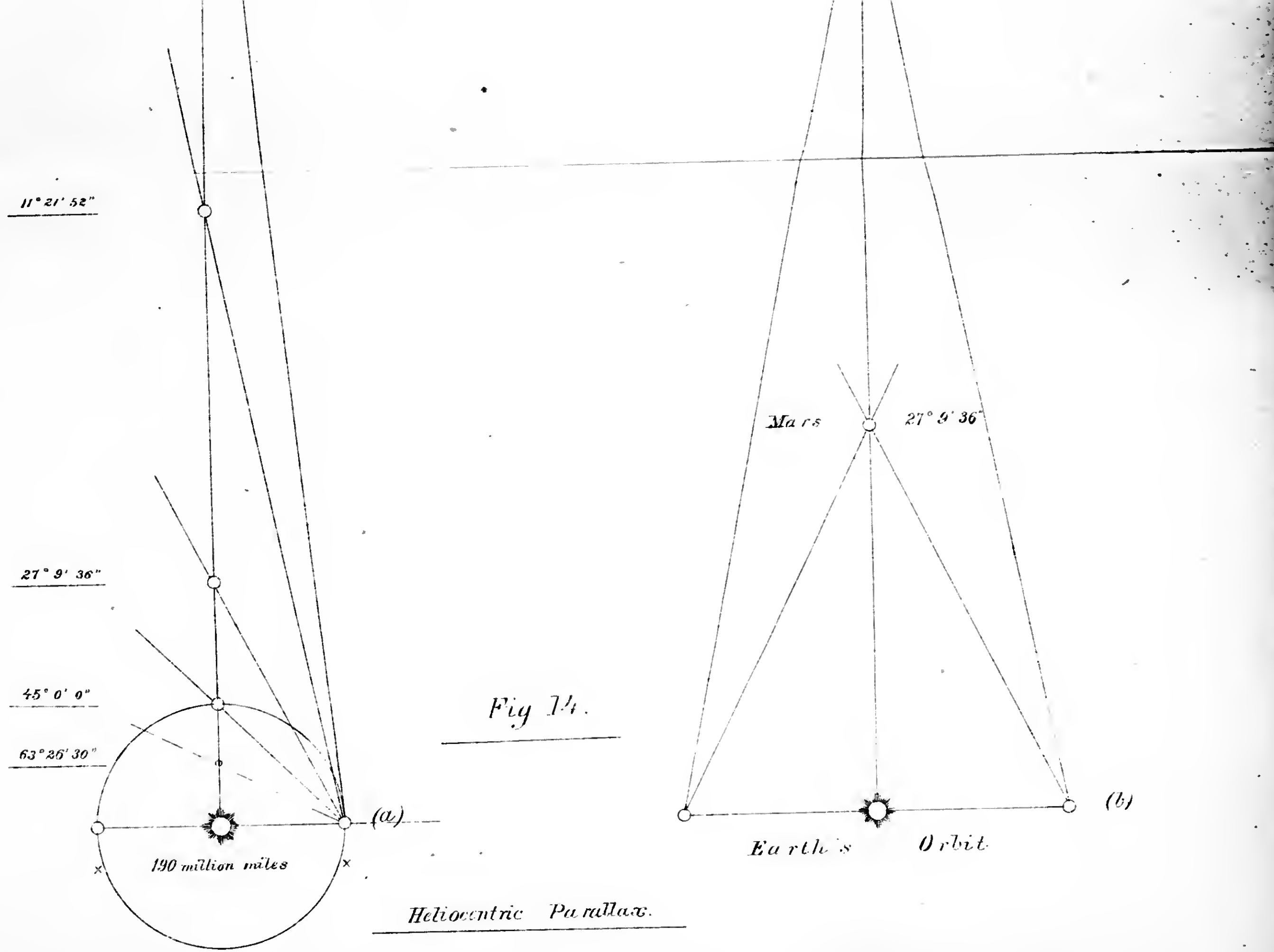


Fig 14.

Heliocentric Parallax.

APPENDIX.

THE OBSERVED DEVIATION OF THE PLANET URANUS FROM ITS (SUPPOSED) SOLAR ORBIT.

From *Herschel's Outlines of Astronomy.*

PLATE 1, FIG. 4.—"The horizontal line, or *abscissa*, is divided into equal parts, each representing 50° of heliocentric longitude in the motion of Uranus round the sun, and in which the distances between the horizontal lines represent each 100″ of error in longitude. The result of each year's observation of Uranus (or of the mean of all the observations obtained during that year) in longitude is represented by a black dot placed above or below the point of the *abscissa*, corresponding to the mean of the observed longitudes for the year, above if the observed longitude be in excess of the calculated, below if it fall short of it, and on the line if they agree; and at a distance from the line corresponding to this difference, on the scale above mentioned. Thus, in Flamsteed's earliest observations in 1690, the dot so marked is placed above the line at 65″.9 above the line, the observed longitude being so much greater than the calculated."

(763.) "If, neglecting the individual points, we draw a curve (indicated in the figure by a fine unbroken line) through their general course, we shall at once perceive a certain regularity in its undulations. It presents two great elevations above, and one nearly as great intermediate depression below the medial line or *abscissa*. And it is evident that these undulations would be very much reduced, and the errors, in consequence, greatly palliated, if each dot were removed in the vertical direction through a distance, and in the direction indicated by the corresponding point of the curve *ABCDEFGH*, intersecting the *abscissa* at points 180° distant, and making equal excursions on either side. * * * *"

(764.) "Let us now consider the effect of an erroneous assumption of the *place* of the perihelion. Suppose in Fig. 2, *o x* to represent the longitude of a planet, and *x y* the excess of its true above its mean longitude, due to ellipticity. * * * *"

(766.) "Let this increase of period be made, and in correspondence with that change let the longitudes be reckoned at *a b*, and the residual differences from that line instead of *A B*, and we shall have done all that can be done in the way of reducing and palliating these differences."

The above quotation sufficiently explains the plate in its application to our argument: namely, as indicating the nature of the methods adopted for reconciling the discordance between the theory and the observed facts. For the full and more particular explanation of the plate, the reader is referred to the work to which it belongs.

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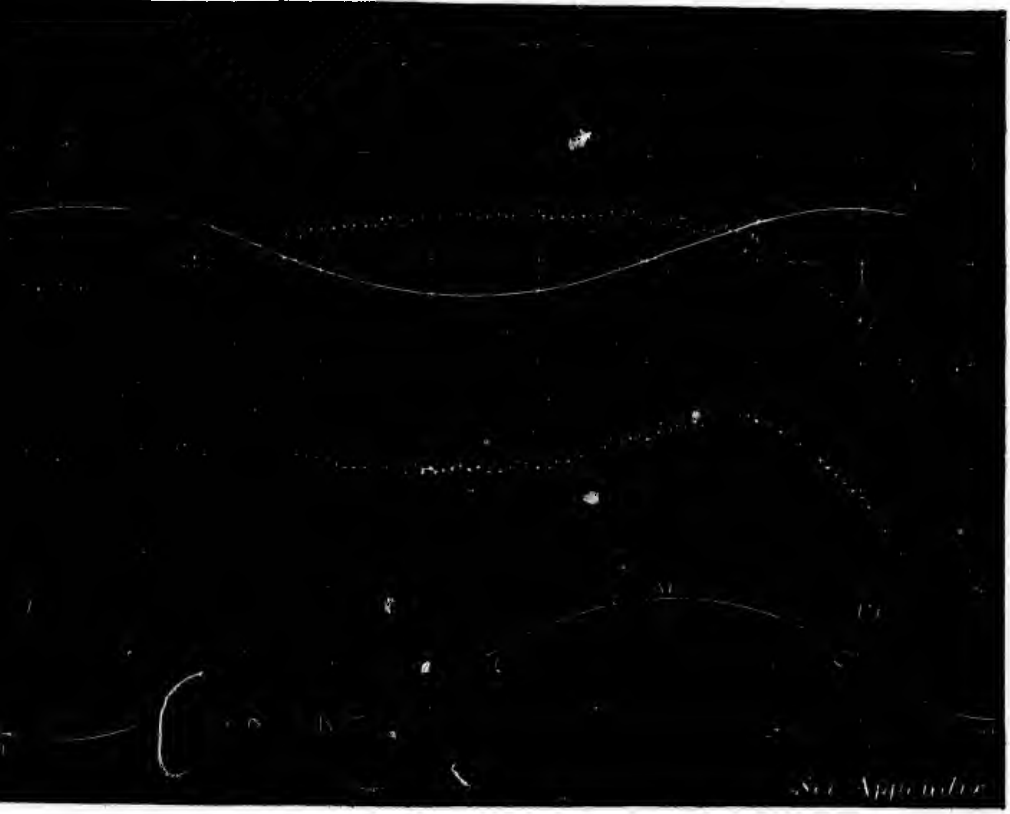
See Appendix