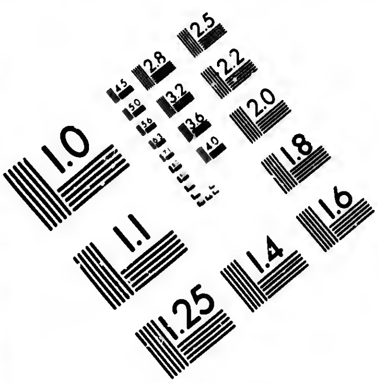

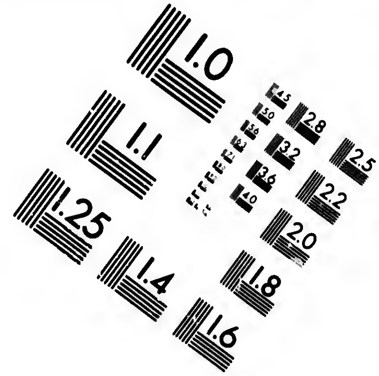

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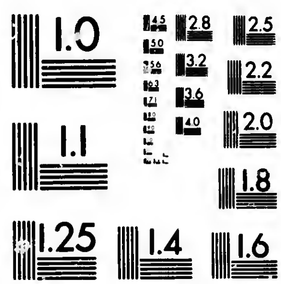

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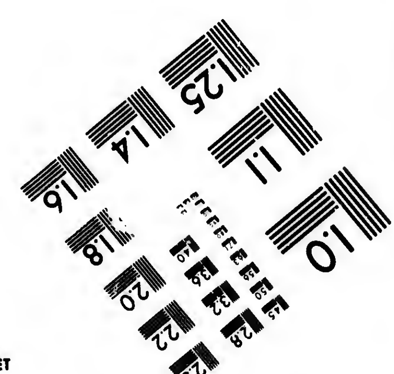

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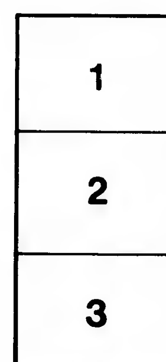
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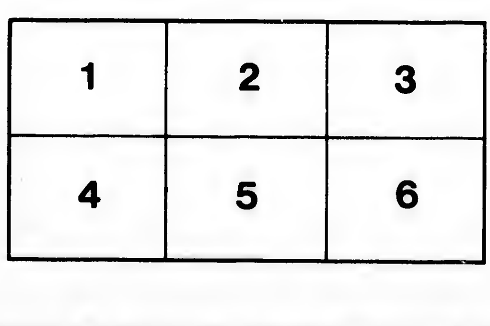
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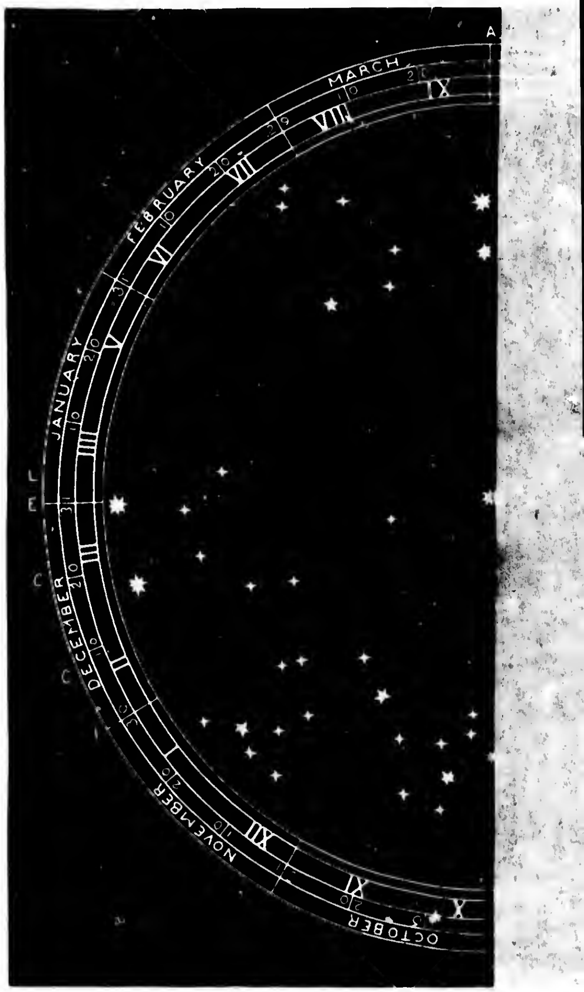
PLATE XI.

THE N

CIRCUMPOL



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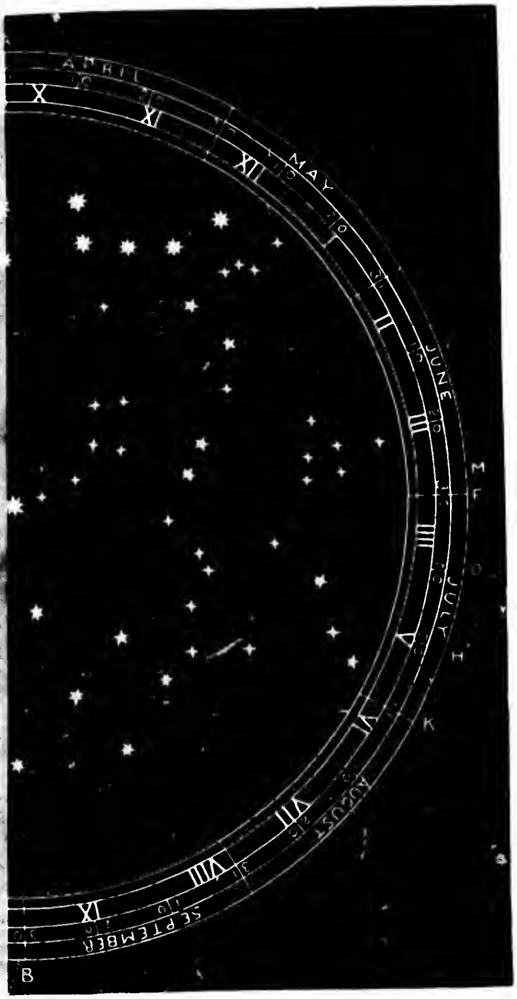
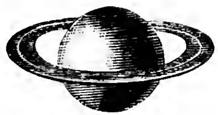
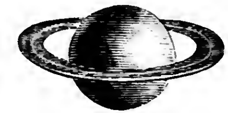
LAR STARS. (From Dick's Astronomy.



THE PLANET

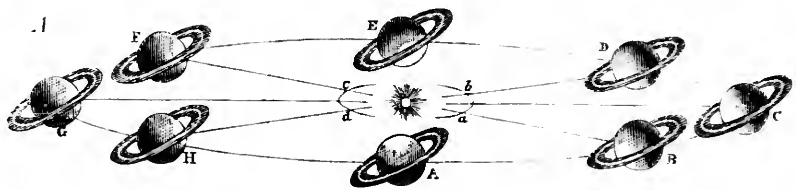
SATURN.





The diameter of Saturn is about 10 times that of the earth, and its bulk (aggregate mass) about 1000 times that of the earth.

A



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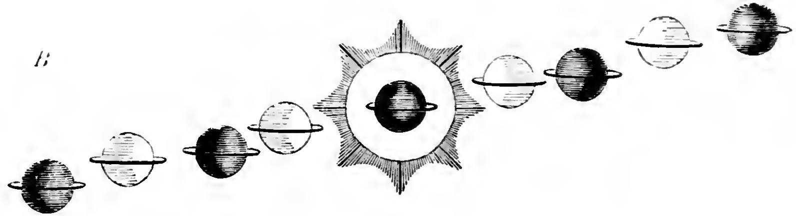


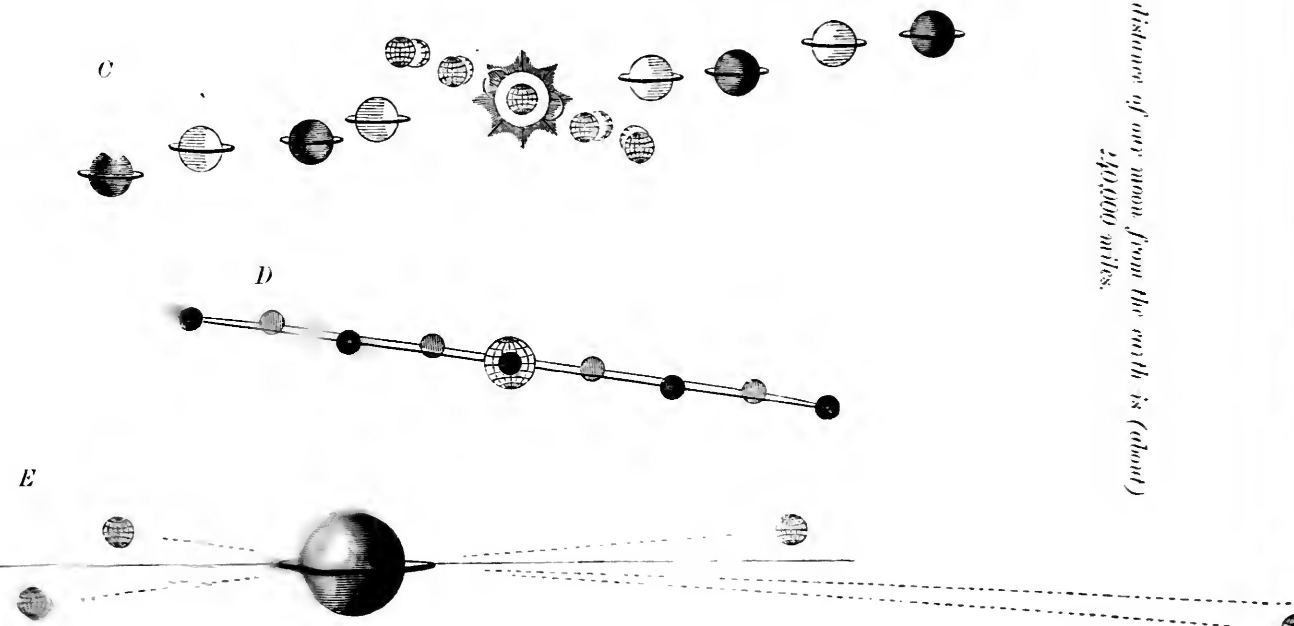
A. Illustrating the theory of the oblique axis and orbital plane inclined to the ecliptic.

B. Illustrating the theory of the perpendicular axis, and deviation above and below the horizontal plane of the ecliptic.

orbital

THE PERPENDICULAR AXIS.

C. The Sun, the Earth, and Saturn.
D. The Earth and Moon (the moon's orbit).
E. Saturn and four satellites (the fifth omitted).



The distance of Saturn's fifth moon from that planet is estimated at (about) 2,000,000 miles.

The distance of our moon from the earth is (about) 240,000 miles.

Plate II

The Solar System

And the neighbouring

Stellar System

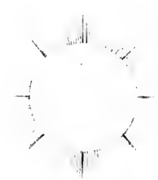
The Sun
Earth
Saturn

The Star
Neptune
Uranus

Note
The Earth's orbit, in this illustration, is made to appear much greater than the actual proportion, in other respects the proportions are supposed to be rough approximations to the actual distances

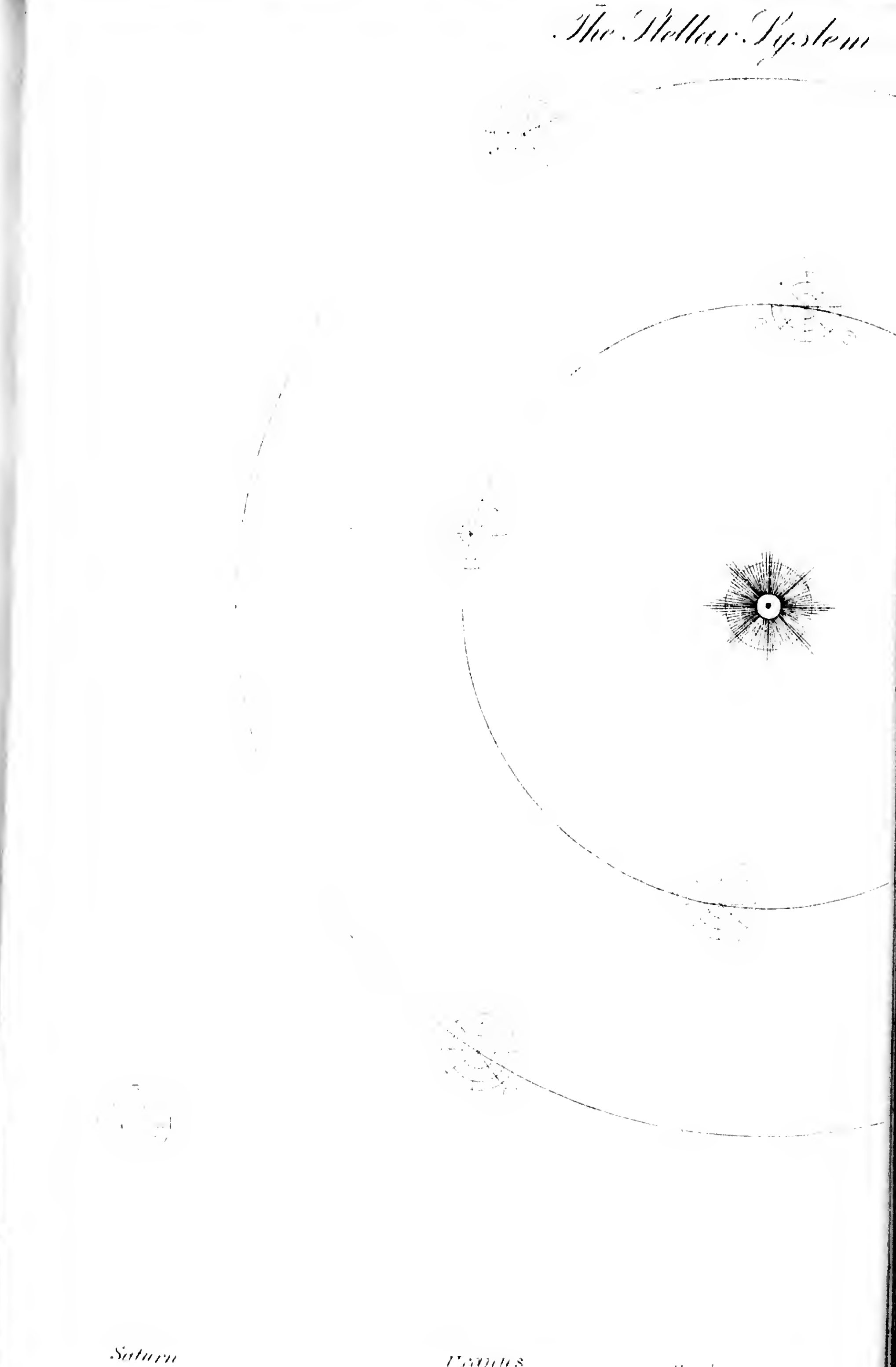
Uranus Neptune Stella

The Solar System
Vertical axis



Saturn Earth Sun Earth

Earth

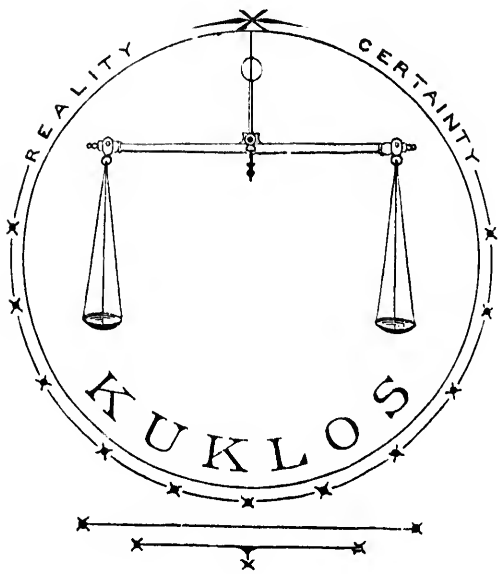

The Stellar System
Saturn
Uranus
Neptune

Supplement B.

Centrifugal Force

—oo—

Gravitation.



SUPPLEMENT B.

CENTRIFUGAL FORCE

AND

GRAVITATION.

A LECTURE.

BY

JOHN HARRIS.

MONTREAL:
JOHN LOVELL, ST. NICHOLAS STREET.

SEPTEMBER, 1873.

MONTREAL:—J. STARKE & CO, PRINTERS.

THE THEORY OF
THE INCLINED TERRESTRIAL AXIS.

In citing the instance of the pole star as a proof that the astronomical theory of the inclined axis of the earth is not supported by the facts, we stated that the pole of the earth (*i.e.* the zenith place in the heavens above the north pole of the earth) almost coincides (apparently) with the pole of the ecliptic, instead of being constantly situated at a place about $23\frac{1}{2}°$ distant from the pole of the ecliptic. Now this statement is not in accordance with the teaching contained in works on Astronomy; for example:

Herschel's Outlines of Astronomy, page 198:

(307). "The poles of the ecliptic, like those of any other great circle of the sphere, are points on its surface, equidistant from the ecliptic in every direction. They are, of course, not coincident with those of the equinoctial, but removed from it by an angular interval equal to the inclination of the ecliptic to the equinoctial (23° 28), which is called the *obliquity of the ecliptic.*"

The precession of the equinoxes and nutation of the earth's axis are not here the immediate subjects of consideration; but we will continue the quotation somewhat further, for the purpose of more particularly defining the present teaching as to the relative positions of the poles, and of showing the complications which arise from assuming the pole of the earth to be inclined to that of the ecliptic.

(316). "It is found then, that in virtue of the uniform part of the motion of the pole, it describes a circle in the heavens around the pole of the ecliptic as a centre, keeping constantly at the same distance of 23° 28′ from it in a direction from east to west, and with such a velocity, that the annual angle described by it, in this its imaginary orbit, is 50.10″; so that the whole circle would be described by it in the above mentioned period of 25,868 years.* It is easy to perceive how such a motion of the pole will give rise to the retrograde motion of the equinoxes; for in the figure, art. 308†, suppose the pole P in the progress of its motion in the small circle POZ, round K, to come to O, then, as the situation of the equinoctial EUQ is determined by that of the pole, this, it is evident, must cause a displacement of the equinoctial, which will take a new situation EUQ, 90° distant in every part from the new position O of the pole. The point U therefore, in which the displaced equinoctial will intercept the ecliptic, *i.e.* the displaced equinox will lie on that side of V, its original position, towards which the motion of the pole is directed, or to the westward."

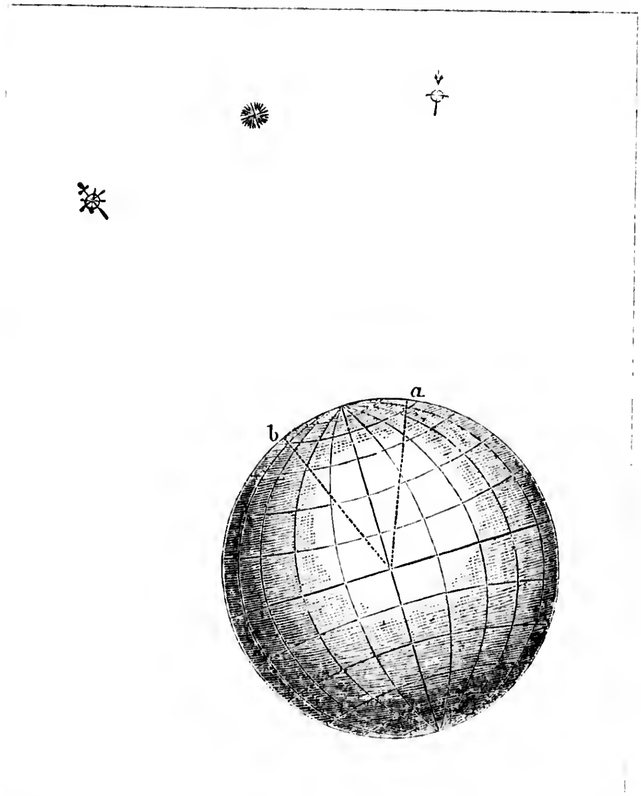
(317). "The precession of the equinoxes thus conceived, consists, then, in a real but very slow motion of the pole of the heavens among the stars, in a small circle round the pole of the ecliptic. Now this cannot happen without producing corresponding changes in the apparent diurnal motion of the sphere, and the aspect which the heavens must present at very remote periods of history. The pole is nothing more than the vanishing point of the earth's axis. As this point, then, has such a motion as we have described, it necessarily follows that the earth's axis must have a conical motion, in virtue of which it points successively to every part of the small circle in question. We may form the best idea of such a motion by noticing a child's peg-top when it spins not upright, or that amusing toy the te-to-tum, which when delicately executed, and nicely balanced, becomes an elegant philosophical instrument, and exhibits in the most beautiful manner the whole phenomenon."

The teaching, therefore, contained in the foregoing is that the pole of the earth is situated at an angular distance of about 23½° from the pole of the ecliptic; the

* This would give a circle of 46° 56′; but, in art. 322, it is spoken of as a circle of 23° 28′; "which, in a small circle of 23° 28′ in diameter corresponds to 6′ 20″ as seen from the centre of the sphere."

† See page 8.

pole of the equinoctial being considered in this connexion an equivalent term with the pole of the earth. How stand the facts? The pole of the ecliptic may evidently be considered as the vertical axis of the sun extended northwards into the heavens; or, in other words, the place in the heavens directly over the northern extremity of the sun's vertical axis (over the north pole of the sun). In Fig. 5 of Supplement A, the arrows crossing the earth indicate the position of the earth's axis, if inclined as assumed by the present astronomical theory at an angle of 23° 28; and they point accordingly to a place in the heavens at an angular distance of 23° 28 from the pole of the ecliptic. Now if we take, in the first instance, the place of the earth, at the extremity of its orbit to the right of the sun, and—supposing an observation of the heavens to have been made from that point of view—we then take the place of the earth at the opposite extremity of the orbit to the left of the sun, and again suppose an observation to be made from the same place on the earth; will the apparent relative place of the pole of the ecliptic to that of the earth be the same from the second point of view as it was from the first? The answer must be that the apparent relative places of the two poles will differ, but will not necessarily differ to more than a very slight extent when viewed from the earth at the opposite extremities of the orbit successively. But it is manifest that the situation of the point of view on the earth relatively to the sun will not be the same at the opposite extremities of the orbit, because, from the inclination of the axis, that locality on the earth, which at the one extremity would have for its zenith a place near the pole of the ecliptic, would at the opposite extremity, if occupying the same position relatively to the axis of the earth, look towards a point in the heavens at a considerable angular distance from the pole of the ecliptic. Let us therefore enquire further whether the apparent relative position of the two poles would be, in the case supposed by the theory of the inclined axis, affected by the rotation of the earth on its axis; that is to say, whether if an observation be made from a definite place on the earth's surface at a certain time of the day—say at midnight; and a second observation be made from the same place at some other time of the day—say at mid-day: would any alteration in the apparent relative position of the two poles be then observed? Evidently there would be a considerable alteration, for let the place of the observer at midnight be at (a) Fig. 1, which may be supposed situ-



ated at a latitude of $66\frac{1}{2}°$ north; so that the zenith of the observer would be considered to coincide with the pole of the ecliptic, and would have therefore an apparent angular distance of about $23\frac{1}{2}°$ from the pole star: then, at the second observation taken at midday, the same place on the earth will be as shown at (b), and the zenith of the observer will be 47° distant from the zenith place of the previous observation: the pole star being situated between the two zenith places at the half distance (and therefore $23\frac{1}{2}°$ west of the last zenith place)*. A little further consideration will suffice to make it evident that—if the axis of the earth be inclined towards the vertical axis of the sun, and the other circumstances are, *in fact*, as they are assumed to be in the astronomical theory—then must the pole of the ecliptic necessarily make an apparent diurnal revolution around the pole star in a circle having a diameter of about 47°. Do the observed facts of astronomy herein support the theory?

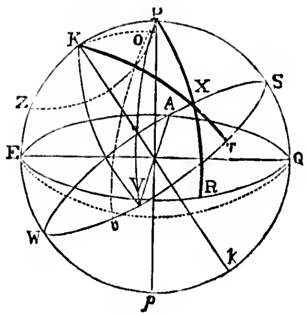
Herschel's Outlines of Astronomy, page 198.

(306). "The position of the ecliptic among the stars may, for our present purpose, be regarded as invariable. It is true that this is not strictly the case; and on comparing together its position at present with that which it held at the most distant epoch at which we possess observations, we find evidences of a small change, which theory accounts for, and whose nature will be hereafter explained; but this change is so excessively slow, that for a great many successive years, or even for whole centuries, this circle may be regarded, for most ordinary purposes, as holding the same position in the siderial heavens."

(308). "Since the ecliptic holds a determinate situation in the starry heavens, it may be employed, like the equinoctial, to refer the positions of the stars to, by circles drawn through them from its poles, and therefore perpendicular to it. Such circles are termed, in astronomy, circles of latitude—the distance of a star from the ecliptic, reckoned on the circle of latitude passing through it, is called the *latitude* of the stars—and the arc of the ecliptic intercepted between the vernal equinox and this circle, its *longitude*.

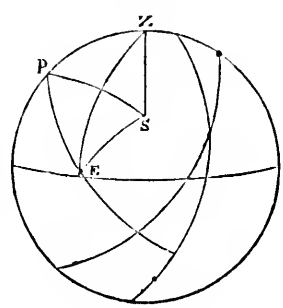
* From the place of the first observation, the observer saw the pole star beyond the pole of the ecliptic which was over his head; in the place of the second observation the pole star is nearer to the observer, and he sees the pole of the ecliptic $23\frac{1}{2}°$ beyond it.

In the figure, X is a star, PXR a circle of declination drawn through it by which it is referred to the equinoctial, and KXT a circle of latitude referring it to the ecliptic — then, as VR is the right ascension, and RX the declination of X, so also is VT, its longitude, and TX, its latitude. The use of the terms longitude and latitude, in this sense, seems to have originated in considering the ecliptic as



forming a kind of natural equator to the heavens, as the terrestrial equator does to the earth—the former holding an invariable position with respect to the stars, as the latter does with respect to stations on the earth's surface. The force of this observation will become apparent."

(310). "It is often of use to know the situation of the ecliptic in the visible heavens at any instant; that is to say, the points where it cuts the horizon, and the altitude of its highest point, or, as it is sometimes called, the *nonagesimal* point of the ecliptic, as well as the longitude of this point on the ecliptic itself from the equinox. These, and all questions referable to the same data and quaesita, are resolved by the spherical triangle ZPE, formed by the zenith Z (considered as the pole of the horizon), the pole of the equinoctial P, and the pole of the ecliptic E. The siderial time being given, and also the right ascension of the pole of the ecliptic (which is always the same, viz. $18^{h.}\ 0^{m.}\ 0^{s.}$), the hour angle ZPE of that point is known. Then, in this triangle we have given PZ, the colatitude; PE, the polar distance of the pole of the ecliptic, 23° 28, and the angle ZPE from which we may find, 1st, the side ZE,



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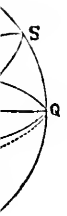

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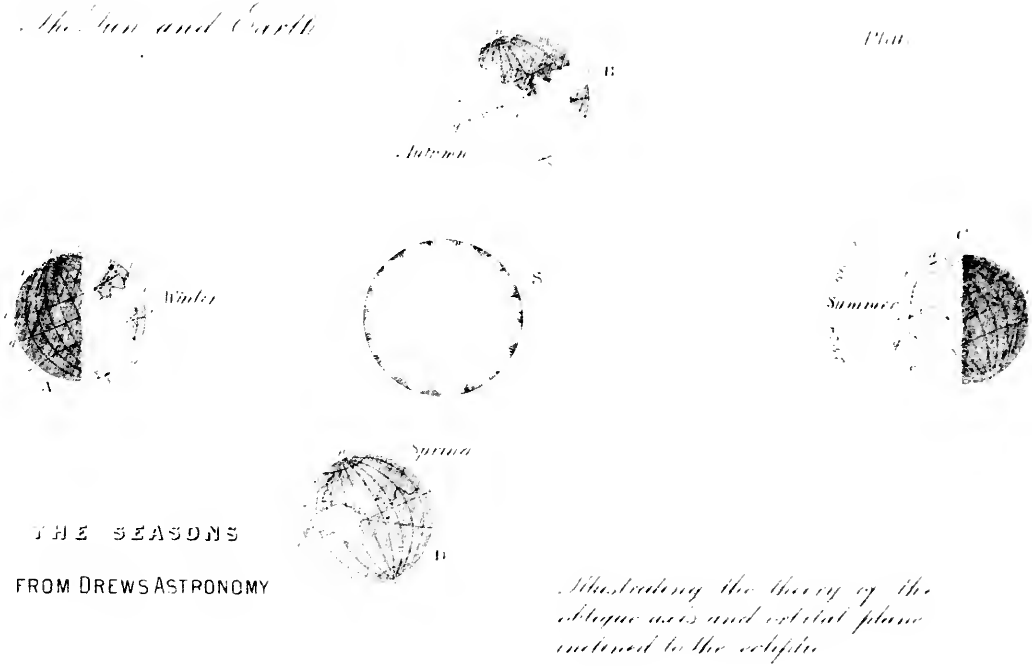


THE SEASONS

FROM DREWS ASTRONOMY

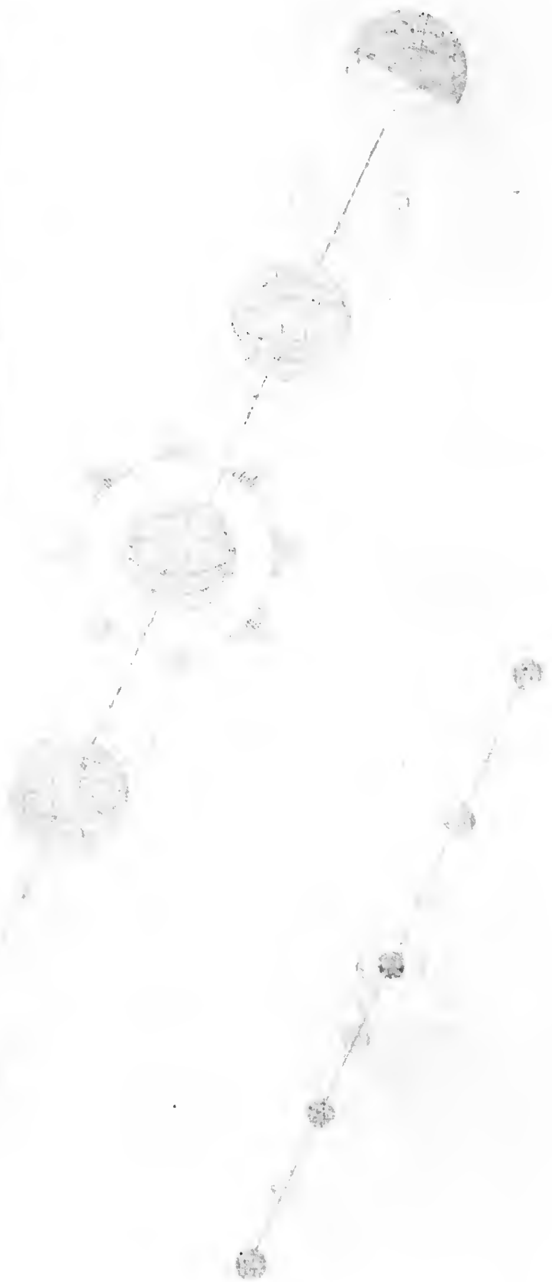
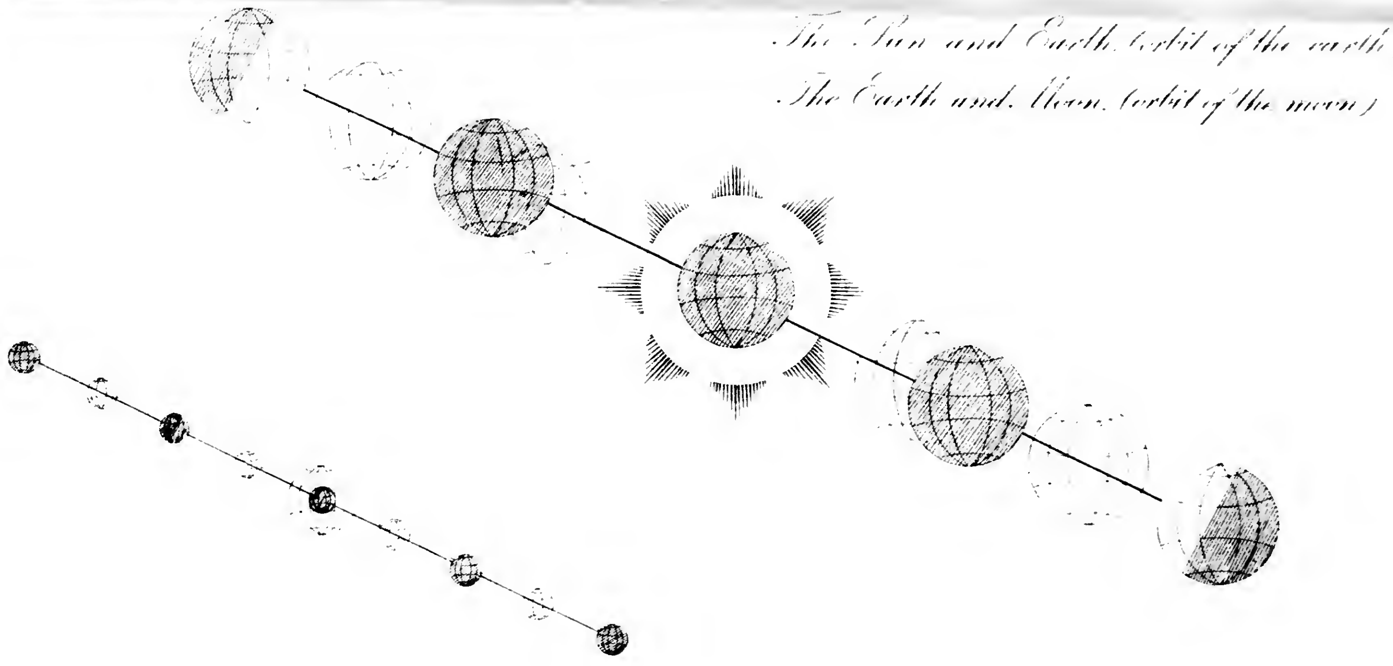


Plate 9

Plate 9



Illustrating the theory of the perpendicular axis and vertical deviation above and below the horizontal plane of the Ecliptic.

which is easily seen to be equal to the altitude of the nonagesimal point sought; and 2ndly, the angle PZE, which is the azimuth of the pole of the ecliptic, and which, therefore, being added to and substracted from 90°, gives the azimuth of the eastern and western intersections of the ecliptic with the horizon; lastly, the longitude of the nonagesimal point may be had, by calculating in the same triangle the angle PEZ, which is its complement."

The place of the pole of the ecliptic in the heavens cannot be considered as an observed fact, because the pole itself is suppositious or imaginary; and its situation (locality) is deduced from (and therefore the correctness of its localization is dependent upon) the theory which determines (explains) the path of the earth's revolution around the sun; but the place (of the pole of the ecliptic) having been theoretically determined or localized, immediately becomes related to the places or situations of stars which are subjects of direct observation; and, consequently, we thus obtain a means of indirectly observing (so to speak) the supposed place of the pole, and of verifying its correctness.

Returning again to the enquiry, at page 5; we will suppose the two observations from the same definite station on the earth to be repeated; the first, at midnight; and the second, at midday. On observing the pole star it is seen to be surrounded by certain stars more or less near to it. Now if we, adopting the theory of the inclined axis, assume the place of the pole of the ecliptic to be at about 23½° east of the pole star, that place will be seen to be likewise surrounded by certain stars which will be at distances varying from 20° to 30° from the pole star. The position of these last (*i.e.* the stars near the assumed place of the pole of the ecliptic) being noted at the first observation taken at midnight, will certainly be found at the second observation taken at midday to have undergone a considerable alteration relatively to the pole star—namely, each of the stars belonging to the last group will have revolved through the half of a circle around the pole star, and will now (*i.e.* at the second observation) be found at the same distance, about

$23\frac{1}{2}°$ to the west of the pole star. That this must be so is obvious because the place of the observer upon the earth has, in consequence of the earth's rotation, actually revolved through a half circle around the pole; but the place of the observer is to the observer *apparently* motionless, and the pole star is the recognised stationary point of reference: consequently, the other stars appear to make a revolution around the pole star, when observed from the same place at successive times during a complete revolution of the earth on its axis. Again, since the pole of the ecliptic may be correctly (theoretically) considered as an invisible star directly over the northern extremity of the vertical axis of the sun; and, since the pole star is situated directly over the north pole of the earth; evidently the invisible star (or pole of the ecliptic) is in the same case in regard to its position relatively to the pole star, as are the (other) stars by which it is surrounded; when the latter appear to revolve around the pole star, so must likewise the former; and when the position of the other stars relatively to the pole star undergoes alteration, the position of the pole of the ecliptic must undergo the like apparent alteration, precisely the same as though it were actually one of those stars. Now the present assumption, as taught in works of astronomy (see arts. 306, 308, 310 of Herschel's work, quoted, page 7), is that the place of the pole of the ecliptic does not revolve around the pole star (or equinoctial pole), but remains fixed relatively thereto,* and such assumption is, as we have now shown, irreconcilable with the facts of astronomy. But what, if the fixed place of the pole of the ecliptic be given up; and if, still assuming the same relative place, it be conceded that the pole of the ecliptic does remove and has a diurnal revolution around the pole star? Then: the theory of the inclined axis of the earth becomes irreconcilable with the facts of astronomy; and, consequently, untenable.

* As a practical definition of the present teaching, it may be remarked that on the celestial globe the pole of the ecliptic is now shown as a quite distinct centre and at a distance of $23\frac{1}{2}$ from the north pole of the earth.

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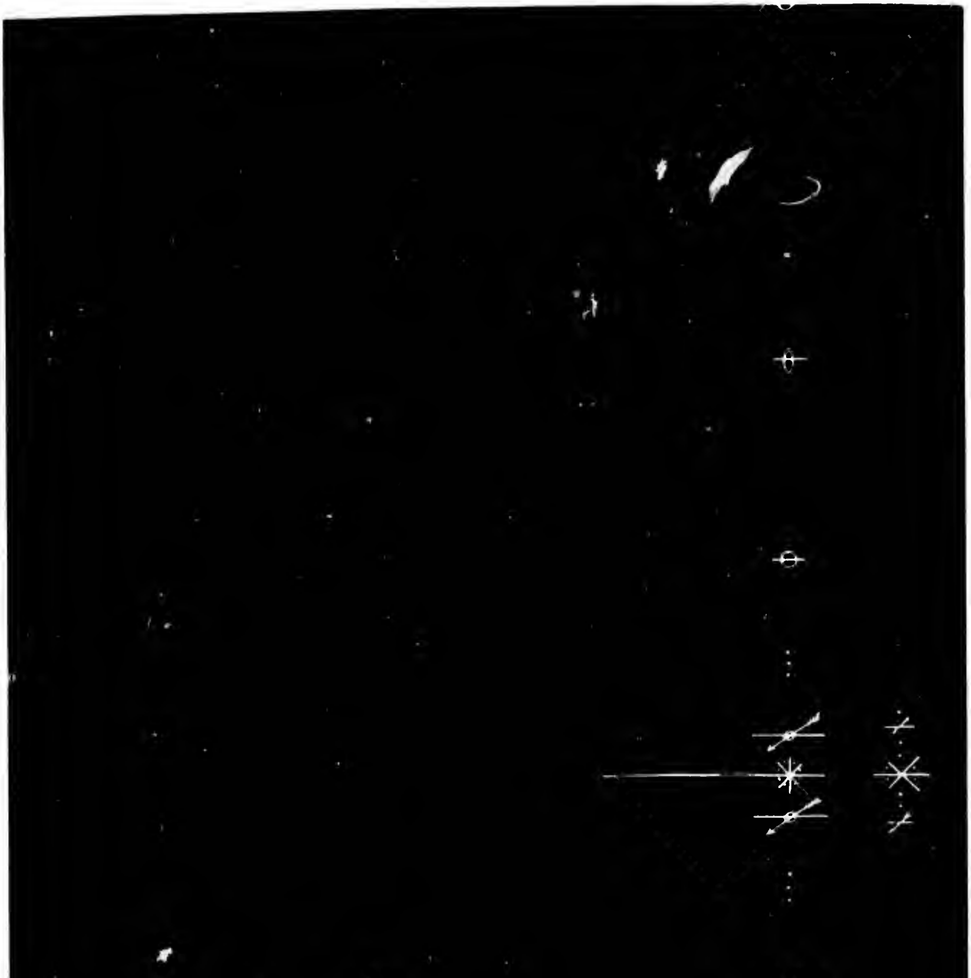
PLATE 3.

Fig. 3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The effect of a stellar system having its orbital plane perpendicular, or at an angle approaching the perpendicular, 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. 3 (Pl. 3), illustrating the pole star and the solar system, the distance of the pole star from the sun as represented is nearly the same as the distance of the planet Neptune (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 plane of revolution 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. 3, 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 deviating not 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 another system having its plane of revolution vertical, or nearly vertical, to that of the solar system, 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 apparent 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 apparent 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.

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 astron-

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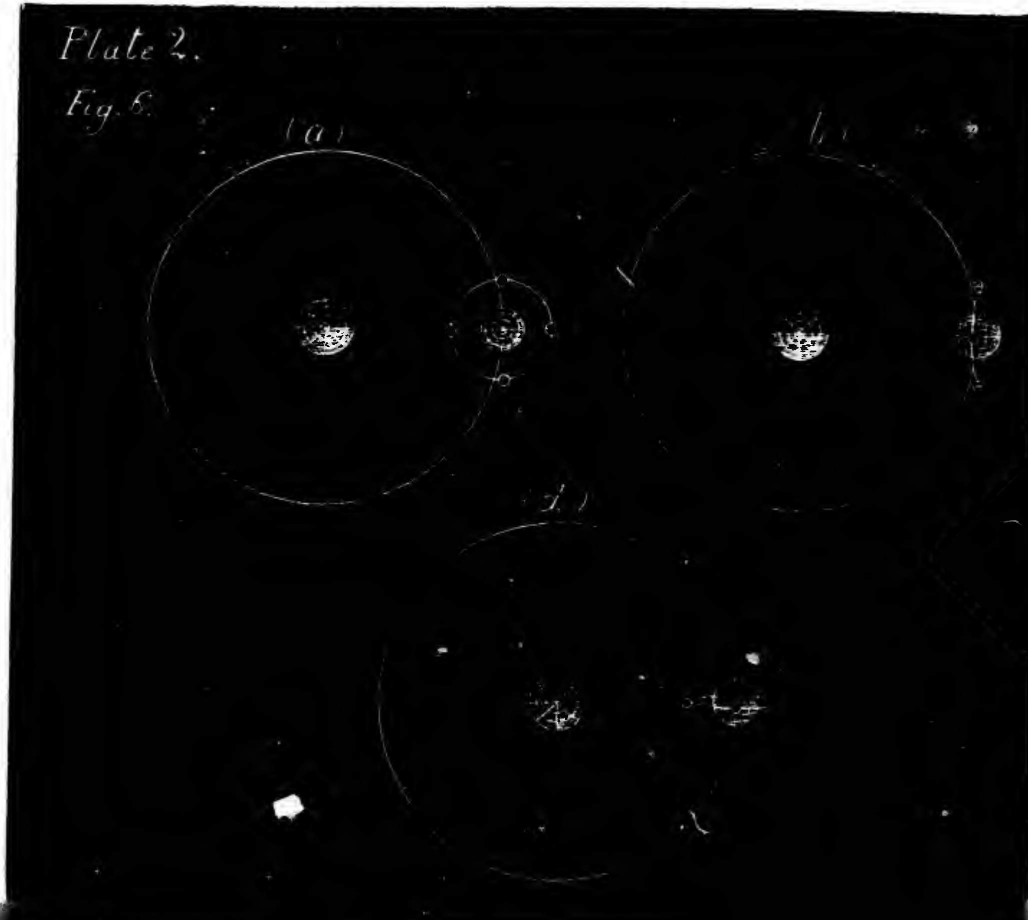
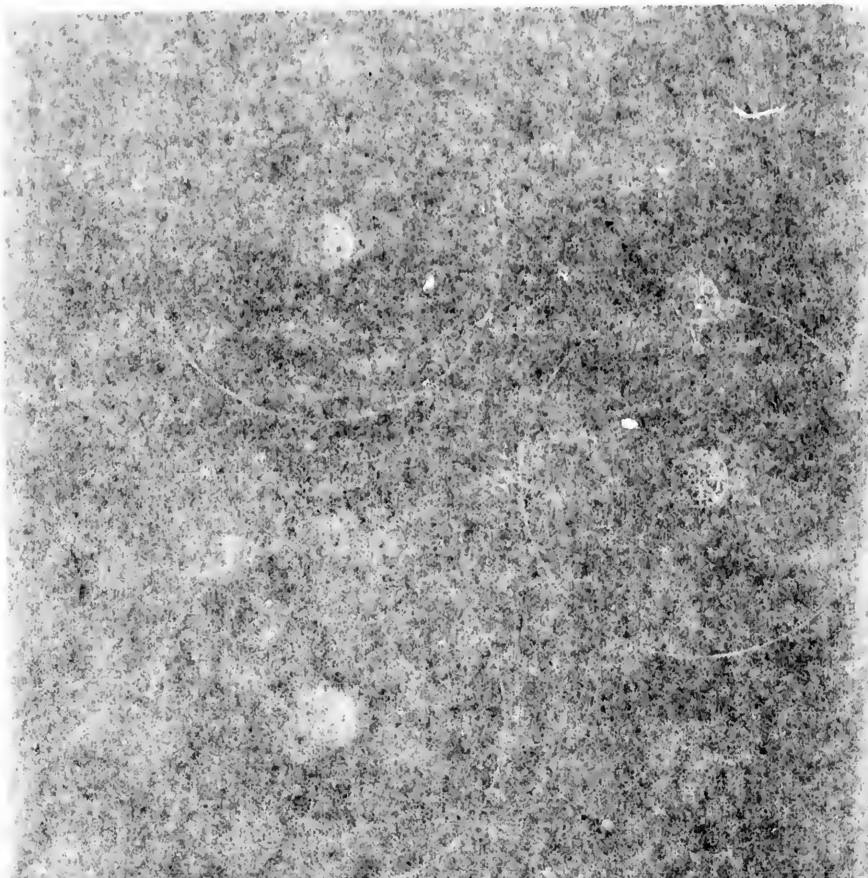


Plate 2.

Fig. 6.

omers, and that its progress could be thereby traced back,

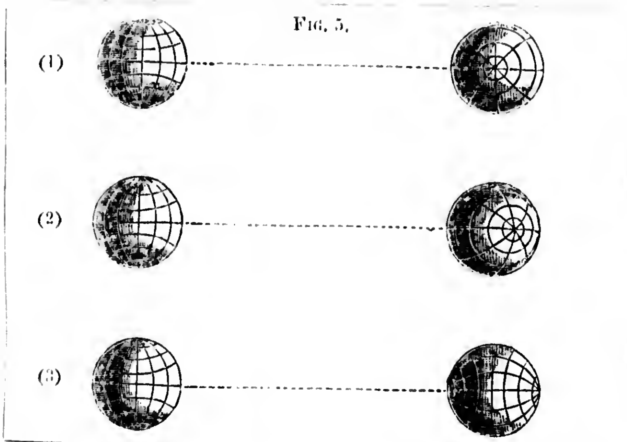


omers, and that its progress could be thereby traced back, with some degree of certainty, to the earliest period of such observations. This having been done, the result showed that the actual orbital path, through which the planet had (appeared to have) moved, differed greatly from the theoretical path 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), taken 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 1865.

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 affected by such source of local gravitating influence (*i.e.* 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 ca vith every other planet and satellite, move in the opp irection. 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 occultations 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.* 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 line joining the planet and the (centre of gravitation) central body of the system; or, (2) it might be situated obliquely to such a line; or, (3) one extremity of the axis might point directly towards the central body.

Fig. 5.



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 orbital 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 also perpendicular to the orbital plane. If, however, we admit the assumption that the planet 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 figure—namely, with the axis of the planet at right angles to a line 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 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 14), 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

* 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 substantially (nearly) the same as if the planet was viewed from the sun: consequently the recorded observation necessitates the inference as to the planet being posited as shown at (1) in the figure.

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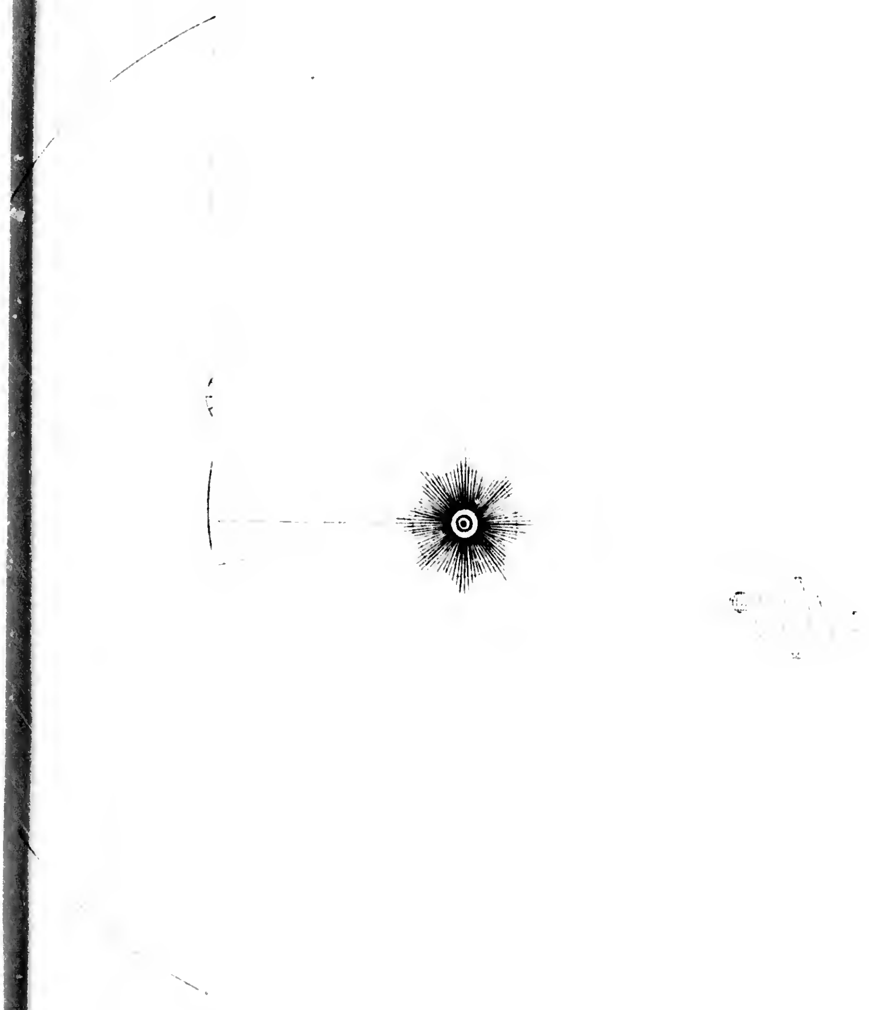
Plate 4

Stellar: System

Hor Vertical axis — The pole of the Ecliptic being considered Horizontal

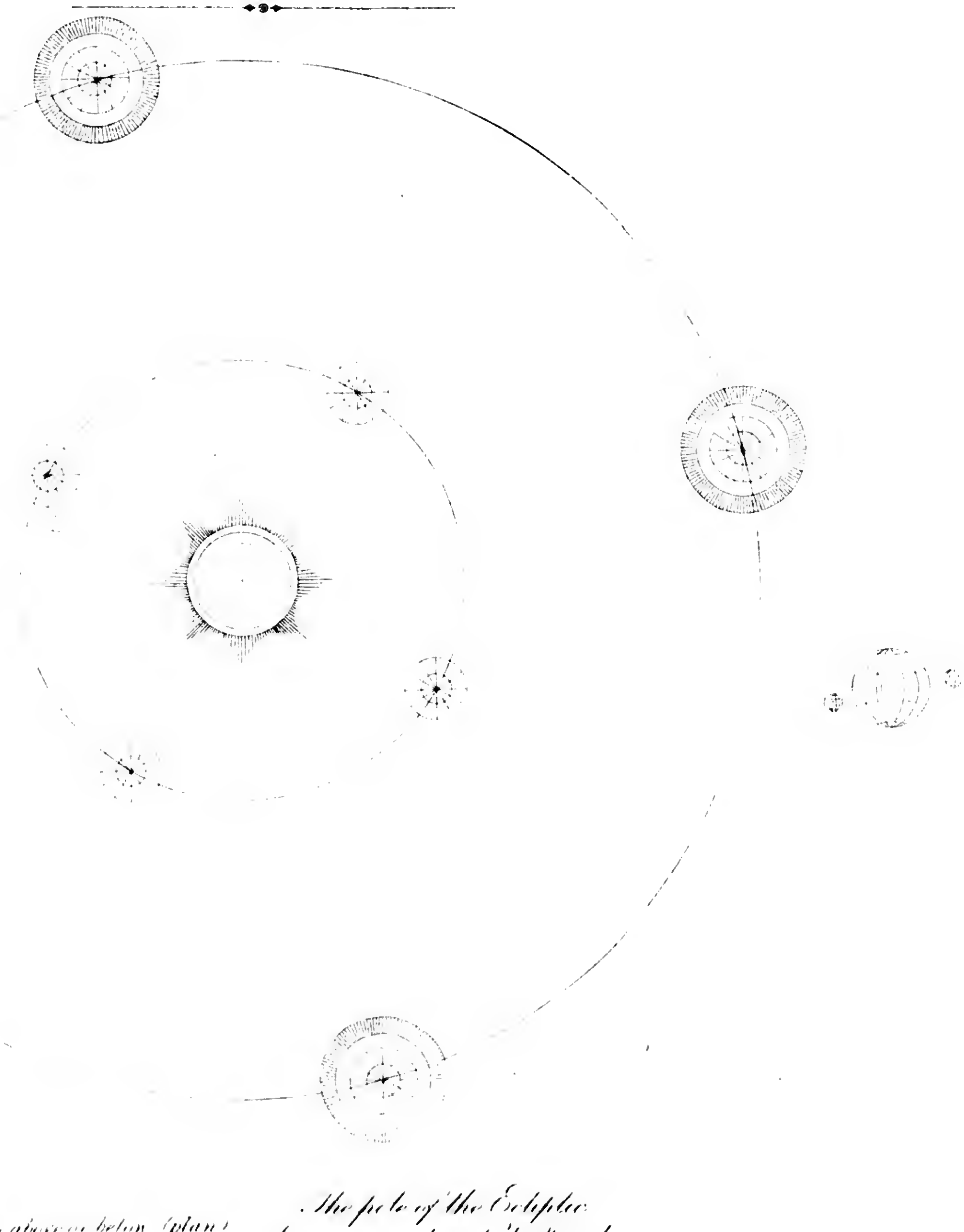


ide view (Elevation) — View from a — The pole of the Ecliptic being considered Horizontal

Plate 4

The Solar System

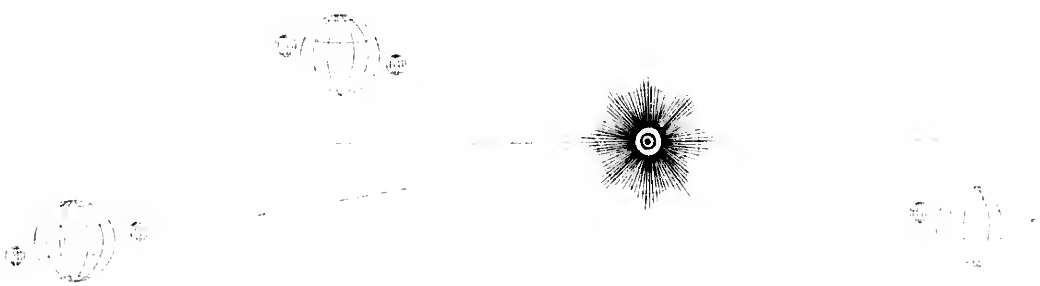
Horizontal axis — The pole of the Ecliptic being considered Horizontal



View from above or below (plan) — The pole of the Ecliptic being considered Vertical

Stellar System

Vertical axis — The pole of the Ecliptic being considered Horizontal



Side view (Elevation) — The pole of the Ecliptic being considered Horizontal

The Stellar System

Horizontal axis

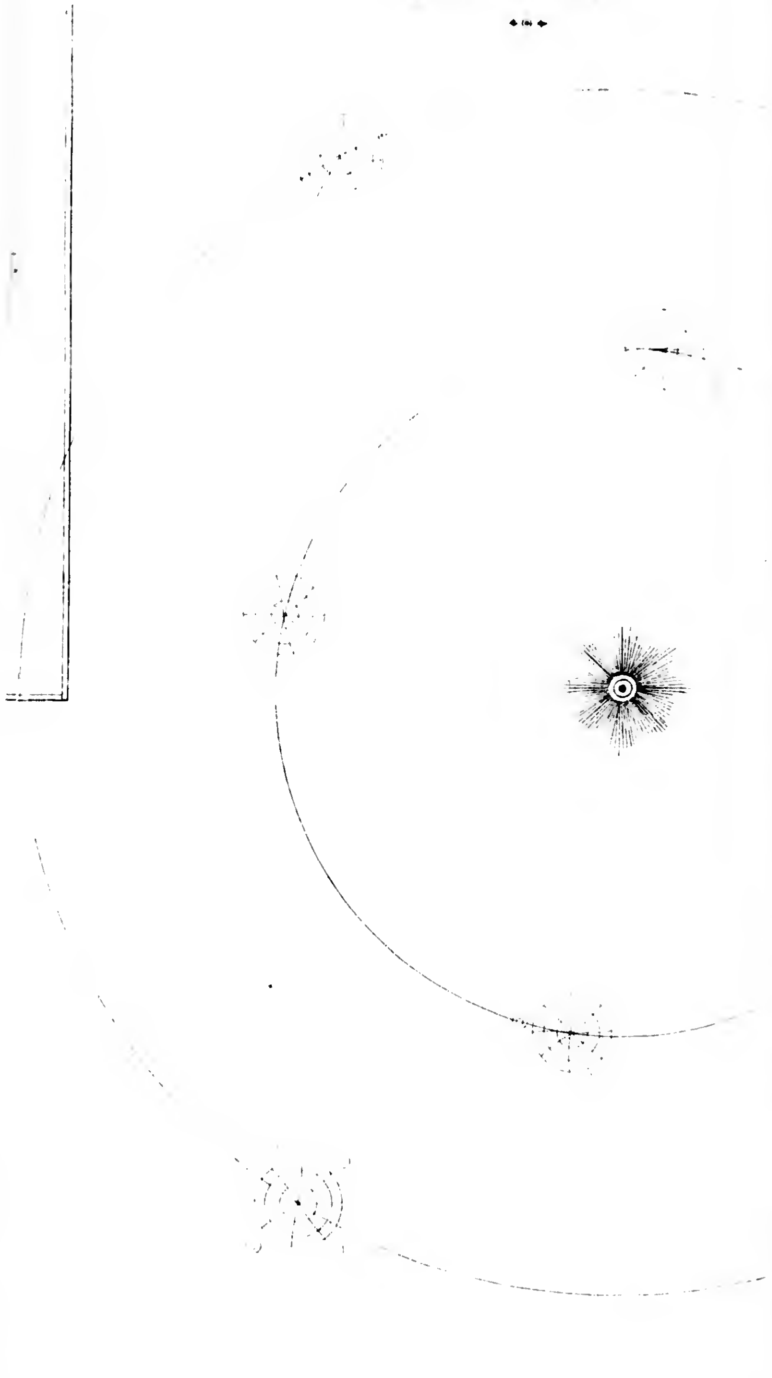
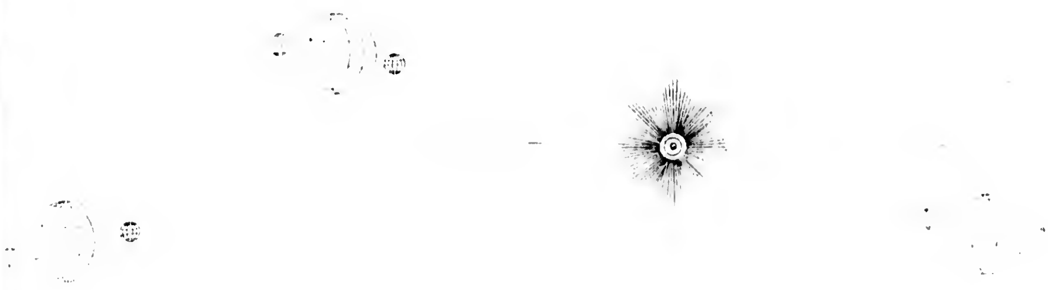


plate 3

Stellar System

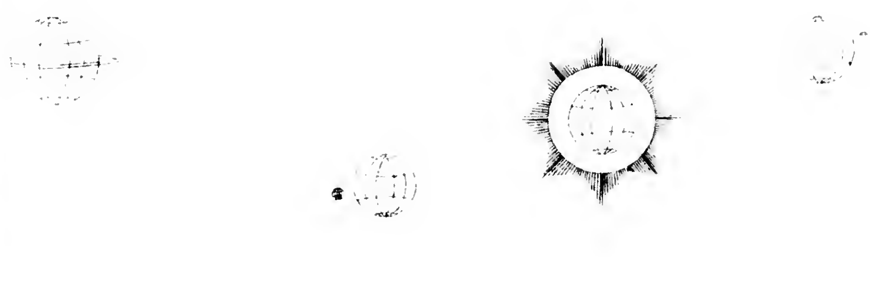
Vertical axis



Uranus — Neptune — Stella — Neptune

The Solar System

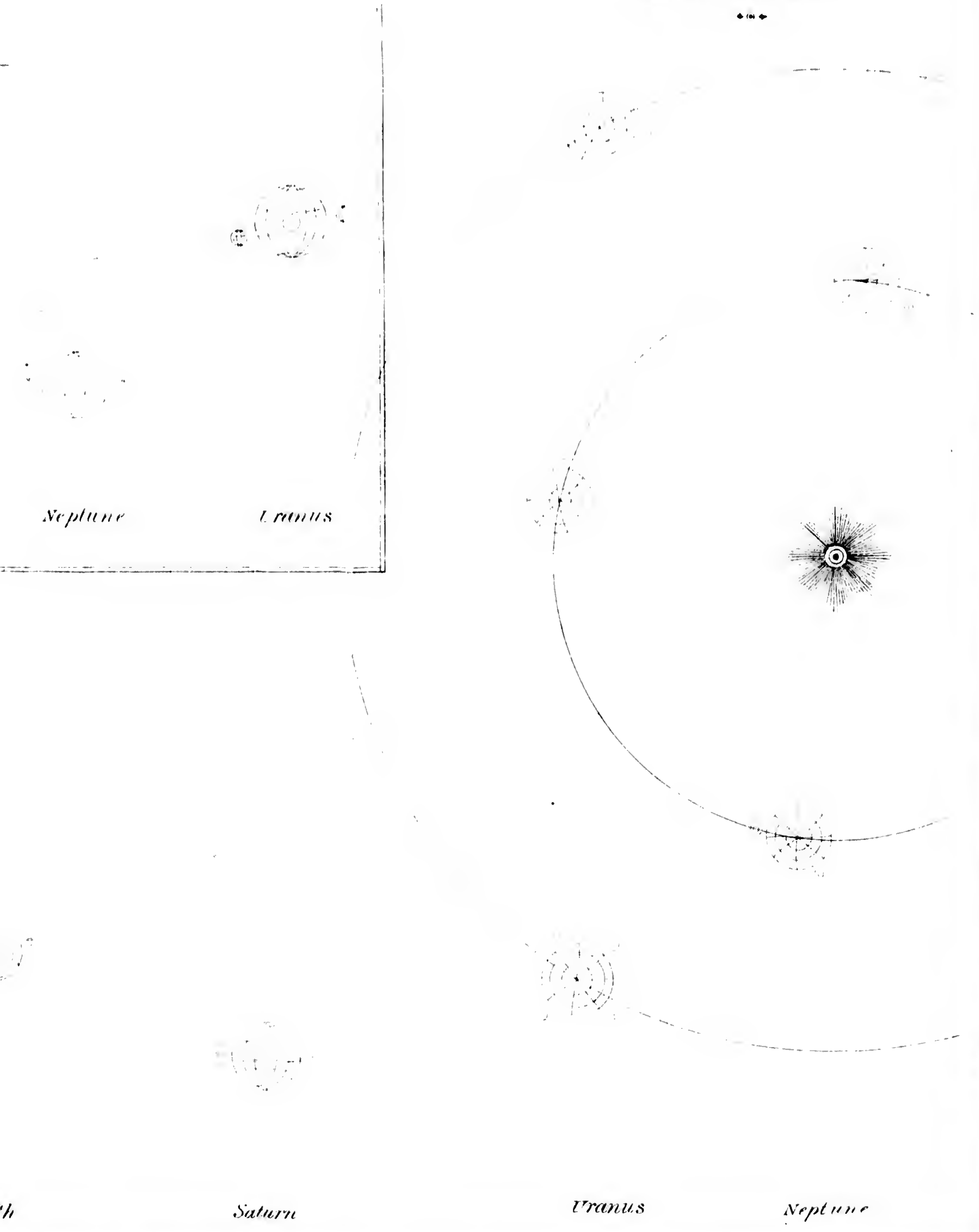
Vertical axis



Saturn — Earth — Sun — Earth

The Stellar System

Horizontal axis



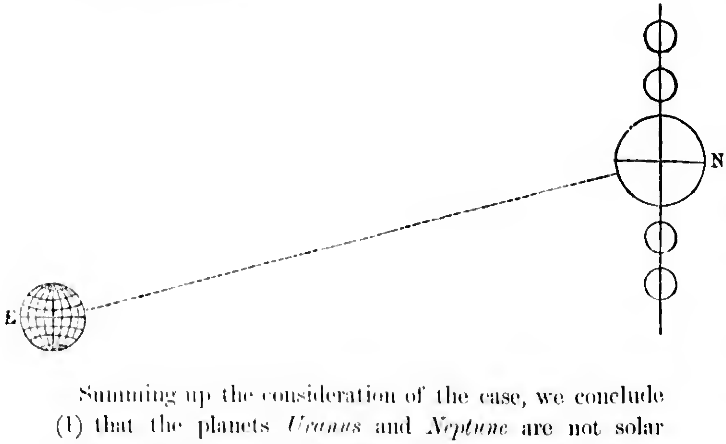
orbit must coincide (or nearly so) with a vertical plane joining the *central star* and the sun; for if it does not, let it be supposed that the plane of the planet's revolution is at right angles to the vertical plane joining the *star* and the sun; then, observation would show the planet's moons revolving 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 joining 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 vertical 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 4 and 5; 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

* 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.

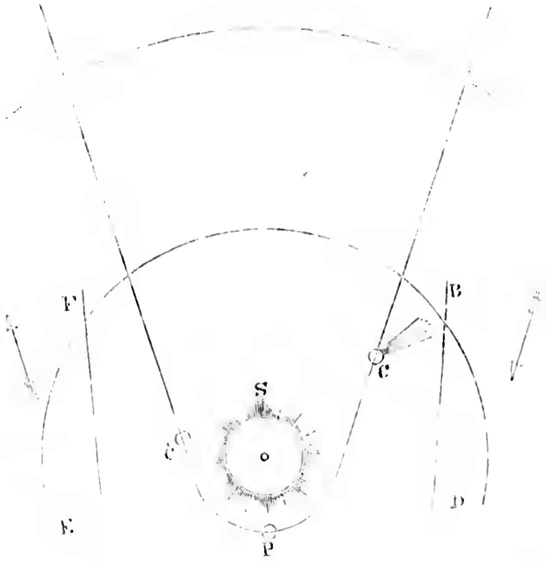
† On the assumption that *Uranus* and *Neptune* belong to the solar system, the orbital distance between *Mercury* and *Neptune* should be, according to Bode's law, twice that between *Mercury* and *Uranus*. It is now estimated, from observation, only to exceed the latter by a little more than half the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

observations as yet recorded of this planet cannot be 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 in regard to the solar spots, Suppt. A, page 11) 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.



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 planes of revolution perpendicular to those 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 4 and 5.)

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 unrecognised by mechanical science. We allude more particularly to those very various bodies at present grouped and classed together under the name *comet*. Plate 6 (from the *Encyc. Brit'a*) 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 recognised both by astronomical and mechanical science. In Fig. 7, 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 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 recognised laws governing matter when moving from B towards D, and if, even after passing its perihelion, it still retains its material nature and recognises 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

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PLATE 6.

From the Encyc. Britta.

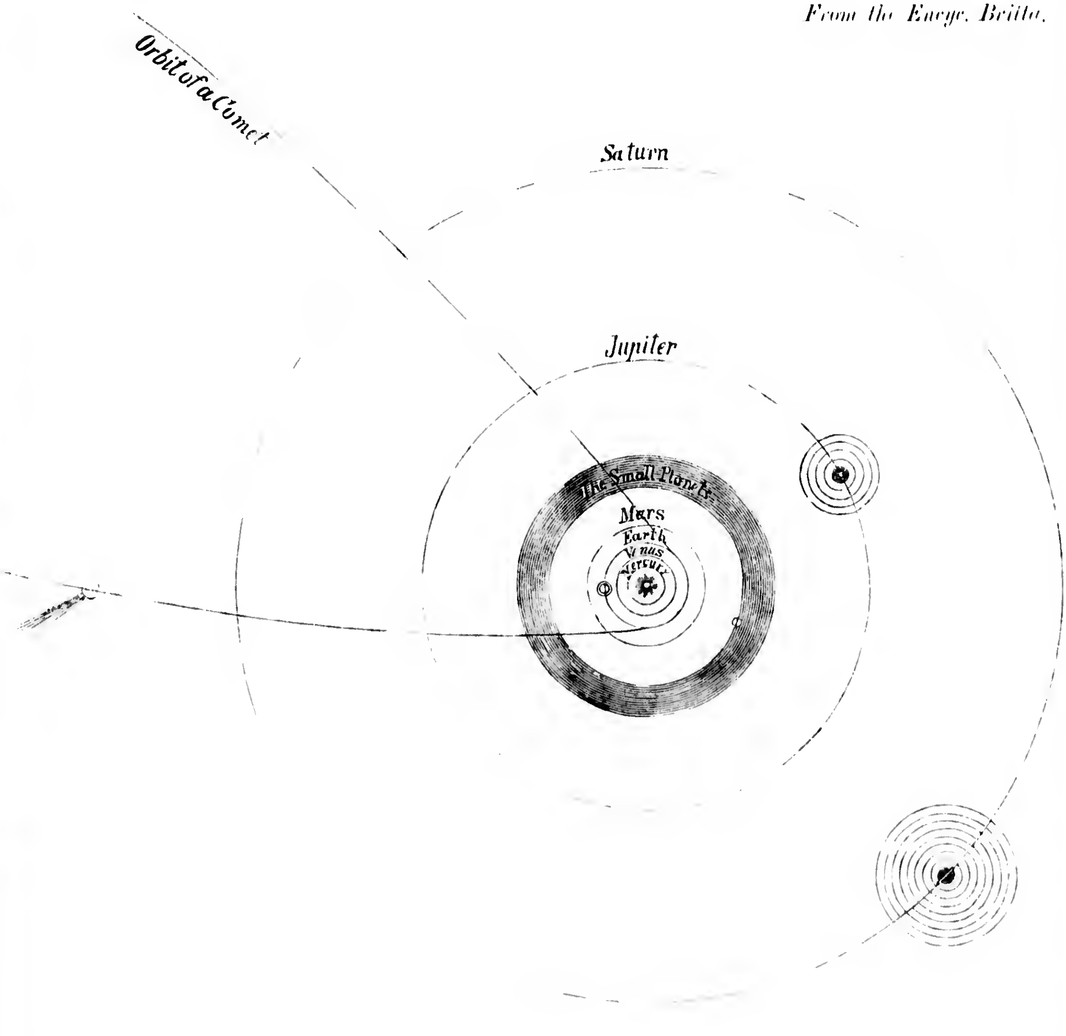

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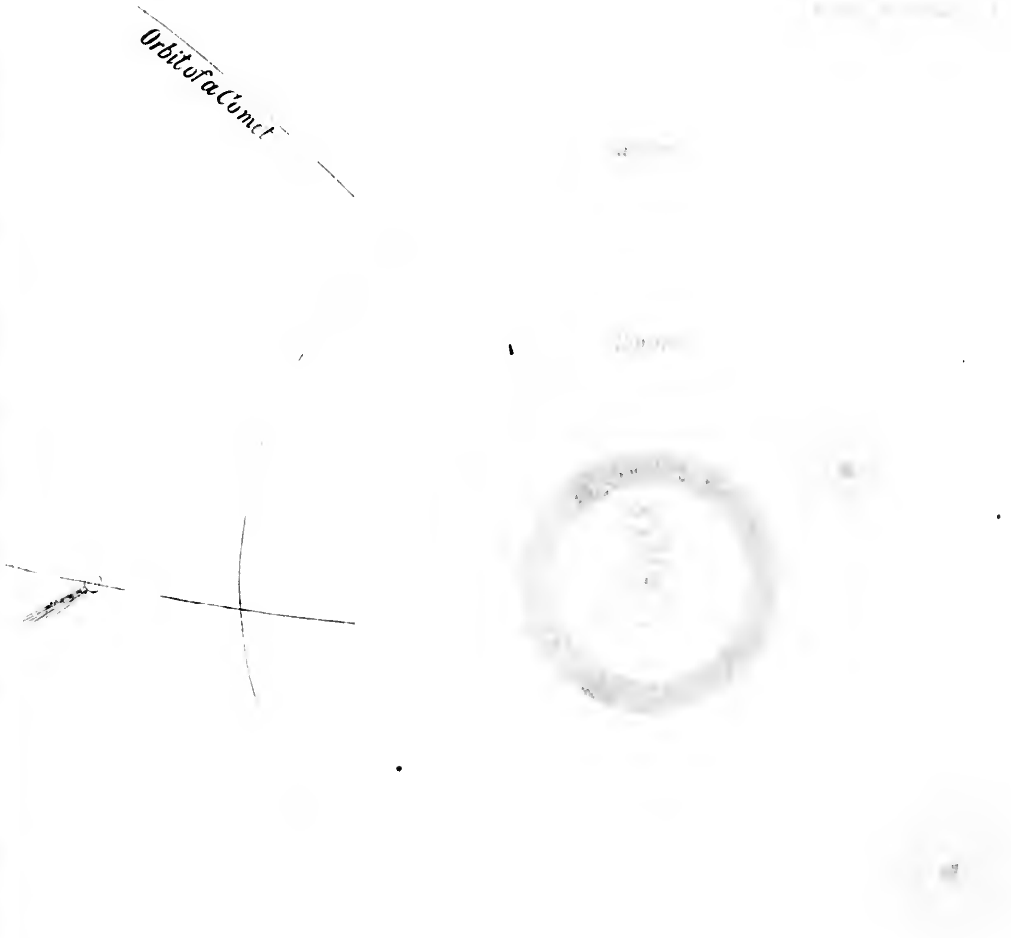
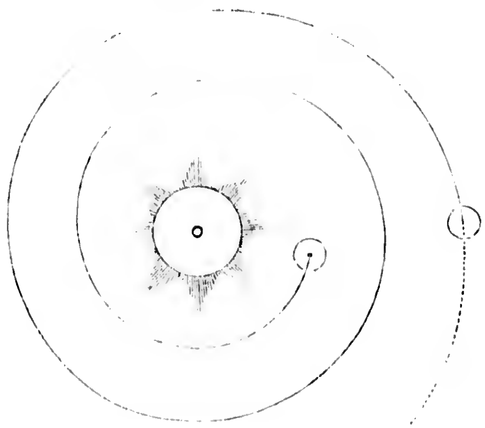
Plate 6



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 enormous 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, if the law of gravitation is interpreted according to the Newtonian theory—*i.e.* that the attractive force varies inversely as the square of the distance—then it also follows that the recession, having commenced, will continue indefinitely; because the *proportion* of the attractive force to the centrifugal force will (according to that theory) continually lessen as the distance increases; but even in such a case the recession could only take place in a curve with a continually increasing radius, 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 the centre.



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 3 (Suppt. A), 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; on the other hand, if the star was directly over the pole of the earth, a point could then be found by comparison with a number of the (so called) fixed stars, 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 sun (or ecliptic); 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;"* and as

* Parallax may be either diurnal or annual; in the one, the diameter, or part of the diameter, of the earth; in the other, the diameter of the

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 extract from

Herschel's Outlines of Astronomy, page 581:

(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

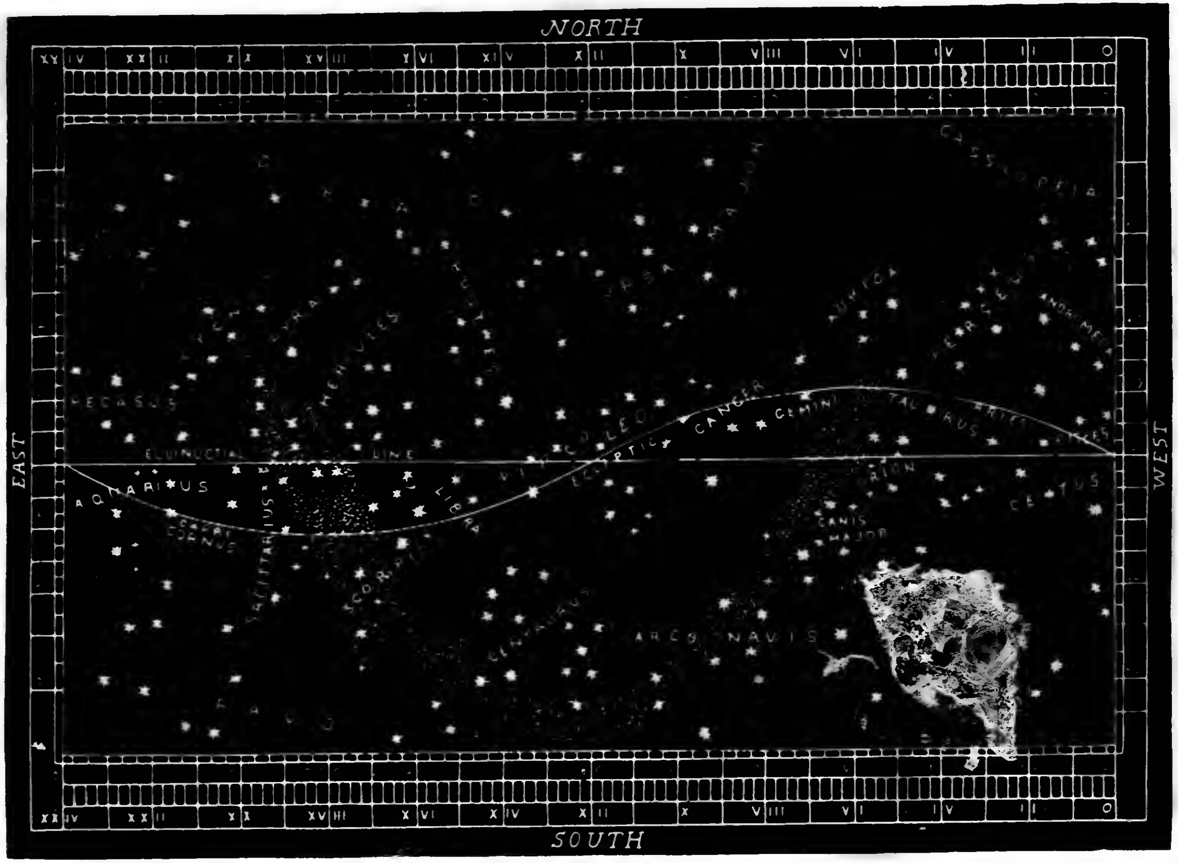
orbital circle of the earth's revolution is the measured base of the triangle. The general expression "parallax" is well defined in *Lardner's Astronomy* as "the apparent displacement of any object seen at a distance, due to a change of position (place) of the observer."

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 206265 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 ascer-

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



tained 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!"

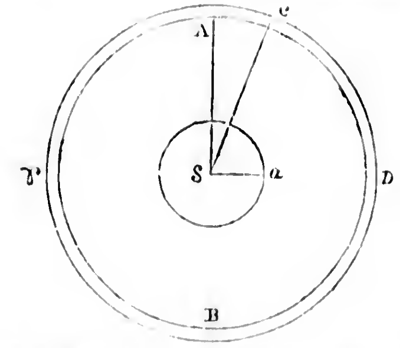
(803.) "The space-penetrating power of a telescope, or the comparative distance to which a given star would require to be removed in order that it may appear of the same brightness in the telescope as before to the naked eye, may be calculated from the aperture of the telescope compared with that of the pupil of the eye, and from its reflecting or transmitting 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 siderial 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 $3\frac{1}{4}$ 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 other 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 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

* "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."

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*SA, being a right angle. Drawing then AC equal and parallel to Sa, and joining SC, 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 (YSC) and that of aberration alone (YSA), 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."

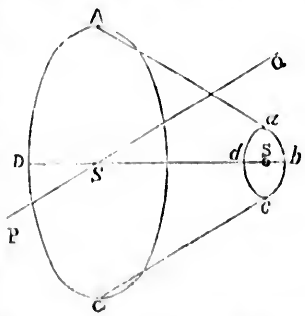
(806.) "But these other difficulties themselves are of no trifling order. All astronomical instruments are affected by differences of temperature. Not only do the materials of which they are composed expand and contract, but the masonry and solid piers on which they are erected, nay even the very soil 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 plumblines 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 α 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 $\frac{11}{12}$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 Konisberg, 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 Könisberg 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 juxtaposed, 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 purpose, 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 C*c*, 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."



(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 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 to 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 *α* 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 $\frac{1}{8}$ 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.)
Laland, 21258 . . .	0″.260	(Krüger.)
Oeltzen, 17415–6. .	0″.247	(Krüger.)
* *α Lyræ*	0″.155	(W. Struve, corr. by O. Struve)
Sirius	0″.150	(Henderson, corr. by Peters.)
70. *p Ophiuchi*	0″.16	(Krüger.)
Ursæ Majoris	0″.133	(Peters.)
Arcturus	0″.127	do.
Polaris.	0″.067	do.
Capella	0″.046	do.

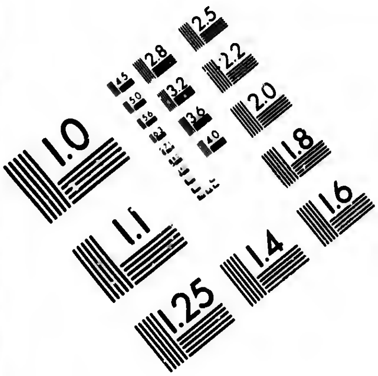
Although the extreme minuteness of the last four of these results deprives them of much numerical reliance, it is at least certain that the parallaxes by no means follow the order of magnitudes; and this is farther shown by the fact that α Cygni, one of M. Peters' stars, shows absolutely no indication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

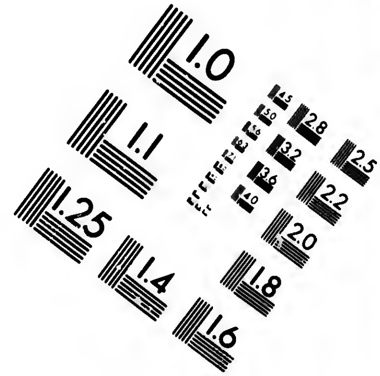
Let us now examine the "theory of aberration," to which (as shown by the foregoing quotation) so great an importance is attached by astronomers.

We will first take the explanation given by Dr. Lardner. *Handbook of Astronomy*, page 173:

(2440.) "*Aberration of light.*—Assuming, then, the velo-

* Qy. 0″.255 (see art. 813).





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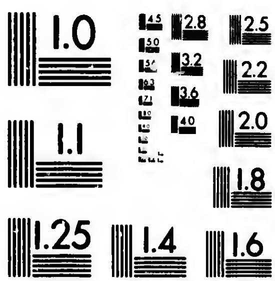

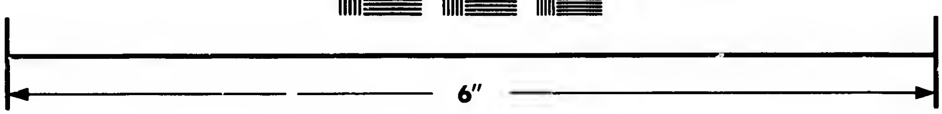

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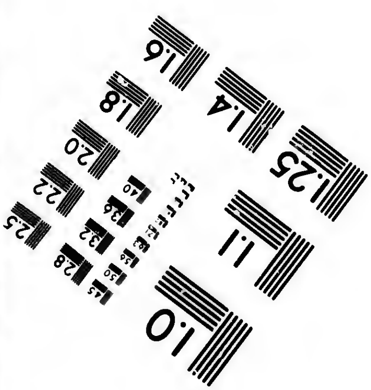
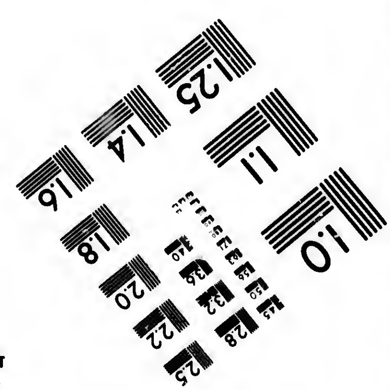
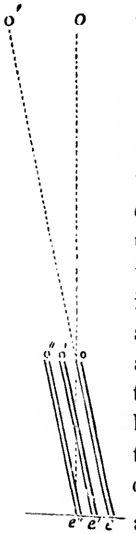




city of light, and that the earth is in motion in an orbit round the sun with a velocity of about 19 miles per second, which must be its speed if it move at all, as will hereafter appear, an effect would be produced upon the apparent places of all celestial objects, by the combination of these two motions 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 $o\dot{O}$, 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 $Oo\dot{O}$ 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 $a = \frac{206.265}{10.000} = 20'.42$. 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.

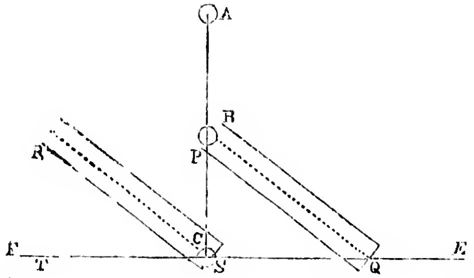
The phenomena may also be imagined by considering that the earth, in revolving round the sun, constantly changes the direction of its motion; that direction making a complete revolution with the earth, it follows that the effect produced upon the apparent place of a distant object would be the same if 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 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 RS of the tube's axis.

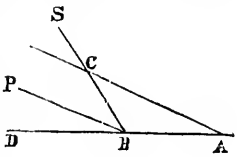
(330.) "Our eyes and telescopes are such tubes. In whatever manner we consider light, whether as an advancing wave in a motionless ether, or a shower of atoms traversing space (provided that in both cases we regard it as absolutely incapable of suffering resistance or corporeal obstruction from the particles 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 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

* "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."

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.



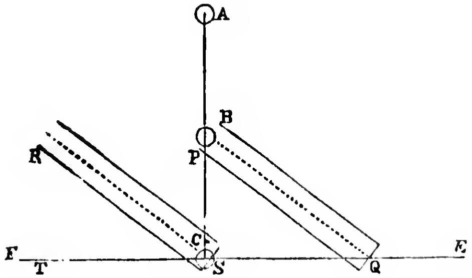
(333.) "The uranographical effect of aberration, then, is to distort the aspect of the heavens, causing all the stars to crowd, as it were, directly towards that point in the heavens which is the vanishing point of all lines parallel to that in which the earth is for the moment moving. As the earth moves 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 isusually 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 astronomical 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 having been in some degree confounded with 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 for particular examination. 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 even in this sense—*i.e.* as a simple statement of fact—it is not strictly true; and, upon more careful consideration, it will further appear, in respect to the application to be made and the inference intended to be drawn from it, that the statement is not at all 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 has 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 the same as if the drop had been suspended at that height from the ground at which it comes in contact with his face. If the rain was descending vertically, or even if descending at an angle in the same direction in which he was running—if his motion was sufficiently rapid, the rain might still come into contact with his face; would he, therefore, conclude that it was raining in the opposite direction to that in which he ran? The expression—"the rain strikes his face"—under such circumstances, although quite usual in ordinary conversation, is not, in a strict sense, correct; it should be, "he strikes his face against the rain." 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 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

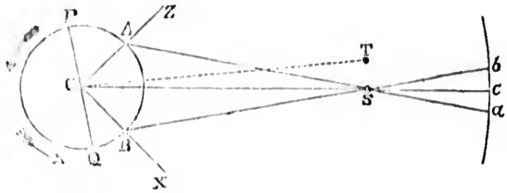


moving horizontally with a certain velocity in the direction EF. At P, in the perpendicular line APS, is a ball falling vertically from A, towards S; the proportional velocity of the moving plane EF to that of the falling ball is such, that a place on the plane will move from Q to S, in the same time 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 tow rds 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 will be continually arriving at the earth in all angular directions, 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; supposing the plane to be in motion, and Q to have been at the base of the tube when the ball commenced to descend, evidently 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 zeniths of the places

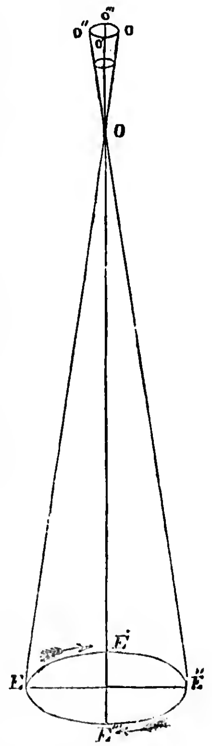


of observation were determined independently of the sun's apparent place, the effect would be to give a different parallax for the two places; that of BTC being greater than ATC; or if the zeniths of the two places of observation were determined by (derived from) the observed place of the sun, then the effect would be to increase the actual parallax—*i.e.* the total apparent displacement—by the distortion due to aberration. (*By an addition of* 20″.5 ?)

We are accordingly obliged to conclude that the aberration of light as described in the works of Lardner and Herschel, having no actual foundation in fact, is altogether imaginary. If, then, we assume that those observed effects which have been attributed by astronomers to aberration of light are 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 any star, even if the distance was much 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 then 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 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 it is supposed to have been found in observing the relative positions of the sun and the star to that of the earth when at the central place equally distant from the two extremities of the orbit; and then again observing the alteration in the relative angular position of the earth and sun, and the earth and star, respectively—in this manner obtaining two comparative angles which are proportional to each other in the same ratio as the distances of the sun from the star, and of the sun from the earth, are to each other; and since the last is a known quantity, the first can be thereby obtained. The following is the description and illustration given in

Lardner's Handbook of Astronomy, page 171:

(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.

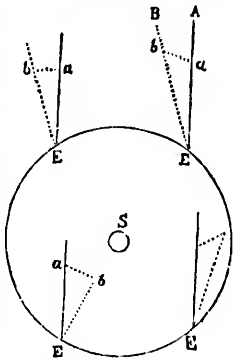


"To comprehend the effect which might be expected to be produced upon the apparent place of a distant object by such a motion, let *E Ė Ë Ë* (fig. 718) represent the earth's annual course round the sun as seen in perspective, and let *O* be any distant object visible from the earth. The extremity *E* of the line *EO*, which is the visual direction of the object, being carried with the earth round the circle *E Ė Ë Ë*, 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 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 *Ë*, it would be seen at o''. The extent of this apparent displacement of the object would be measured by the angle *E O Ë*, which the diameter *E Ë* 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 Brittanica*—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 its 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 always 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."



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."

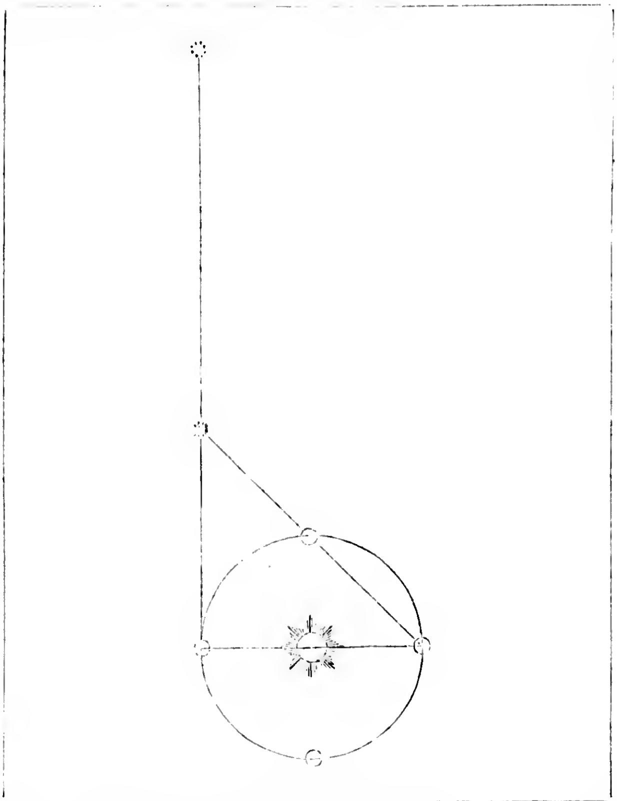
(2448.) "Yet, aberration cannot arise from parallax.—Notwithstanding this close correspondence, the phenomena of aberration are utterly incompatible with the effects of annual parallax. The apparent displacement produced by aberration is always in the direction of the earth's motion; that is to say, 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 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 48, taken from Lardner's own work, will show that the observed effect, amounting to 20″.4*, is precisely that which would be occasioned by parallax; and as it has been now shown that the theory of the "aberration of light" is not based on fact, and since that theory is consequently untenable, there is no longer any obstacle to prevent the observed effect—*i. e.* the 20″.4—being attributed to that cause to which it evidently belongs—namely, parallax. This amount 20″.4, therefore, may be considered as an approximation to the average or mean parallax of a great number of the visible stars. By the method of the heliocentric parallax—if the star was at a distance from the plane of the ecliptic 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—see Fig. 9).

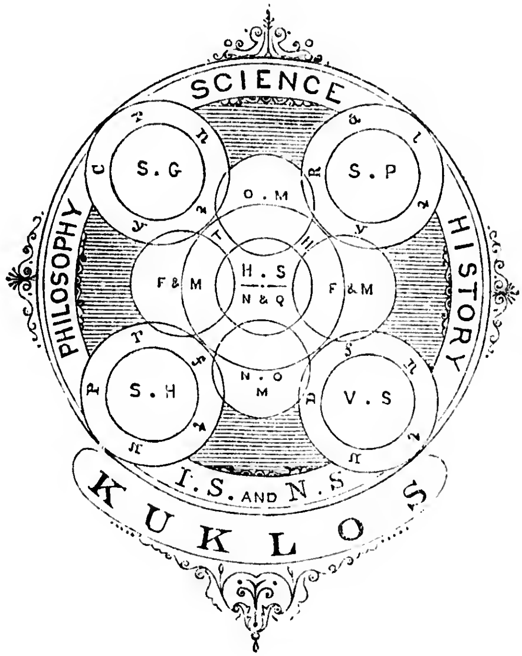
* In the preceding quotation from the *Encyc. Britta.*, this quantity is given as 40″.8; but the writer of the art. therein appears to have thus doubled the quantity, by attributing the effect due to the distance of the entire diameter of the earth's orbit to only half that distance.

We obtain, therefore, the proportion:

As 45° : 20″.4 : : distance of the star : 190 million miles,



which represents (approximately) the average or mean distance of those stars from the sun: (about) 90,529,518 million miles, or 952,942 times the distance of the sun from the earth.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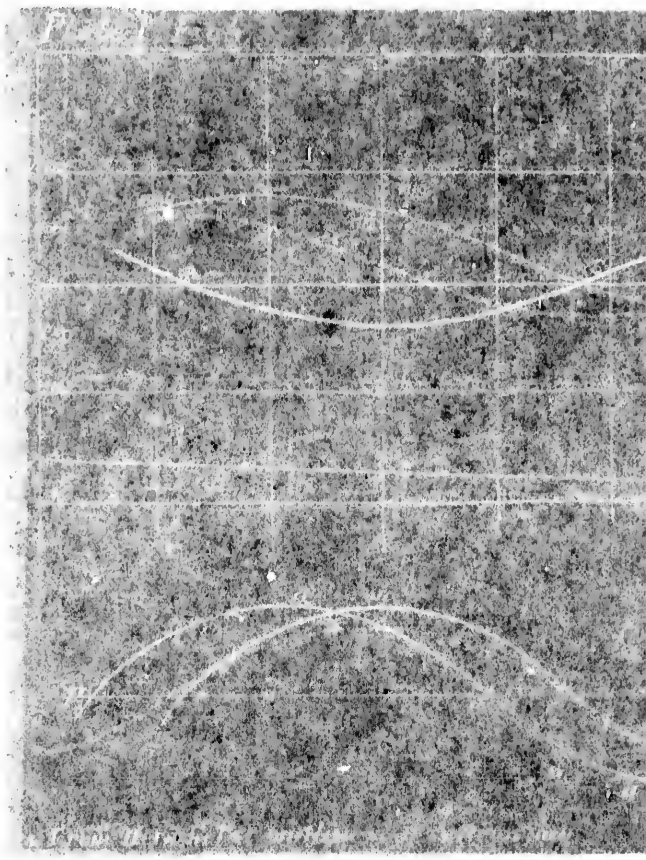


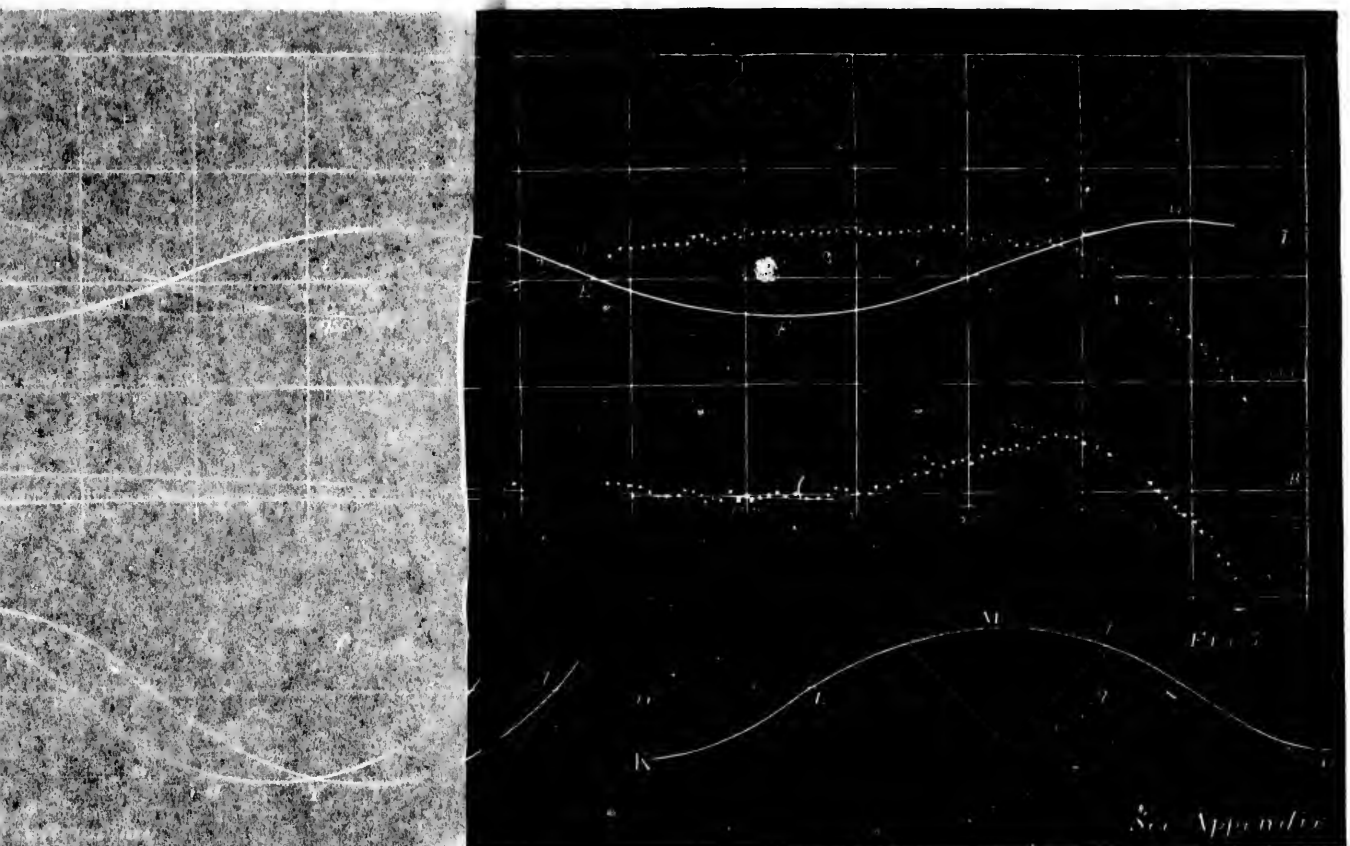
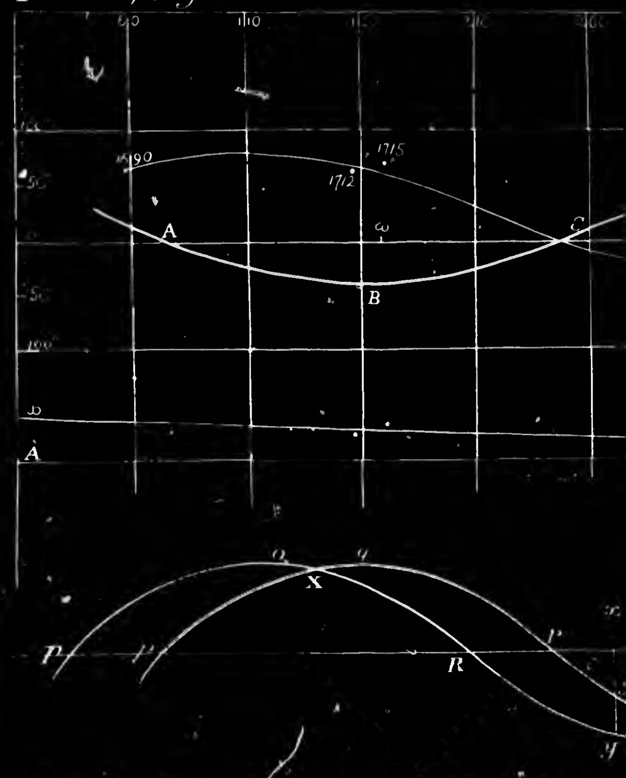
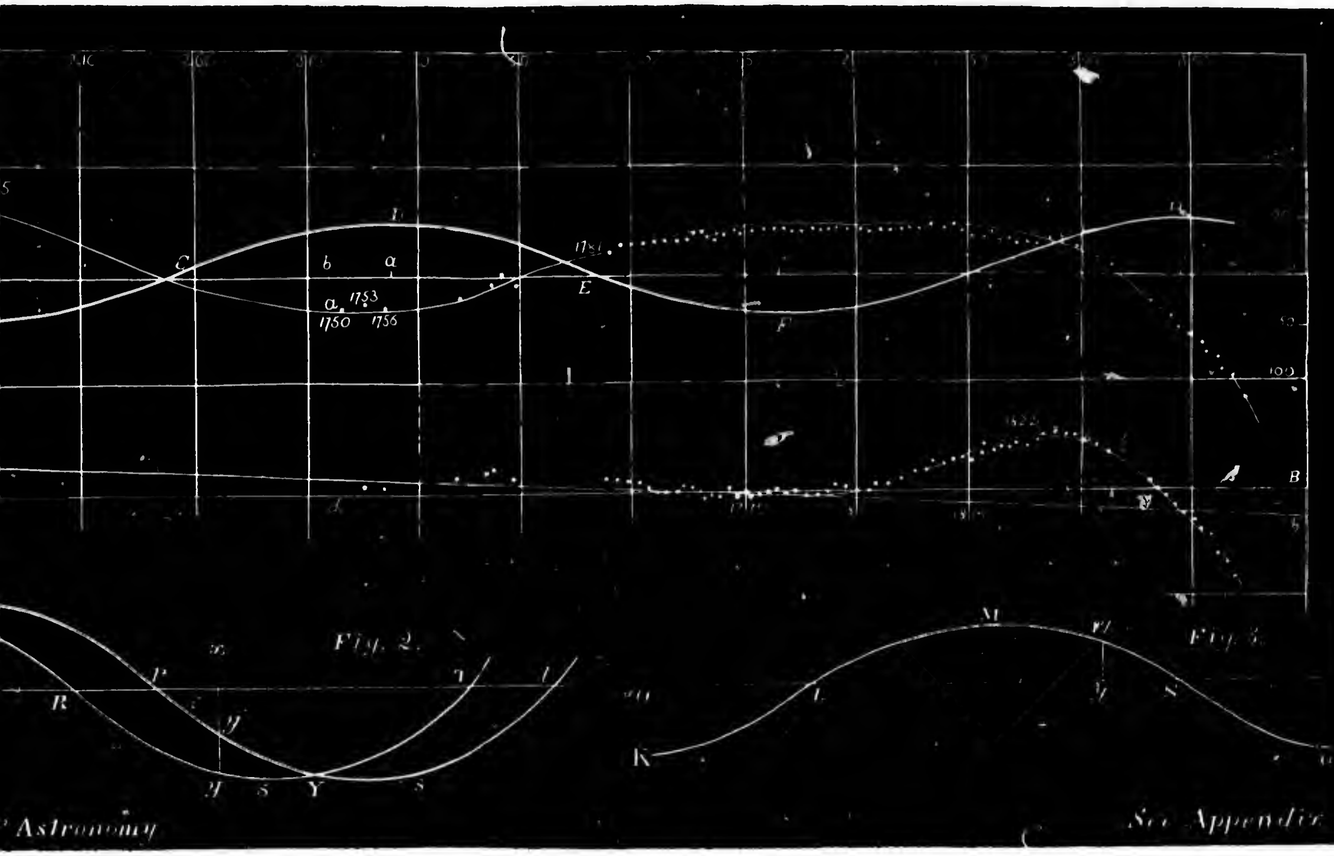

See Appendix

Plate I, Fig. 4.



From Herschel's Outlines of Astronomy


C
D
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1750
1753
1756
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Fig. 2.
P
R
Y
K
M
Fig. 3.
Astronomy
See Appendix

APPENDIX TO SUPPLEMENT B.

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."—(*Herschel's Outlines of Astronomy.*)

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 observations. 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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