## THE MOVEMENTS OF THE EARTH[1]

### V.

WE last appealed to those branches of physical science which are connected with the determination of the velocity of light, in order to see whether we could get any help in that direction on a most interesting question, a question which, like another to which attention has been drawn, might have been considered as an open one, unless one had gone beyond the range of ordinary astronomical observation with regard to it. It has now been seen that by investigating the facts connected with the velocity of light, first, that we could determine that velocity by two different methods with a wonderful agreement between them; and secondly, that, by taking the velocity of light and dealing with it in the way we then did, a perfect demonstration was obtained of the fact that the earth revolves in an orbit round the sun. It was further seen that using this velocity of light, and also this fact of the earth's revolution which it enabled us to demonstrate, we were able to say that the distance of the earth from the sun was, roughly speaking, $92\frac{1}{2}$ millions of miles.

We will now go more into detail with regard to the precise form of the earth's orbit, and consider some of the conditions under which the earth's movement in that orbit takes place. In proceeding to do this let us first suppose the orbit of the earth to to be in the form of a circle with the sun in its centre, then it is perfectly clear that the earth will always be at exactly the same distance from the sun, and that consequently the sun as seen from the earth will always appear of the same size; but on the other hand if the earth does not move in a truly circular orbit round the sun, then, unless she moves with great irregularity—and we shall see subsequently that she does not, the only other possible course for her to take is an elliptical one, because if she took an orbit of any other form—that of a parabola or an hyperbola for instance—she would not revolve about the sun at all, she would not have a succession of years each of $365\frac{1}{4}$ days' duration, but one year, a year of infinite length; she would in fact go off at a tangent into infinite space.

Let us then consider what will happen if the earth instead of moving in a circular, travelled in an elliptical, orbit, with the sun in one of its foci, and not in the centre of figure; then it is perfectly clear that the distance of the earth from the sun will vary, that she is nearer the sun at some points of her orbit than at others. So much for supposition. Let us consider the facts. We know that it is the duty of the astronomers at Greenwich to make daily observations, when possible, of the transit of the sun, by means of one of those transit instruments to which reference has been made. Now if the sun, as seen from the earth, had always the same apparent diameter, it is obvious it would always take exactly the same time to cross the central wire of the transit instrument; but when we turn to the record of the observations made at Greenwich we find this:—Take the year 1878. On January 9 in that year the apparent diameter of the sun was $33' 33''\cdot50$ of arc, whereas on July 13 of the same year it was $31' 30''\cdot24$; the apparent diameter was less, so that if these observations are to be depended on—and I know of none better—we were nearer the sun in January 1878 than we were in July. If that be so, then there should be two intermediate points when the diameter of the sun was the same, with an interval of six months between them. This is what was observed on two such dates in this same year, on April 5 an apparent diameter of $31' 58''\cdot16$, and on October 5 an apparent diameter of $32' 5''\cdot17$. In this latter case we have a difference only of $7''\cdot01$; in the former case a difference of over $2'$, so that the Greenwich observations quite justify the supposition that the earth moves, not in a circle, but in an ellipse; because, the greater the distance of the sun from the earth, the smaller it must appear. While we are on this subject of the ellipticity of the earth's orbit, I am anxious to draw your attention to the two diagrams, so that the matter may be as clear as possible. Let us consider the diagram, Fig. 43. We have drawn there an ellipse, and the earth is assumed to move in the direction of the arrow round the sun placed in one of its foci, S.

Now by the construction of an ellipse we know that S B, which represents the mean distance between the earth and the sun, is exactly the same as the distance A O or P O, which represents what is known as the semi-axis major of the ellipse; further, the eccentricity of any ellipse is defined by the ratio of O S to O A; when the distance O S is very large as compared with O A, then the ellipse is a very flattened one, and the shorter the distance O S as compared with O A the less flattened will be the ellipse and the more nearly will it approach a circle. It will now be clear why the two points are marked A and P, for if S be taken to represent the focus of the ellipse actually occupied by the sun, the point P will represent the place occupied by the earth when it is nearest the sun, which is called by a Greek word, "perihelion," whilst this other point A will mark that point in the orbit of the earth when it is farthest removed from the sun, this being called by another Greek word, "aphelion." This aphelion distance represents the semi-axis major plus the eccentricity, and the perihelion distance of the earth from the sun is obtained by a subtraction of the value of the eccentricity from that of the semi-axis major. These statements are general with regard to ellipses, and in order to make the point quite clear, we have shown them on the very flattened ellipse of Fig. 43, but the true form of the earth's orbit very nearly approaches a circle. If we want to find the greatest distance and the least distance of the earth from the sun at the opposite points of the orbit, we take the best value we can get of the mean distance S B, or O A, which is the same thing, and it is found that the eccentricity comes out about $1\frac{1}{2}$ millions of miles, so that the greatest distance of the earth is less than $94\frac{1}{2}$ millions, whilst its distance at perihelion is a little more than $91\frac{1}{4}$. So much then for the facts with regard to the varying distances at which the earth is found from the sun at different periods of the year.

The next point is this: if the earth moves in this elliptic path round the sun, does she always move with the same velocity, does she go more quickly at some times than at others, or does she travel always with a steady, constant pace? Now here again the question can easily be answered by an appeal to the

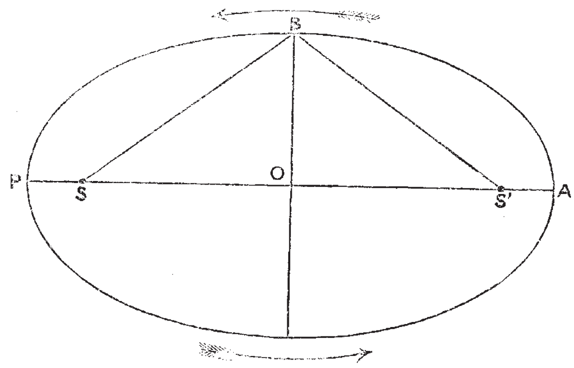


FIG. 43.

useful transit instrument. Our sidereal clock gives us a method, of determining the interval, true to the hundredth part of a second, between one transit of the sun over the central wire of the instrument and another, and so enables us to determine the number of degrees, minutes, seconds, tenths of seconds, and hundredths of seconds of arc passed over by the sun in that time. If the earth, therefore, in her revolution round the sun moves with an equal unchanging motion then it is clear that the number of degrees, minutes, and seconds of arc passed over in any given time will be always the same. Let us again consider the facts according to the Greenwich record. On December 27, 1877, the transit of the sun's centre occurred at 18h. 25m. 44·9s. sidereal time, but on the day before it took place at 18h. 21m. 18·5s. If this second quantity be subtracted from the first, the difference comes out as 4m. 26·4s., that being the amount of arc passed over by the earth in that interval. Now on June 29 of the same year we get 0h. 33m. 51·7s., whereas on the 28th the time was 0h. 29m. 43·3s., a difference of 4m. 8·4s. It is thus obvious that the motion of the earth is not uniform, and that being so, the question arises, Is this want of uniformity constant, or is it irregular? Is there, in short, any law governing it? It will be seen that there is a most perfect law about it; that when the sun looks biggest, that is to say, when we are nearest the sun, the earth moves most quickly, and that when the sun looks smallest from the earth, when the earth is at its greatest distance from the sun, it moves with its least velocity. This fact brings us face to face with a most fundamental law of astronomy—that law which is known as the second law of Kepler. This can be gathered from Fig. 44. Here S represents the sun in one focus of the ellipse

[1] Continued from p. 113.

representing the orbit of the earth, and we have P, $P^1$, $P^2$, $P^3$, $P^4$, and $P^5$ representing different positions of the earth at different times of the year, the distance between these points P and $P^1$, $P^2$ and $P^3$, and $P^4$ and $P^5$ representing the portions of the orbit passed over by the earth in equal intervals of time. This law is known as the Law of Areas. It states that in equal intervals of time the radius vector or line joining the earth and sun passes over equal areas in its revolution. Thus the area of the triangle S P $P^1$ is equal to the area of the triangle S $P^2$ $P^3$, and is also equal to the area of the triangle S $P^4$ $P^5$, and these areas of the orbit are passed over by the radius vector in equal intervals of time. When the earth is nearest to the sun she travels most quickly; when she is at her greatest distance from the sun she

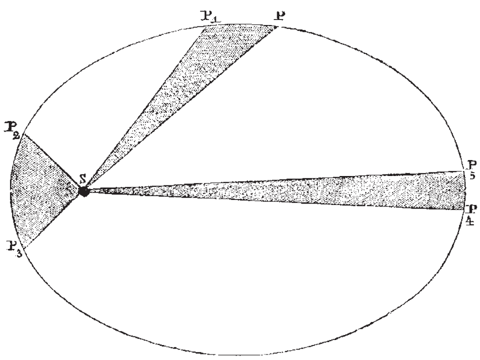


FIG. 44.—Explanation of Kepler's second law.

travels most slowly; and thus she keeps the figures inclosed by the radii vectores always of equal area during equal times. Let us be quite clear on this point: the law is not that the earth moves through equal distances in equal times, but that the areas of the spaces swept over by the radius vector are the same for equal intervals of time.

We come then to this: that the earth moves round the sun; that she moves in an ellipse; that she moves unequally, that is to say, with different velocities at different times, but that these different velocities are bound together by a well-defined and well-recognised law.

Now comes another question connected with this movement of the earth round the sun. When the movement of the earth on its axis was being discussed, it was pointed out that observations made by the transit instrument gave ample evidence that the movement was a perfectly equable one, and of such a nature that the axis of movement remained always practically parallel to itself. Attention must now again be turned to this axis of rotation. Let us take the earth in any part of its orbit, then the question is this: Is the plane of the earth's motion round the sun, or, as it must now be called, the plane of the ecliptic, identical with the plane of the earth's motion of rotation? That is to say, if the earth were half immersed in an ocean of infinite extent, whilst it was performing its orbital motion, would its axis of rotation be at right angles to the surface of the ocean in which it swam. Suppose we had a globe to represent the earth, and on it a model of a transit instrument were placed in the direction it is pointed at Greenwich when the sun is being observed. Then if the axis of the earth were really vertical the instrument would always be at right angles to it, or practically so, for sun observations. Further, if the model were turned round to represent one rotation of the earth, then if the axis on which it turned were really perpendicular, the sun's declination would remain unchanged, and its polar distance would always be 90°. Now let us refer to the Greenwich observations of the north polar distance of the sun.

| | | | |
|---|---|---|---|
| On March | 16 | N.P.D. was | 91·34 |
| ,, | 22 | ,, | 89·12 |
| June | 22 | ,, | 66 |

That is to say, the observers at Greenwich in going from March to June had to alter the inclination of their instrument, in consequence of this variation in the N.P.D. of the sun, to the extent of the difference between 90° and 66°. On September 21 of the same year the N.P.D. was 90°, but on December 17 instead of being 90°, or 66°, it was 113°·24. How can these facts be explained? Suppose we had a lighted lantern to represent the sun, and round it four globes were placed with their axes vertical to represent the earth in four different positions in its orbit. It will be obvious that if we bring the light of the lamp in succession upon the four globes with the axes in each thus vertical, then the zenith distance of the sun, represented by the lamp, would be the same in each case. In this position of the globes we get the boundary of light and darkness at the poles, and the line joining the centres of earth and sun

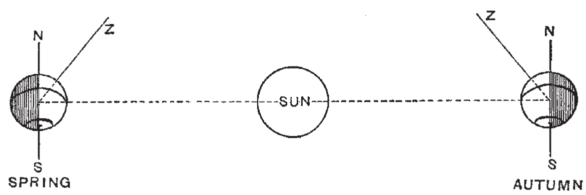


FIG. 45.—Diagram showing the equality of the sun's zenith distance at the two equinoxes. N, north pole of the earth; S, south pole; Z, zenith of Greenwich.

will give us the zenith distance of the latter. Now assume that the axis of the earth is not vertical but is inclined 23½° to the plane of the ecliptic. In that case its spin of course would not be at right angles to this plane. If the four globes were then illuminated in succession, it would be found that the presentation of Greenwich to the sun would be vastly different at the four

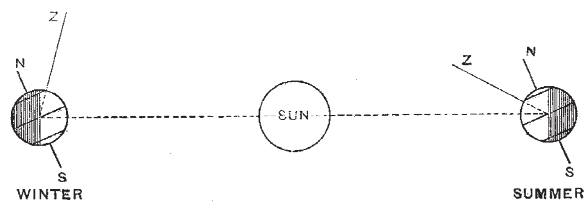


FIG. 46.—Diagram showing the variation of the sun's zenith distance from solstice to solstice. N, north pole of the earth; S, south pole; Z, zenith of Greenwich.

different positions. In the first, if it were placed in the proper part of the orbit, we should get Greenwich, not turned fully to the sun, but still well in his rays. In the second one we should find the vertical at Greenwich pointing very much more to the sun than before, when the axis was vertical. In the third globe the conditions would be about the same as in the first, while in

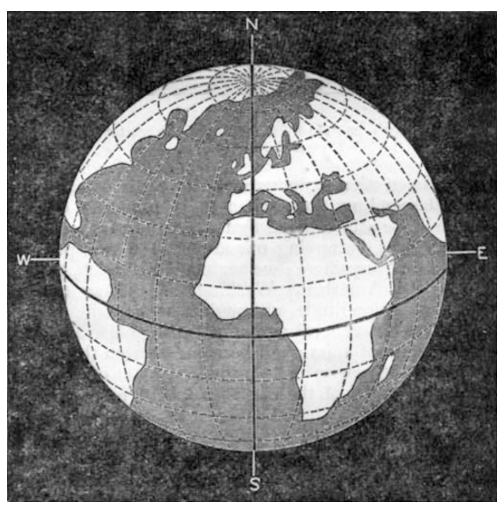


FIG. 47.—The earth, as seen from the sun at the summer solstice (noon at London).

the fourth the line which points towards the zenith at Greenwich, instead of being turned almost directly to the sun, would be turned most away from it. This fourth position is that in which the zenith distance, and therefore the N.P.D., was greatest, *i.e.* when it was 113°. The second represents the position of the earth when it was the least possible, whilst the first and third positions would occur when the N.P.D. of the sun was neither great nor small, but midway between the two extremes. These facts will be made clearer by the accompanying woodcuts, in which the globes are shown in four different positions. Fig. 45 represents cases 1 and 3, and Fig. 46 cases 2 and 4. In Figs. 47 and 48 these facts are shown in different ways: Fig. 47 represents the aspect of the earth as seen from the sun at the summer solstice, when it will be seen that England is seen to lie near to the centre of the hemisphere; while in Fig. 48, representing the conditions at the winter solstice, England is so near the edge that it cannot be properly represented. This experiment then will enable us to go further, and to say that the plane of the earth's equator, and therefore of the earth's spin, is not parallel to the plane of the ecliptic, but is inclined to it at an angle represented by the difference between 90° and 66°, or 90° and 113°; that is to say, the angle between these two planes, that of the earth's rotation and that of its revolution, is something like 23°.

In the non-coincidence of these two planes we have one of the most fundamental points in astronomy, for the reason that what Greenwich is to earth measurement the point of intersection of these two planes is to heaven measurement. The result of this inclination of these two planes is that at one particular point in its course round the sun the equatorial plane of the earth seems to plunge below the plane of the ecliptic, whilst at another and an opposite point it seems to come up from below that plane.

These two points are known as the nodes of the orbit, the

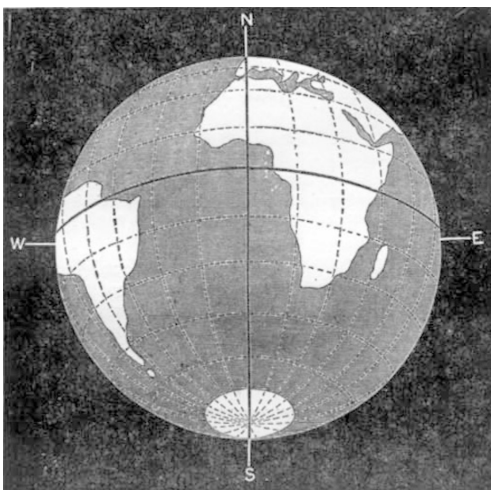


FIG. 48.—The earth, as seen from the sun at the winter solstice (noon at London).

ascending node at that point where the earth comes up from below, the descending node when it is plunging down from above. It will be remembered that when the question of terrestrial longitude was occupying our attention it was pointed out that it might begin anywhere: we begin at Greenwich, the French prefer Paris, the Americans Washington, and so on. With regard to celestial longitude, although it also might begin anywhere, yet there is a general agreement among astronomers that the right ascension of stars shall be counted from this ascending node, or, as it is otherwise called, the first point of Aries, where we get the intersection of the earth's plane of rotation with the ecliptic plane of revolution. That is the start-point not only of right ascension for the stars, but of celestial longitude, because it is necessary that we should have a means of determining the positions of stars, not only with reference to the plane of the earth's rotation, but with reference to the plane of the ecliptic itself, and the number of degrees which a heavenly body is observed above or below that plane (such degrees being called degrees of celestial latitude) require to be known in order to determine absolutely the position of any star. With the transit instrument and the sidereal clock the precise angle of intersection of these planes is determined, but it is necessary to know also the precise point in the orbit at which the intersection takes place, before we can use either our transit instrument or our clock for the determination of the precise position of a heavenly body. And now that so much has been said, we can go further with regard to our sidereal clock, and say that it shows oh. om. os. when the first point of Aries is exactly on the central wire of the transit instrument, and that it will come back to that time, oh. om. os., after an interval of twenty-four hours. In that way, by discussing the point of the intersection of the planes, we come to the conclusion not only that the earth's axis is inclined $23\frac{1}{2}$° to the ecliptic plane, but that we have at that point the most convenient starting point both for the right ascension of stars as determined by a sidereal clock, and the longitude of stars, if we choose to define their positions with reference to the ecliptic plane, instead of with reference to the plane of the earth's rotation. It is curious how in dealing with these matters we find that phenomena apparently the most diverse are really bound up in a most intimate connection with each other. In further considering the subject it will be seen that not only do we get these precious start-points from these considerations, but that they bring before us questions of the greatest interest and value to all earth-dwellers, questions that enable us accurately to study not only time as applied to the dealing out of our days and nights, as applied to those changes which take place during the year, as applied to those changes which effect the years themselves, but as applied to those yet greater changes which have probably been going on in this planet of ours for very many millions of years. J. NORMAN LOCKYER

(*To be continued.*)

## ZOOLOGICAL NOMENCLATURE

ON Tuesday last week a meeting was held in the Lecture Room of the Natural History Museum, where a number of leading British zoologists assembled to meet Dr. Elliott Coues, who is now on a visit to this country, and to hear from him an exposition of the views advocated by himself and the leading American zoologists with regard to the adoption of Trinomial Nomenclature.

Among those present were representatives of many branches of science, and we noticed the following British naturalists:—Lord Walsingham, Prof. Flower, F.R.S., Dr. Günther, F.R.S., P. L. Sclater, F.R.S., Dr. H. B. Woodward, F.R.S., Prof. Traquair, F.R.S., W. T. Blanford, F.R.S., Henry Seebohm, F.L.S., Howard Saunders, F.L.S., Prof. F. Jeffrey Bell, J. E. Harting, F.L.S., G. A. Boulenger, H. T. Wharton, F.L.S., S. O. Ridley, F.L.S., W. F. Kirby, Sec. Ent. Soc., Herbert Druce, F.L.S., W. R. Ogilvie Grant, and R. Bowdler Sharpe, F.L.S.

The chair was taken at 3 p.m. by Prof. Flower, F.R.S., the Director of the Natural History Museum, who briefly opened the proceedings by reading a letter from Prof. Huxley, P.R.S., expressing his great regret at not being able to be present, being prevented by pressure of official business.

The Chairman said:—The subject we have met to discuss is one of extreme importance as well as difficulty to zoologists, for though in so many respects the name attached to any natural object is the most trivial and artificial of any of its attributes, and may hardly be thought worthy of scientific consideration, laxity in the use of names causes endless perplexities and hindrances to the progress of knowledge. I must confess that I feel some sympathy with the young lady, lately quoted in a speech by Sir John Lubbock at the University of London as an instance of hopeless stupidity, who, after listening to a lecture on astronomy, said she had no difficulty in understanding how the distances, motions, and even chemical composition of the stars were discovered, but what puzzled her was how their names were found out. Now, I have often had little difficulty in making out the characters and structure of an animal, and even the functions of some of its organs, but when I have to decide by what name to call it, I am often landed in a sea of perplexity. Yet those of us who work in museums are constantly engaged in cataloguing and labelling, and we are supposed to be able at once to give the correct name to every creature in the collection. I hope that this discussion will help to clear up our ideas upon the subject. With the impartiality due from the chair, I shall not give any opinion upon the merits of the rival schemes to be proposed, at all events not until after hearing the arguments to be brought forward for or against them, and I cannot say that I am very sanguine of being able to do so then. I now call upon Mr. R. Bowdler Sharpe to read a paper "On the expediency, or otherwise, of adopting Trinomial Nomenclature in Zoology."