UNIVERSITY LECTURES.

ASTRONOMY.

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LECTURE III.

Annual motion of the sun only apparent.—Earth's annual revolution around the sun, the cause of the aberration of light.—The phenomena of aberration.—Illustrated by a moving body in a swift current of wind.—Form of the earth's orbit.—How determined.—Astronomical terms defined.—Apparent angular velocity of the sun.—Earth's real velocity variable.—Sun's distance.—How obtained.

In the preceding lectures we have demonstrated the earth's diurnal rotation from west to east in the period of twenty-three hours, fifty-six minutes and four seconds, mean solar time.

This period is called a sidereal day, because it is the time in which the earth performs its diurnal rotation in regard to the stars; for instance, if at 6 o'clock this evening a certain star is observed to be on the meridian, to-morrow evening the same star will come to the meridian at 5h. 56m. 4s. Therefore, a sidereal day, or a day reckoned from the successive returns of the meridian to the same stars is 3 m. 56 s. shorter than the mean solar day. The excess of the solar day above a sidereal day is occasioned by the apparent motion of the sun among the stars. The sun appears to move from west to east at an average rate of 3m. 56s. per day. At this rate he apparently moves round the whole circle of the heavens in 365d., 6h., 9m., 9.6s. This is called a sidereal year, or the time in which the sun apparently performs an entire circle, or comes round to the same stars whence the reckoning commenced.

This apparent motion of the sun will, perhaps, be more easily comprehended, if we suppose the earth to have no rotation upon its axis. Let us suppose that precisely at 32m. past four o'clock on the evening of the 21st of December the earth had ceased to rotate upon its axis. This being the precise time in which the sun was in the act of setting to the inhabitants of our city. Therefore if the rotation had then ceased, the sun would have ceased to descend behind the western horizon; the upper portions of his disc would still be visible

Now if the sun *had* no apparent motion in relation to the stars, he would still continue to remain in the horizon; but having a slow motion from west to east, he would in 24 hours appear to have risen above the western horizon, a distance nearly equal to twice his own apparent diameter. In a period of time equal to fifteen days, he would appear to have risen from the west nearly an hour above the horizon. In three months time, or about the 20th of next March, the sun would appear directly on the meridian at the equator. During the following three months the sun would gradually descend from the meridian towards a point in the eastern horizon which is 23 deg. 27 min. and 30 sec. north of the equator; it would arrive at this point about the 21st of next June; at this point the sun would gradually set, not to rise again until the 21st of next December, when he would be seen at the same point where he was seen to set just one year before. Thus the rising point of the sun would be in the western horizon 23 deg. 27 min. 30 sec. south of the equator, while his setting point would be on the eastern horizon the same number of degrees north of the equator as his rising point is south.

Under these circumstances, the inhabitants of the whole earth would have six months day and six months night. The general course of the sun during our day would be to the east-north-east; while to the inhabitants 180 deg. east of us his general course would be, during their day, east south-east. When the sun crossed the equator about the 20th of March, it would be our noon; when he recrossed the equator about the 22nd of next September, it would be midnight with us. Thus, if the earth had no diurnal rotation, we should still have one day and night in a year, resulting from the apparent annual revolution of the sun around the earth, from west to east.

The rotation of the earth upon an axis does not change the apparent annual motion of the sun, but if closely observed from day to day, he will appear to move to the eastward nearly one degree every day. This will appear more evident by watching the time of the rising of the stars on each successive morning.

For instance, if the stars which rise at 6 o'clock to-morrow morning be particularly noticed, it will be found that the same stars will rise on the next succeeding morning 3m 55. 908s before six. At this rate, in about one month from this time it will be observed that the same stars arise about 4 o'clock, and that the interval of time between the rising of the stars and the sun will be about two hours longer than now; and in three months time the same stars will rise about 12 o'clock at night, making the interval between their rising and that of the sun still greater. Therefore, by these phenomena we know that the sun has an apparent motion eastward which constantly increases the interval of time between his rising and that of the stars. For if the same stars be observed six months hence they will be found rising at six in the evening instead of six in the morning, the sun having progressed from them by degrees until he has passed one half round the great circle of the heavens. If the same stars be observed by a telescope about nine months hence, they will be found to rise about 12 o'clock in the day, and will set about 12 at night, the sun having in that interval gone ½ round the heavens. In about eleven months hence, the sun will have so nearly described a circle, that the same stars will be but a few degrees east of the sun, and will set shortly after the sun sets; while in one year from this time, the sun, having passed by those stars will rise in the morning later than they, having performed one complete circle of the heavens; and all the stars will have the same relative position in regard to the sun that they now have.

From these appearances alone, it is impossible for us to decide whether the sun actually goes around the earth once a year, or whether the earth goes around the sun. It is very evident that either the former or latter motion would present the same appearances, in the same order, and in the same time. This may be illustrated in the following manner: Let a man, stationed upon a table in the centre of this Tabernacle represent the earth: let a lighted candle be carried around him, representing the apparent annual revolution of the sun; let the walls of the house represent the sphere of the starry heavens. In the revolution of the candle around the man in the centre, it will be referred successively to every point in a horizontal plane cutting the sides of the house. Now if the light should perform one revolution around the man in about 365 days, it would be equal to the period of the sun's revolution.

If, furthermore, the man should not turn round during the revolution of the candle, each side of him would be successively six months in the light and six months in the shade; which would represent day and night upon the earth providing it had no rotation.

If the man were to turn round in the same direction that the candle was moving at the rate of 366 times while the candle made one annual revolution round the room, then each side of him would be successively turned to the light of the candle and then into his own shade 365 times during that period, but as he would have to rotate upon his axis 366 times in order to face the candle 365 times, he would therefore face the stars that might be delineated upon the walls of the tabernacle once more in the year than what he would the revolving candle.--Now all these appearances are exhibited by the sun. The earth turns upon its axis 366 times in 365 solar days, consequently the same side is presented to the stars 366 times, and to the apparently revolving sun only 365 times in the same *period*.

Next let the man and the candle exchange places, that is, let the candle remain stationary upon the table while the man shall walk around it once in 365 days. During this period, he will refer the candle successively to the different sides of the building which are directly opposite from him; and when he has completed one revolution, the candle will appear, by referring it to the walls, to have completed one revolution also. If the man while performing his annual revolution around the central candle, should not turn upon his axis, that is, if he should not face in different directions, but keep in a position constantly fronting in a particular direction, as for instance towards the east, then each side of himself would be successively 6 months in the light and 6 months in the shade of his own body; this phenomenon would be the same if he were stationary and the candle moving around him.

Suppose again, that during the time of his annual revolution around the stationary candle, he should make 366 complete rotations of his body; let the directions of these rotations be such that the side of himself most distant from the central candle shall be constantly turning in the direction of his annual motion. Under these conditions, he would successively face the central light 365 times, while his face would be turned, during the same period, to the stars delineated upon the walls of the building 366 times; the former would represent the number of solar days in a year while the latter would represent the number of sidereal days in the same period. Hence it will be seen that a moveable man around a central light, or a moveable light around a central man, will produce all the above described phenomena in precisely the same order.

Observations upon the sun's relative position among the fixed stars, demonstrate this alternative—either that the earth or sun has an annual motion; for there is no other motion that would be consistent with the phenomena observed. It is evident that if the earth were in motion, we should not be sensible of that motion by our feelings, any more than we would be sensible of motion in a smooth, uniform current that was gently carrying us down a river.

From any of the appearances which we have described, it would be impossible to determine whether it were the earth or sun that performed this annual circuit. But we have other evidence of a very decisive character.

If the annual motion of the sun be considered real, it must revolve around the earth under the influence of a force directed to the centre of the earth. This force, whatever it may be, is the same as that which retains the moon in its orbit around the earth. From observations upon the periodic revolutions of the moon, it is easily demonstrated, that this central force varies in its intensity as you recede from the earth in the exact propertion of the inverse square of the distance. It is also demonstrable from a principle in mechanics, that if a system of bodies revolve around a central force varying according to the duplicate ratio of their distances, that the squares of their periodic times are proportional to the cubes of their respective distances.

Now by the application of this law, it is easy for us to determine the exact distance at which a body must be placed from the centre of the earth that it may have a period exactly equal to that of the sun's annual period. The following proportion will determine this question:

The square of the moon's sidereal period (=27. 32 days)^2 : the square of [the sun's sidereal period

(= 365. 26 days)^2. : : the cube of the moon's mean distance (= 237, 600 miles)^3 : the cube of the sun's mean distance (=1,354,000 miles.)^3.

Thus it will be seen that a body revolving around the earth in 365 1-4 days, must have a distance not greater nor less than about 1,354,000 miles; but the sun's horizontal parallax obtained by the most careful observations, shows that he is situated more than 70 times further off than he should be in order to have his periodic time correspond with the above law. Therefore his annual motion around the earth must be apparent, and not real.

But should any one feel disposed to doubt that the force which binds the moon in her orbit was extended to the sun, and suppose that the sun revolves around the earth under an entire different force from that exerted upon the moon, then we should be under the necessity of searching for some other phenomena to decide the question whether the sun's annual motion were *apparent* or *real*.

Fortunately the great discovery of the aberration of light furnishes us with the most incontestible evidence of the earth's annual motion around the sun. Roemer, a Danish astronomer, in the year 1667 from a comparison of the observed times of the eclipses of Jupiter's satellites with their computed times, discovered the progressive motion of light. He found its velocity to be about 192,000 miles per second. A little over a half century afterwards, Dr. Bradley, an English astronomer of great eminence, commenced a series of observations of great accuracy upon the fixed stars to ascertain, if possible, whether they were subject to any minute apparent changes in their relative positions in consequence of the annual revolution of the earth in its orbit. He soon found that there were apparent changes constantly taking place; but not such as should result from the different positions of the earth in its orbit. Each star in the heavens seemed to revolve, once a year, in a very small elliptical orbit whose greatest diameter never exceeded 41″ of a degree. Those stars situated near the poles of the ecliptic, or at right angles to the plane in which the sun performs its apparent annual motion, appeared to revolve in small orbits very nearly approaching circles. As you proceed from these polar points towards the ecliptic, the eccentricity of these small elliptical orbits seems to increase. The major axis in each of these ellipses was observed to remain constant, being equal to 40″. 72, while the minor axis seemed to vary in proportion to the latitude of the stars, decreasing as the latitude decreased. A star situated in the ecliptic seemed to oscillate in a straight line, the minor axis being reduced to nothing. These strange phenomena were such as could not be accounted for upon the principle of the annual parallax of the stars, or upon any other principle then known.

Dr. Bradley, after many trials to reduce these phenomena to a general law, at last happily succeeded in discovering the true causes of these curious appearances. He demonstrated that they were the results of the combination of the motion of light with the motion of the earth in its annual revolution around the sun.

If the motion of light were instantaneous, that is, if it required no appreciable time to come from a distant luminous body to the eye, then all these displacements of the stars in the form of little elliptical orbits would entirely cease; and the stars would be seen in their true places directly in the centre of those ellipses, whether the earth were at rest or in motion; but the velocity of light is an appreciable quantity, and when combined with the velocity of the earth, it appears to come from a different direction from what it would if the earth were at rest.

This may be illustrated in the following manner: Suppose that the wind should blow directly from the north with a velocity of 30 miles per hour; a weather-cock or vane on the top of a railroad car at rest would point out the true direction of the wind. Suppose now that the rail car should be put in motion due east with a velocity of 30 miles per hour, the direction of the wind would no longer appear to be north, but it would seem to come from the north east. Next let the car go directly to the west with the same velocity; the vane upon the top will now point to the north west, which will be the apparent direction of the wind. The less the velocity of the car, the less will be the angle of the apparent displacement of the wind from its true direction. Suppose then that the velocity of the car be about 10,000 times less than that of the wind; the apparent displacement of the wind would then be about 20″ of a degree from its true place.

Now let us apply this principle to the combination of the motion of light with the motion of the earth. Let us suppose the light to come from a star in the pole of the ecliptic with the velocity of 192,000 miles per second; if the earth were at rest we should see the star in its true place. Suppose next that the earth should be put in motion in the plane of the ecliptic to the eastward with the velocity of about 19 miles per second; we should no longer see the star in its true place, but the rays of light would have an apparent displacement of about 20″ of a degree to the eastward of its true place. If the velocity of the earth were increased to 192,000 miles per second, the star would apparently be displaced 45 degrees; being equal to the apparent displacement of the wind when the velocity of the car was equal to the velocity of the wind. As the velocity of the earth decreases so will the angle of apparent displacement decrease. If the earth should go to the westward in the ecliptic at the rate of 19 miles per second, the apparent position of the star would be 20″ of a degree to the westward of its true place. In whatever direction the earth may be moving in the plane of the ecliptic, the stars will appear to be displaced in a direction parallel to that motion, towards a point in the heavens which the earth, for the moment, seems to be approaching.

Hence, as the motion of the earth is not in a straight line, but nearly in a circle, it is evident that a star situated in a pole of the ecliptic, perpendicular to that motion, must constantly alter its apparent direction as the earth in its orbit alters its direction. And, therefore, it must necessarily have an apparent annual revolution in a very small orbit around its true place, which will be exactly in the centre.

We will suppose next that the wind was blowing from the northeast, while the car was going with the same velocity east, the vane would now point east-northeast; hence the displacement of the apparent direction of the wind would only be one half what it would have been had the motion of the car been at right angles to the motion of the wind. Were the true direction of the wind to the northwest, while the direction of the car was east, the vane would point to the north-northwest, if the velocities were equal. In this case, the apparent direction would be more northerly than the true direction; while in the other case, it would be more southerly; and in both cases, the wind, by the motion of the car, would seem to shift 22 1-2 degrees towards the point to which the car was moving.

Thus it will be seen that the nearer the true direction of the wind is to the line of the motion of the car, the less will be its apparent displacement. When it blows in the direction that the car is moving, or in the opposite direction, its displacement will be nothing, and the vane will point out its true direction.

Now if the motion of the earth be taken for that of the car, and the motion of light for that of the wind, phenomena precisely of the same same kind will happen in regard to the apparent direction of a star situated in the ecliptic; for instance, if about the time of sunset on the 21st of December we observe a star situated in that portion of the ecliptic which is on our meridian, we will see it in its true place, because the earth will be going in its orbit directly from the star; if the star be observed every day for three months to come, it will be seen to move apparently to the westward, arriving at its maximum distance about the 20th of March next, when the direction of the motion of the earth would be at right angles to the motion of light from the star; it would then gradually begin to recede back again towards its true position; and at the end of three months more, or about the 21st of June, it would be seen in its true position, as the motion of the earth would then be directly towards the star; during the next three months its apparent motion would be to the eastward in the ecliptic, obtaining its maximum distance about the 21st of September, when the motion of the earth would be again at right angles to the motion of the rays of light from the star; and for the next three months it would apparently recede back again to its true place, at the end of which it would be seen in the same position as it occupied one year before. Thus each year it would appear to oscillate in a straight line in the ecliptic, deviating from its true place, on each side about 20 seconds.

These phenomena will perhaps be more clearly perceived by supposing a railroad car to be drawn round the circumference of a circle once a year, while the wind blows constantly from one direction, say from the north; let the car start from a point on the east side of the circle towards the south with a velocity ten thousand times less than the wind, which is about the proportion of the earth's velocity to that of light; when the car starts it will be going directly from the wind; hence the vane will point the true direction of the wind. While the car gradually describes the first quarter of the circle, it will gradually deviate from a southern to a western