UNIVERSITY LECTURES.

ASTRONOMY.

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LECTURE V.

The Sun.—His Distance and Magnitude.—Trigonometrical terms defined.—Sun's Volume.—Weight of the Sun.—How determined.—Law Governing the Revolution of Bodies.—Density of the Sun.—Relative Weight of Materials on the Sun's Surface.—How ascertained.—Rotation of the Sun.—Determined by spots on his surface.—Inclination of the Sun's Equator to the Ecliptic.—Velocity of the Sun's Equator.—Distance through which a body will fall in one second at the Sun's Equator.—Rapid Vibrations of a Clock Pendulum on the Sun's Surface.—What Velocity of Rotation will Destroy the Weight of Bodies at the Sun's Equator.—Ellipticity of the Sun's Figure.

OUR inquires have hitherto been principally restricted to the form, magnitude, diurnal and annual motions of the earth—to the form, dimensions and positions of its orbit, and to the principal phenomena arising from its transition in space.

The next most important and interesting subject of inquiry is the Sun—the great central luminary, from which is received an inexhaustible supply of light and heat; and by which the countless species of organized beings which people our globe, are sustained in life.

We have already learned, by our former investigations, that the sun is situated in one of the foci of the elliptic orbit, described by the earth, as it wheels its annual course around that resplendent luminary.

It would certainly be a subject of great interest to learn the distance, magnitude, motions, weight, density, physical constitution and all other important features of the great centre of our system.

The distance of the sun is, as we have already observed, obtained by a simple trigonometrical computation from the observed horizontal parallax, and is in round numbers about 95,000,000 of miles. Let me here observe, that, though we have hitherto been somewhat particular in expressing magnitudes, distances, times and motions within a small fraction of their true numerical value, yet we shall hereafter abandon this strictness, as being, for general information, not only unnecessary, but inconvenient.

Round numbers are more easily remembered than others; and for conveying general information, they answer every purpose.

Where great accuracy or strictness is required, tables are constructed with the greatest of care, to which the astronomer can, at any time, refer for the numerical elements necessary to be used in his researches.

Knowing the distance of the sun, let us next inquire how its magnitude can be ascertained.

This problem, like that of the distance, is solved by the simplest principles of trigonometry.

As the magnitude of all the heavenly bodies which have been determined, have been obtained by the same principles, it may not be uninteresting to explain some of the principles of trigonometry. An angle is the inclination or opening between two straight lines; the angle is greater or less as the lines are more or less opened.

A right angle is the opening made when each line is perpendicular to the other; the opening of a right angle is equal to 1-4 of a circle; all angles less than a right angle are called acute angles; all angles greater than a right angle are called obtuse angles. The fences enclosing our city blocks are intended to stand at right angles to each other.

A triangle is a plane enclosed by three sides; to every triangle there are three angles, as well as three sides.

If, in a triangle, the three sides, or two sides and an angle, or one side and two angles, be known, the other angles or sides can be easily calculated.

Now if we conceive lines drawn from our eye to each side of the sun's disc, it is evident that the length of these lines will be known, each being equal to the sun's distance.

The angle, or opening of these two lines may be measured by a micrometer, or any accurate instrument. This angle is equal to the sun's apparent diameter, whose disc subtends or opens these two lines; hence, we shall have two sides and their included angle given or known, to find the other side of the triangle, which will be the real diameter of the sun. It is upon this simple principle that the real diameter of the sun is ascertained to be in round numbers equal to 888,000 miles.

Perhaps this may be simplified in another way, so as to be brought more fully within the comprehension of those who are not in the habit of reflecting upon these subjects. It is a fact well known by every one, that the sun and full moon appear to be of the same size. If their angular breadth be measured by instruments, they will on an average, be found to subtend about the same angle.

This is apparent to any one who will compare the breadths of the two discs in a solar eclipse; for then the moon is in a direct line between the earth and sun; and when their centres are in a direct line, it will be observed that the moon's disc sometimes entirely covers the disc of the sun, producing a total eclipse; at other times, a narrow circular ring of light will be seen, while the other portions of his disc will be hid by the central interposition of the dark body of the moon.

This is called an annular eclipse. This slight deviation in the apparent size of the two discs is owing to the variation of the relative distances of the sun, moon, and earth at different seasons of the year. Upon the whole, then, it may be safely asserted, that the average apparent dimensions of the sun and moon's discs are equal.

The distance of the moon from the earth is about 240,000 miles, or about 400 times nearer the earth than the sun; yet these two bodies appear to be of the same size.

Now suppose the moon to be removed as far from the earth as the sun, the apparent breadth of its disk would be 400 times less than the apparent breadth of the sun. If the moon were really of the same dimensions as the sun, it would have the same apparent size as the sun when removed at the same distance.

But as it has the same apparent dimensions only, when it is situated 400 times nearer, it follows of necessity that its real diameter must be 400 times less than the sun's.

Now the real diameter of the moon has been determined by the most careful observations and measurements to be a little over two thousand miles; let this be multiplied by 400, the product will be 800,000 miles.

Therefore the diameter of the sun must be 800,000 miles, or more accurately, as we observed before, 888,000 miles.

It is very difficult for us to form any conception of such stupendous magnitudes.

If the centre of the sun coincided with the centre of the earth, its surface would extend more than 200,000 miles beyond the moon's orbit.

The diameter of the earth is about 8,000 miles; but the sun's diameter is 111 ½ times greater.

Having once ascertained the diameter of a globe, it is an easy matter to calculate its volume, for the volumes or real bulks of globes are to each other as the cubes of their diameters.

Therefore, by multiplying 111 ½ into itself three times, we get the volume of the sun compared with the earth; which is equal to 1,386,196 times the volume of the earth; or in round nambers, the sun is about 1,400,000 times larger than the earth; in other words, if 1,400,000 globes of the size of the earth were united and moulded into one, they would form a globe of the dimensions of the sun.

If all the planets and satellites of our system were united in one, their bulk would not be the one-five hundredth part of that of the sun.

In some of our former lectures, we pointed out the method of weighing the earth; but the astronomer is required to perform still greater wonders than this.

It is his duty, not only to weigh the globe which we inhabit, but to soar aloft with his astronomical balances through the vast spaces which separate the planetary bodies, and accurately weigh those stupendous globes, and declare the quantity of matter which each contains.

Even the sun itself can be weighed with the most unerring certainty. But how can this be accomplished? Where can balances be found of sufficient magnitude to contain these vast bodies?

What astronomer is capable of winging his flight to those distant worlds to examine the materials of which they are composed; to place them in balances, or make experiments of any kind so as to form an accurate judgment as to their weights?

We reply that the astronomer has his balances on hand—balances too, of the most perfect kind; he is not under the necessity of leaving his native earth to explore the solar system, but can with the greatest of ease balance world with world, and determine which is the heaviest.

Every astronomer is in possession of such a balance.

The great astronomical Balance for weighing worlds, was not made by our American or London artists, but was constructed by the great Architect of nature; its use was entirely unknown until discovered by the gigantic mind of the immortal Newton; since whose time, astronomers have been as familiar with weighing worlds, as chemists are in weighing the proportional ingredients which enter into the various compounds which come under their investigation. But what is the nature of this balance?

We reply, that it is the amount of deflection which one body has towards another, which determines the quantity or weight of the matter towards which the deflections are made; for instance, the relative quantities of matter in the earth and sun are ascertained by comparing the moon's deflections towards the earth with the earth's deflections towards the sun.

The amount of these deflections can be calculated if we know the distances and periodic times.

Now the distances of the sun and moon from us are known, as also the periods of the moon's revolution around the earth, and of the earth's revolution around the sun, therefore, from these data, the deflections, and consequently the relative quantities of matter contained in the earth and sun can easily be deduced.

It may not be uninteresting to this audience if this principle should be illustrated by a reference to some of the most common and familiar experiments, with which we are all more or less acquainted.

We all know that when a body is made to revolve in a circle, it has a tendency to recede from the centre.

This tendency will be greater as the velocity of revolution becomes greater, and as the distance from the centre increases.

This fact is manifest by the whirling of a stone in a sling; the longer the string, or the greater the velocity with which it is whirled, the more will the string be stretched.

If the velocity be sufficiently augmented, the string will break and the stone will recede from the centre.

It is not the force of gravity which tightens the string; for if the stone be whirled in a horizontal instead of a vertical plane, the same tendency to recede from the centre will be manifested. If the string be lengthened or shortened while the time of revolution remains the same, the tendency to stretch the string will be proportionally increased or diminished.

On the other hand, if the string remain of the same length while the velocity of the stone in its revolution is increased or diminished, or (which amounts to the same thing) while the time of revolution is diminished or increased, the tendency to stretch the string will be proportionally increased or diminished.

Thus, it will be perceived, that there are two causes which increase or diminish the tendency of the whirling body to recede from the centre; one is the increased or decreased distance from the centre of motion—the other is the decreased or increased time of its period.

Now let us endeavor to ascertain the exact law of the force which stretches the string, as depending on each of these causes separately. 1st. What will be the force which stretches a string that is twice the length of another string, if they be attached to equal weights and be made to whirl round in a circle in equal times?

It is evident that the weight attached to the long string would have twice as far to move as the other weight—and the deflections from the tangent would be twice as great as in the smaller circle; therefore, the tension of the longer string will be twice that of the shorter. When the time of revolution is the same, if the string be three times longer, the tension will be three times greater; if it be four times the length, the tension will be four times greater, and so on.

Now the distance from the centre of the earth to the moon is about 240,000 miles, which is equal to 1,267,200,000 feet; hence, if a string equal in length to the moon's distance, with a weight attached, be made to whirl round in the same time as a string one foot in length, the tension, or the centrifugal force which stretches the longer string, will be 1,267,200,000 times greater than the tension or centrifugal force of the shorter one.

Again, if one string, equal in length to the distance of the sun, be made to whirl round in the same time as another string, equal in length to the distance of the moon, the tension, or centrifugal force of the longer string would be about 400 times greater than the tension of the shorter, for the distance of the sun is about 400 times greater than the distance of the moon.

In all these cases, it is supposed, that the weights or masses of matter attached to the ends of these several strings, are equal and that the periods or times of completing their respective revolutions, are also equal. Under these conditions, we easily perceive the law of the increased or decreased tension of the string; depending on the distance of the revolving weights, that is, the tension varies directly as the distance; this is the law.

2nd. What will be the force which stretches two strings of equal lengths, if the weights attached to them be equal and they be made to revolve in circles in unequal times? According to the mathematical principles of mechanics, the strings would be stretched inversely as the squares of the times of their respective revolutions; for instance, if one of the weights be made to revolve twice as quick as the other, the tension of the string will be 4 times greater than the one having the greater period. If one performs its revolutions 3 times as quick as the other, the tension of the string will be 9 times greater. If the period of one be 4 times sooner than the other, the tension or centrifugal force will be 16 times greater, and so on.

It makes no difference how long these strings are, provided they are of equal lengths; for at all equal distances at which the weights are made to whirl round, the inverse squares of the respective times of their revolutions will be proportional to the tension of the two strings.

Now let us suppose that each of the strings is 95,000,000 miles long, and one be whirled round in one year, and the other in 600 years; in what proportion will the two strings be stretched.

The string whose period is 600 times less than the other, will be stretched 360,000 times more than the one having the greater period. Therefore, the law of tension, governing strings of equal length, to which are attached equal weights, may be expressed in the following words:

The tension of the strings varies inversely as the squares of the times of their respective revolutions. It will be perceived that the law of force by which a string is stretched, as depending on the lengths when the times and weights are equal, and also as depending on the times of revolution when the lengths and weights are equal, has been investigated. From these two laws, it is evident that we can calculate the proportional tensions of strings, although their given lengths and periods of revolution are unequal; for instance, what will be the proportional tensions of two strings, one of which is one foot long, and the other four feet long, the time of the revolution of the shorter being one second, and that of the longer being two seconds. According to the law depending on the lengths, when the times are equal, the tension of the longer would be four times greater than that of the shorter one; but, according to the law depending on the inverse square of their times, when the lengths are equal, the tension of the longer would be four times less than the shorter; from both of these causes, combined, their tensions would be equal. Again, what will be the proportional tensions of two strings, one of which is 240,000 miles long, and the other 96,000,000 of miles long; or in other words, whose lengths are as the respective distances of the moon and sun, the time of the revolution of the weight, attached to the shorter string being 27.322d. and the time of revolution of the longer 365.26d.

The tension of the longer string, according to the law, depending on the distance, when the times are equal, is 400 times greater than that of the shorter one, because the length of one is 400 times greater than the other, but the tension of the longer string is about 179 times less than the shorter, according to the law of the inverse squares of their periodic times, when the lengths are equal.

If 400 be divided by 179, the quotient will be about 2 1-4; therefore, from the law of the periodic times and distances, it is proved that the longer string has nearly 2 1-4 times more tension than the shorter one; that is, if the longer string connected the centres of the earth and sun, and the shorter string connected the centres of the earth and moon, the earth, in revolving round the sun in 365.26 d, would pull upon or stretch the string, by its tendency to recede from the centre of motion nearly 2 1-4 times more than the moon would stretch a string, connecting it with the earth, her period being 27.322 d.

This tendency of the earth to recede from the sun, and of the moon to recede from the earth in their respective revolutions, is called the centrifugal force; and the strings which we have supposed to connect these bodies and which prevent them from flying from their centres are called the forces of gravitation, or the centripetal forces.

In circles the centrifugal and centripetal forces are exactly equal; therefore, as we have shown above, that the centrifugal force of the earth, as it whirls around the sun, is about 2 1-4 times the centrifugal force of the moon, as it whirls around the earth, it follows that the gravitation of the earth towards the sun is 2 1-4 times greater than the gravitation of the moon towards the earth.

Thus, it will be seen, that the proportional forces of gravitation, exerted by the heavenly bodies at different distances, are calculated by the same law or rule, as the proportional tension of strings of different length, and which are whirled round by means of weights attached to their ends, with different degrees of velocity.

But, as will be shown more fully hereafter, gravitation increases as the square of the distance decreases; that is, at 1-2 the distance, gravitation is four times as great. At 1-3 the distance it is nine times as great. At 1-4 the distance it is sixteen times greater. At 1-400 part of the distance, it is 160,000 times greater. Therefore, if the earth were placed as near the sun as the moon is to the earth, the gravitation of the earth towards the sun would be 160,000 times greater than it is now; but it is now 2 1-4 times greater than the moon's gravitation to the earth; consequently, if we multiply 160,000 by 2 1-4 the product will be 360,000.

Therefore, at equal distances, the earth gravitates to the sun 360,000 times more than the moon does to the earth; that is, the sun contains 360,000 times more matter than the earth.

We have thus explained how to use the great astronomical balance for weighing worlds, and have given an example by weighing the sun, which we find to be about 360,000 times heavier than the earth. We now leave this balance in your hands; and if you will follow the simple rules which we have given, you will be enabled to weigh Jupiter, Saturn, and some of the other great bodies of our system.

We will here observe, that the numbers used in the above calculation are not as exact as would be requisite for computing the relative masses of the sun and earth for astronomical purposes, yet the principle being the same, they answer every purpose for scientific illustration.

The solution of this great problem may be ranked among the wonders, unfolded by the mathematical principles of mechanics.

Who could have supposed, that the revolution of planets in their orbits was a phenomenon precisely of the same kind, as the whirling of a stone in a sling.

Who could have believed, that by simply knowing the weight of the earth, its periodic time, the length of a string, the weight