UNIVERSITY LECTURES.

ASTRONOMY.

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LECTURE VIII.

Saturn.—Its Rings.—Belts of Saturn.—Rotation of the Planet and Rings.—Stability of the Rings dependent on three Causes.—Variety of Saturnian Seasons. When the Rings are Invisible.—Phases of the Rings.—Scenery from the Surface of Saturn.—Fifteen Years Total Eclipse.—Eight Moons.—Their Periods and Phases. Uranus.—Its Characteristics.—Satellites of Uranus.—Their Anomalous Orbitual Motions.—Seasons on Uranus.—Peculiar Adaptations.

SATURN.

Of all the grand objects of the solar system, Saturn is truly the most wonderful. This magnificent orb, encircled by a system of rings, and accompanied by eight moons, performs a revolution around the sun at the mean distance of 906,000,000 of miles in 10,759¼ of our days, or in about 29½ years: When nearest the earth, it is 811,000,000 of miles distant, an interval which could not be traversed by a cannon ball, flying with a velocity of 500 miles an hour, in less than about 184 years. ehT circumference of its orbit is 5,695,000,000 of miles; a distance so great that a steam carriage, moving at the rate of 20 miles an hour, would require above 32,500 years to complete the journey. Saturn rolls in silent grandeur around this whole circuit at an average rate of 22,000 miles every hour.

Saturn is nearly as large as Jupiter, being 79,000 miles in diameter; around this stupendous globe are two magnificent rings, situated in the plane of the equator, and nearly concentric with the planet and with each other. The inner edge of the interior ring is several thousand miles distant from the surface of the planet, and consequently has no contact or connection with it. From the inner to the outer edge of the interior ring, or its breadth, is nearly equal to its distance from the planet. The interval between the interior and exterior rings is 1,791 miles. From the inner to the outer edge of the exterior ring, or its breadth, is 10,000 miles. The thickness of these rings can not exceed 250 miles. These rings have no connection or contact with each other. Let it be understood, that these rings do not encircle the planet in the form of a broad belt or zone, extending several thousand miles each side of the equator, but they encircle that globe in the plane of its equator with their edges directed towards its centre. The dimensions of this extraordinary appendage, as calculated from Professor Struve's micrometric measures are as follows:

Exterior diameter of exterior ring,	176,418	miles
Interior do do	155,272	"
Breadth of do	10,573	"
Exterior diameter of interior ring,	151,690	"
Interior do do	117,339	"
Breadth of do	17,175	"
Equatorial diameter of the planet,	79,160	"
Interval between the planet and the interior ring, - - -	19,090	"
Interval between the rings, - -	1,791	"
Thickness of the rings not exceeding	250	"

It will be perceived that the thickness of the rings is incomparably smaller than their breadth. From recent observations it is believed, that the rings are not only double, but that they are separated by four, and, as some observers declare, by six divisions. If these observations can be depended upon, then there must be five, and perhaps seven, rings concentric with each other. The interval between each ring must be exceedingly narrow.

The disc of Saturn appears striped with dark and bright belts, running parallel with its equator. These belts are broader than those of Jupiter, but the alternations of light and shade are less strongly marked. These belts are, no doubt, produced by a similar cause to that operating upon Jupiter, being the results of the great atmospheric currents, arising from the difference of temperature in different latitudes, and greatly modified in their direction and velocity by the swift rotation of that planet upon its axis.

The axis of rotation is perpendicular to the plane of the rings, and also to the belts. The planet revolves from west to east in a period of 10 hours, 29 minutes, and 17 seconds. The ring revolves around the planet in its own plane in the period of 10 hours, 32 minutes and 15 seconds; which is almost exactly the same period as the planet's rotation, there being only two minutes and 58 seconds difference. Whether the several rings revolve in the same period, has not been determined by observation, but it is extremely probable from certain mechanical considerations, founded on the laws of force and distance, that there must be a difference in their periods in order that the system may be maintained in a stable form of equilibrium.

It may be enquired, how the rings are prevented from breaking up and falling down upon the surface of the planet? The answer to this is the great centrifugal force of rotation. If a moon were placed at the distance of 79,924 miles from the centre of Saturn, it would revolve around the planet in exactly the same period that the ring now revolves. A satellite then, in order to have the same period with the ring, would actually occupy a position in the exterior ring at a distance of 2288 miles from its interior edge or 8285 miles from its exterior edge. The centrifugal force of a satellite in the exterior ring would be just equal to the centripetal force towards the planet; therefore it would have no tendency to fall towards or recede from the planet. Now if we suppose two, three or a hundred moons situated at the same distance from the planet, they would all have the same period, and consequently would be under the same influence of the same two antagonistic forces, and would continue to revolve at the same distance. Now, if instead of a hundred moons, we suppose a ring of moons, joined side by side, encircling the planet at the same distance from its centre; such a ring of moons would have no more tendency to collapse or fall towards the planet, than one moon would. And further, if every moon in this ring, instead of being spherical, should be flattened out so as to form a ring similar in every respect to the exterior ring that actually surrounds Saturn, such a ring would revolve in the same period and at the same distance as one moon, and would have no disposition to fall towards Saturn, though it were broken into any number of fragments.

The interior ring, if it had the same period of rotation as the exterior, would have a tendency to fall towards the planet; for with the same period the centrifugal force would be less than the centripetal. To prevent this tendency to fall, the rotation of the interior ring must have its velocity increased in the inverse proportion of the square roots of the distances of the two rings; that is, the middle portion of the interior ring is 67,257 miles from the centre, while the distance of the point in the exterior ring at which a satellite would revolve in the same time as the ring, is 79,924 miles. The square root of the first number is 260; the square root of the second is 283; therefore a point on the middle of the breadth of the interior ring would move 283 miles, while the point in the exterior ring moved 260 miles.

The actual velocity of the nearest point would be 14.326 miles per second; while the actual velocity of the other point would be 13.238 miles per second. If the exterior ring revolves in 10h 32m 15s, the interior ring should revolve in 8h 11m 37s, nearly 2h 21m sooner. With these velocities, neither of the rings would have any tendency to collapse.

The quantity of matter towards which the outer ring gravitates is a trifle greater than the quantity towards which the inner one gravitates; therefore, for this reason, the inner ring must move a very small degree slower than it otherwise would. I have not made the necessary allowance in the foregoing calculations.

Although the great centrifugal force of rotation is calculated to preserve the rings from contracting until they finally coalesce with the surface of the planet, providing that the centres of gravity of the rings and planet exactly coincide,—yet if these centres, from any external causes whatsoever, become separated by ever so small an amount, it can be demonstrated that the derangement will go on increasing more and more, until the edge of the ring nearest to the centre of the planet will finally come in contact with its surface. An equilibrium of instability is the name given to this kind of mechanical conditions; it may be exemplified by balancing a rod upon the tip of the finger. While the rod stands in an exact vertical position, it maintains itself in a state of equilibrium, and has no tendency to fall, but this equilibrium is unstable; for the slightest deviation from the vertical will constantly be increased until the rod falls, and the equilibrium is destroyed.

There is another species of equilibrium that may be called the equilibrium of indifference; for instance, let a rod be suspended by its centre of gravity upon an axle, if it be turned in any position in a vertical plane, it will have no tendency to restore itself to its original position, or to increase its deviation, but will remain entirely indifferent to any change. If this rod be suspended like a pendulum, and be made to deviate from the vertical, it immediately seeks to return again to its original position, as is manifested by its oscillations on each side of its centre of gravity. This is an equilibrium of stability. All derangements from this kind of equilibrium, are not permanent; neither do they go on increasing, but are counteracted by the constant tendency to return to the primitive condition of equilibrium.

In case the rings of Saturn were equally thick and homogeneous, (that is, composed of matter of equal density) whether they were exactly concentric with the planet or not, the system would be in a condition of unstable equilibrium, and therefore would, with the slighest derangement, speedily destroy itself.

To construct an equilibrium of stability, three things are necessary; first, one part of the ring must be thicker or denser than other parts; second, the centre of position of the ring must be without the centre of the planet; and, third, the centre of the ring must revolve around the common centre of gravity of the planet and ring in a minute orbit. It can be analytically demonstrated, that with these three conditions, the system would be in a state of stable equilibrium. By observation, it is found that these conditions do actually exist. The ring is actually observed to be thicker in some parts than in others; it is also actually observed that the ring is not concentric with the planet, and it is further observed that the centre of the ring does revolve around the common centre of gravity.

Through these causes, therefore, the system will be maintained through indefinite ages without any danger of permanent derangements, arising from the slight deviations, occasioned by the unequal action of satellites, or by other causes.

When it is known that the interval between the rings does not exceed 1,800 miles, how exquisite must be the adjustments; to prevent them from collapsing! Neither of the rings or planet, if of equal thickness and density, would alter its relative position by its own mutual gravitations, but one ring, in the course of a very short time might be precipitated upon the other by the operation of some external force, unless prevented by the three conditions which we have already specified as necessary to their stability.

The velocity of the rotation of the rings is much greater than their orbitual velocity around the sun. The circumference of the exterior edge of the outer ring is over 554,000 miles; it must revolve, therefore, over 52,000 miles every hour; while the velocity in the orbit around the sun is only about 22,000 miles per hour. During their midnight, the absolute velocity of that point of the ring the most distant from the sun, resulting from both of these motions, will be 74,000 miles per hour to the east; while that point of the ring nearest the sun, will be moving with an absolute velocity of 30,000 miles per hour to the west. From their noon till their midnight,—a period of only about 5¼ hours, there must be an average change of absolute velocity of about 20,000 miles per hour.

The inclination of the orbit of Saturn to the plane of the ecliptic is equal to 2 deg. 29 m. 35.7 s. The inclination of the equator and ring to the plane of its orbit is equal to 28 deg. 11m. The plane of the ring in the year 1871 intersects the plane of the ecliptic in two points, namely, 167 deg. 47 m. 57.7 s. and 347 deg. 47 m. 57. 7s. of longitude. The nodes of the ring are not quite stationary, but advance on the ecliptic about 46. 462 s. per annum.

The variety of seasons upon Saturn and his rings will be somewhat more striking than with us, because the inclination of his equator to his orbit is greater than ours. Summer, winter, spring, and autumn, will each be about 7 1-2 years long. Every 15 of our years the sun will apparently pass through the equinoxes of Saturn, at which time it will be vertical to the outer edge of the ring. The sun will apparently recede to the south side of the rings as far as the southern tropic or about 30 deg. south, and then return back again crossing the equator or plane of the ring, and continue 30 deg. north, or to the northern tropic; therefore the sun shines 15 years on the southern side of the rings, and then the same length of time on the northern. Each side of the rings, therefore has alternately 15 years day and 15 years night.

Saturn's rings are not always visible in consequence of their relative positions in regard to the sun and earth. There are three causes for their disappearance:

First, when the sun is vertical to the edge of the ring, the edge will be the only illuminated part; the sides of the ring, therefore, will be invisible; and as the edge is so very thin, it will also be invisible to all telescopes but those of the most extraordinary power. This disappearance will happen once in fifteen years, when Saturn is at or near his equinoxes. When in this case, the ring is rendered visible by the aid of the most powerful telescopes, it "can only appear as a very narrow straight line of light, projecting on either side of the planet as a prolongation of its diameter."

Second, when the edge of the ring is presented to the earth, though one of its sides may be obliquely enlightened, yet it will be invisible because of its plane being in the direction of the line of vision, and the edge being too thin to be seen. This will never happen only when the planet is within 6 deg. 1 m. of either node—or only once in fifteen years.

Third, when the sun and earth are on the opposite sides of the ring, the dark side being towards us, will be invisible. This also can never happen only once in fifteen years, when the planet is within 6 deg. 1 m. of either node. In this case, no power of the telescope would render the ring visible; but the aspect of the planet would be very singular, appearing like a bright round disc, striped with belts of a darkish shade, and crossed equatorially by a narrow and perfectly black line. This of course would be the projection of the dark invisible ring upon the bright disc.

The ring of Saturn will always be visible, in every part of its orbit, except in a space of about 6 deg. 1 m. on each side of either node where it may, under the foregoing circumstances, become invisible. Saturn passes through this small arc where the disappearances may happen in about 359½ days, or in a little less than one of our years. When Saturn passes over that portion of its orbit between 173 deg. 49 m, and 341 deg. 47 m. of heliocentric longitude, the northern side of the ring is enlightened and visible. When he passes over that portion of his orbit, included between the longitudes of 353 deg. 49 m. and 161 deg. 47 m. the southern side of the ring is enlightened and visible.

The greatest opening of the ring occurs about 7½ years after the planet passes either node; when the plane of the ring will be inclined to the line of our vision about 30 deg.

This will be the greatest angle under which we can ever see the ring. By the effect of perspective, it will then appear like an ellipse whose greatest diameter will be double the shortest. This is the most favorable position for viewing the ring. This occurred in 1869-70, and will occur again in 1884-85. From this most open position, the ring for 7½ years, continues to change its apparent aspect by becoming more and more narrow, until it finally vanishes in a straight line.

All these various phases are only apparent, arising from the relative position of the ring in regard to the eye. These effects may be exemplified by holding a broad thin ring between our eye and one of the walls of this house, and varying its position. It is evident that when held in any given position, it will hide a certain portion of the wall; let this portion be marked. Now change the position of the ring, and the portion of the wall obscured will be changed also. If the ring be held with its plane inclined 30 deg. with the line of vision, the portion of the wall that will be hid will be an ellipse whose greatest diameter will be double the shorter. If the angle of the inclination of the ring be less, the minor axis of the ellipse will be less; and this axis will decrease its length as the inclination decreases, until finally the ellipse will coalesce into a straight line. Now all these phases actually happen in viewing the ring of Saturn.

The scenery from the surface of Saturn must be grand and imposing beyond conception. The enlightened side of the ring will be seen for fifteen years alternately in the northern and southern hemisphere. It will appear, like a vast arch of light, extending from the eastern to the western horizon. The mountains, vallies and landscapes will be very distinctly visible; while the difference of the rotations of the planet and ring will be so small that the ring will appear to them to rotate from east to west once in about 212 of their days; during which time every part of the enlightened side of the ring will successively pass their meridian.

While in one hemisphere they are enjoying the beautiful and sublime scenery of this gorgeous ring; in part of the other hemisphere they will be suffering a fifteen years total eclipse, occasioned by the interposition of the ring between them and the sun.

Saturn is accompanied by eight satellites; all of which revolve around him from west to east. The most distant has its orbit inclined to the plane of the ring 12 deg. 14m., which is nearly one-half of the angle of inclination between the plane of the ring and that of its orbit. All the rest of the satellites move in or nearly in the plane of the ring. To these satellites the following names have been given, beginning with the nearest to the planet and proceeding outwards, namely:—

Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion and Iapetus. The discovery of Hyperion is quite recent, having been made on the night of the 19th of September, 1848, by two different discoverers far separated from each other, namely, Mr. Lassell, of Liverpool, and Prof. Bond, of Cambridge, U. S.

The nearest, or Mimas, revolves in an orbit only 5228 miles above the outer ring, or 93,437 miles from the planet's surface; its period is 22h. 37 m. 22. 9 s.

Enceladus is 131,109 miles from the surface of the planet, and revolves around it in 1 d. 8 h. 53 m. 6.7 s.

The distance from the surface of the planet to Tethys is 171,761 miles; its period is 1 d. 21 h. 18 m. 25.7 s.

Dione is 231,139 miles from the planet, and revolves around it in 2 d. 17 h. 41m. 8.9 s.

Rhea is 338,520 miles distant, and revolves in 4 d. 12 h. 25 m. 10.8s.

Titan is 836,918 miles from the surface of the planet, and revolves around it in 15 d. 22 h. 41 m. 25.2 s.

Hyperion is 1,068,060 miles from the planet, and revolves around it in 22 d. 12 h.

Iapetus is 2,507,749 miles from the planet's surface, and revolves around it in 79 d. 7 h. 53 m. 40.4 s.

The first four satellites are nearer to Saturn than the moon is to our earth; and if we suppose them to be as large as our moon, the apparent disc of the first will be about eight times larger than that of our moon's; that of the second, four times larger; that of the third, over twice as large; that of the fourth will appear about the same size. The first will pass from new to full moon in one of Saturn's days, and the next day it will pass from full to new moon. The second will pass through all the phases from new to full and full to new moon in about three Saturnian days. The third will pass through all the same aspects in a little over four of Saturn's days; and the fourth will undergo the same changes in a little over 6 of Saturn's days. The four most distant satellities will probably appear somewhat smaller than our moon and each will exhibit all of its phases during the period of its revolution.

How splendid must be the firmament of Saturn! New moons, half moons, full moons, rings, all revolving—all changing