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Dr. J. Lunt, F.I.C., President, in the Chair.

SATURN.*

It is at once evident to us that the ancients never saw Saturn as we see it in the telescope, else they would not have chosen it from among the planets to be the omen of bad luck. They called it the unlucky planet, and persons born under its supposed influence were thought to be destined to experience the greatest misfortunes and griefs. It is probable that Saturn attained its sinister reputation on account of its slowness of movement among the stars, and because of the dullness of its light. True, it excels Mars and Mercury at times, but both these planets considerably outshine Saturn when they are at their maximum brightness.

Though its lustre is inferior even to the stars Sirius and Canopus, Saturn becomes the most beautiful, the most interesting and the most fascinating object in the heavens when viewed through the telescope. Its glorious ring system and magnificent retinue of satellites suggest anything but misfortune and calamity, and we cannot associate evil with so much beauty and charm. The ancient idea of Saturn dies hard, and in modern times there have been many who still retained the old legendary impression. Flammarion tells us that the great poet, Victor Hugo, assured him that Saturn could be only a prison or a hell.

Until the time of Herschel, Saturn was considered to be the frontier of the solar system. Indeed it was held to be impossible that there could be another member of the Earth's family, which then numbered seven, the perfect number.

"In the times of Hesiod and Homer men believed that the extent of the whole universe had been measured by the myth of Vulcan's anvil, which took nine days and nine nights to fall from the sky to the Earth, and as many more to descend from the Earth to the infernal regions." This ancient estimate of the boundary of the universe would work out at about 358,000 miles or half more distant than the Moon actually is. That is but a

* A choice collection of Lantern Slides was specially made, to illustrate the paper, by Mr. W. Reid, several others being kindly lent by the Royal Observatory.

trifle in comparison with the known distance of Saturn, 886,000,000 miles, which in its turn fades into insignificance before the distance of the nearest fixed stars.

Galileo was the first to discover that Saturn differed from the other planets, in having something in the nature of an appendage. In 1610 with the newly-invented telescope he saw something strange about the aspect of this planet. It seemed to be accompanied by a small body on either side. He announced his discovery to Kepler in a logogriph. Kepler sought in vain for a key to this enigma. He thought it might refer to the discovery of Martian satellites. The clue to the meaning of the string of meaningless letters lay in their transposition into the Latin sentence: "Altissimum planetam tergeminum observavi," which means: "I have observed the planet Saturn to be triple." We get an idea of how the rings appeared to Galileo in his letter written at a later date to the Ambassador of the Grand Duke of Tuscany. "When I observe Saturn the central star appears the largest; two others, one situated to the east, the other to the west, and on a line which does not coincide with the direction of the Zodiac, seem to touch it. They are like two old servants who help old Saturn on his way, and always remain at his side. With a smaller telescope the star appears lengthened, and of the form of an olive."

The rings of Saturn are sometimes presented to us edgeways when they disappear on account of their thinness. Unfortunately for Galileo this phase of the ring system was approaching at the time of his discovery. Galileo therefore noticed that with the lapse of time the supposed satellites gradually decreased in size until at length he found it impossible to see them. He expresses his feelings of disappointment and doubt in a letter dated December 4th, 1612:—"What is to be said concerning so strange a metamorphosis? Are the two lesser stars consumed after the manner of the solar spots? Have they vanished or suddenly fled? Has Saturn, perhaps, devoured his own children? Or were the appearances indeed illusion or fraud, with which the glasses have so long deceived me, as well as many others to whom I have showed them? Now, perhaps, is the time come to revive the well-nigh withered hopes of those, who, guided by more profound contemplations, have discovered the fallacy of the new observations and demonstrated the utter impossibility of their existence. I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken, have greatly confounded me." Galileo was so deeply discouraged and disgusted with his failure to establish the truth of his early observations that he took no further notice of Saturn, and, sad to relate, died without knowing that the strange appearances he had seen and reported had a real existence.

During the next fifty years very little advance was made. Several drawings published in this interval show that the phenomenon seen by Galileo was observed by others. There was still, however, much scepticism as a drawing by Fontana in 1645, when the rings were well open, depicts the planet without any appendage. It appears what was observed came to be looked upon as due to the existence of two ansae or handles attached to the planet. The cause of their disappearance from time to time, however, could not be accounted for.

Christian Huygens, Dutch scientist, and a maker of clocks and telescopes, who was the first to definitely define the wave theory of light, and the first to apply the pendulum to regulate the movement of clocks, was also the first, in 1655, to give a correct explanation of the mysterious ansae. His discovery was partly due to the greatly improved telescope which he had made by new methods of grinding and polishing, and partly to clever reasoning. After spending several years in scrutinising Saturn, he finally decided that " a very thin broad flat ring entirely separate from the planet which it encircled was the only structure that could give rise to all the various puzzling appearances observed." Like Galileo, he hesitated to publish his discovery lest he might be mistaken and held up to ridicule, so in order to secure for himself priority of discovery he resorted to a device common enough in those days, though appearing very absurd to us, and published his finding in an anagram in which the letters of a latin sentence announcing his discovery were disarranged. Afterwards in 1659, believing his theory to be invulnerable, he re-arranged the letters into the proper order, and announced to the world that " Saturn is encircled by a thin flat ring not adhering to the body of the planet at any point, and inclined to the ecliptic." This conclusion was plainly not the result of a chance inspiration. The evidence of his long and painstaking study of the planet and its peculiar attachment is shown in his prediction that the appendage would disappear again in July or August 1671. Cassini, an Italian who had been appointed the Astronomer Royal at Paris, watching for the disappearance of the ring, found that this occurred in May 1671 or within two months of Huygen's prediction.

Cassini continued his observations of the Saturnian system, and discovered, in 1675, that what appeared to Huygens as one ring was in reality two lying concentric with each other. He saw the ring divided by a dark line into two parts of unequal brightness. " The interior part is," said he, " very bright, and the exterior a little dark, the difference being that of dull silver and burnished silver."

Sir William Herschel nearly a century later refused to acknowledge that there was a gap in the ring. He called it "the broad black mark," and because he could not detect changes in its appearance, he argued that it could not indicate the existence of, either a zone of hills on the ring or a cavernous groove. In 1790, however, eleven years from the beginning of his observations, he perceived a similar black mark on the opposite face of the ring, and was led to admit that the black stripe denoted the existence of a circular gap, nearly 2,000 miles in width, dividing the ring into two concentric portions. Had the knowledge we now possess been available in those days, it would not have been necessary to wait for confirmation of this theory until a star had been seen through the division. For, according to Professor Tyndall, "if the Moon's whole surface could be covered with black velvet, she would appear white when seen on the dark background of the sky." The darkness of the seeming stripe is therefore in itself evidence that the dark line first observed by Cassini is a real division in the ring.

When Herschel was satisfied that the gap existed, he foolishly asserted that there was only one division in the ring. Since his time, however, it has been clearly demonstrated that a division first seen by Encke in 1837 exists in the exterior ring near the outermost edge.

There has also been further development of our knowledge of the ring system in the direction of the planet. Galle in 1838 was the first to draw attention to a shading off of the interior ring towards the planet, but it was not until the close of the year 1850 that it was definitely ascertained that there was an interior ring of a less luminous nature. This dusky ring was soon found to be divided into two or more concentric rings. The transparent nature of the dusky ring was not detected until two years later. Lassel spoke of it as something like a crape veil. It is abundantly evident that the crape, or gauze ring as it is sometimes called, cannot be solid, as the globe of Saturn is seen clearly through it.

In 1861, when the rings were seen edgeways, Wray made a very interesting observation, which would indicate that the dusky or crape ring is much thicker than the outer rings. He says that he saw "a prolongation of very faint light stretched on either side of the dark shade on the ball, overlapping the fine line of light formed by the edge of the ring, to the extent of about one-third of its length, and so as to give the impression that it was the dusky ring and seen edgeways projected on the sky."

Speaking generally, the thickness of the rings is quite inconsiderable. Miss Agnes Clerke calls them "flat sheets without (so to speak) a third dimension." In the year 1892, when the rings were about to disappear, Prof. L. W. Underwood saw the satellite, Titan, apparently moving along the needle-like appendage to the planet. He says: "The apparent diameter of the satellite so far exceeded the apparent thickness of the rings that it gave the appearance of a beautiful bead moving very slowly along a fine golden thread." Sir John Herschel estimated the thickness of the rings to be 250 miles, and Bond suggested 40 miles. By ascertaining the perturbing effect of the rings on the satellite Titan, Bessel estimated the mass of the rings to be 1/118 of the mass of the planet. If it be assumed that the density of the rings is the same as that of the planet, which Chambers says is probably the case, the thickness of the rings would work out at 138 miles, which is practically the mean between Sir William Herschel's and Bond's estimates. From measurements made of certain light spots, with the great 40-inch Yerkes telescope in 1907, when the rings became invisible, Prof. Barnard concludes that the thickness of the rings "must be greatly under 100 miles, and probably less than 50 miles."

The ring system was at first supposed to be circular, but it is now generally conceded that the true form of the rings is elliptical. Secchi came to this conclusion after making exhaustive measures of the rings. He found that the measurements of two consecutive days did not harmonize, while those at intervals of three and nine days did. He explained this by supposing the rings to be elliptical; sometimes presenting to us the longer, and sometimes the shorter diameter. It has also been determined that the rings and the ball are not concentric. Struve ascertained micrometrically that at the mean distance of Saturn from the Earth, the Eastern vacuity was 11.288 seconds of arc, while that of the Western was only 11.073. Chambers says:—"This peculiarity has been shown to be essential to the stability of the system of rings. Without this feature and without rotation they would fall on the planet."

If the rings were in the plane of the ecliptic, we would be unable to see them, as they would always be presented to us edgeways. They are, fortunately for us, inclined to the ecliptic at an angle of 28 deg. 10 min., and are therefore visible to us when the Earth is above or below the plane of the rings. They appear to us foreshortened in the form of an oval. The plane of the rings intersects the ecliptic in longitude 168 deg. and 348 deg. The former point is the ascending node, and the latter the descending node. When Saturn reaches one of these points, being then in the plane of the ecliptic, the rings will disappear. Saturn's period being 29·458 years, the average time which elapses between two successive nodal passages is 14·729, or, roughly, 15 years.

The last nodal passage took place in 1906. The rings were widely open in 1913, and are now closing in. The southern hemisphere of the planet is presented to us at present, and a small portion of the northern hemisphere appears beyond the ring. The next nodal passage occurs at the end of 1920. It will be interesting to possessors of small telescopes to ascertain the time at which they lose sight of the ring, and the duration of the interval which must elapse before they pick it up again; this period depending on the diameter and the quality of the object glass. The ascending node towards which the planet is moving is in the succeeding part of Leo about 2 degrees south of the fourth magnitude star Sigma. The ring is most open when Saturn is in the constellations Taurus and Ophiuchus, or what are called the signs of Gemini and Sagittarius. Saturn will be in the latter position in 1928, when it will be most favourably situated for southern observers. We hope members of the Cape Astronomical Association will then be able to make a valuable contribution to our knowledge of this most mysterious planet.

There are two disappearances about the time of the planet's arrival at a node. Besides being invisible when at the node, because it is presented edgeways, the ring is also invisible when, owing to Saturn's slight departure from the ecliptic, the Sun and Earth are on opposite sides of the plane of the rings. In this case, the dark surface of the ring is turned towards us, and the disappearance is complete; whereas when turned edgeways to us the ring may still be seen in powerful telescopes as "a faint broken line of a dusky colour."

O. Struve advanced a theory that the rings were expanding inwards, so that ultimately they would come into contact with the planet. According to measurements by Huygens, Struve, Herschel, and others, the distance between the ring and the planet decreased during the period 1657 to 1851 from 6.5 to 3.7 seconds of arc. In drawing attention to Struve's theory Flammarion asks the question: "Shall we witness some day the grand and tremendous spectacle of the disruption of Saturn's rings and their fall on the globe." He assigns 2150 as the date on which the luminous ring will smash against the planet, if the rate of approach which he estimates at 1.3 seconds per century be not diminished. It would be unwise, however, to depend too much on a theory built up on the earlier measurements. Struve himself afterwards tested the truth of it by executing careful micrometric measurements of the dimensions of the rings in 1851, and again in 1882, but the expected diminution in the space between the planet and the rings had not taken place. Later measures by Hall in 1884-1887, and by Barnard in 1894-5, showed no sensible encroachment of the ring towards the planet.

Many attempts have been made to fathom the mystery of the nature and constitution of the rings. It was at first imagined that they were of a solid nature resembling wide flat hoops, but it was soon shown that the attraction of the planet and its satellites would not only have dislocated and shattered such rings if they existed, but would absolutely have prevented their formation. Assuming first that the ring did not rotate, Proctor shows that the ring, if solid, would be like a mighty arch, each portion being drawn towards Saturn's centre by its own weight. He says: "The strains and pressures upon the various parts of the system would exceed thousands of times those which even the strongest material built into their shape could resist. The system would no more be able to resist such strains and pressures than an arch of iron spanning the Atlantic would be able to sustain its own weight against the earth's attraction." Afterwards, assuming that the ring system rotated, as is the case, he shows how if the rings were solid the several parts would have to rotate as a whole, the inner slower and the outer faster than their proper rate, and the consequent strains would be hundreds of times greater than the cohesive power of its substance could resist. He also disposes of an arrangement of narrow hoops, which might appear to be a possible condition, by showing that the hoops would "before long be made to rotate eccentrically, and eventually be brought into destructive collision with the planet." In this connection he quotes Prof. Nichol, who says: "If this arrangement, or anything like it, were real, how many new conditions of instability do we introduce. Observation tells us that the division between such rings must be extremely narrow, so that the slightest disturbance by external or internal causes would cause one ring to impinge upon another, and we should then have the seed of perpetual catastrophies."

It was suggested at an early date that the rings might perhaps be fluid, but it has been shown that violent wave motions would inevitably be set up in the fluid rings, which would quickly destroy them.

The question was satisfactorily solved by Clerk Maxwell in 1857. He proved theoretically that the marvellous structure of Saturn's rings is formed out of dense swarms of minute satellites revolving independently in distinct orbits in periods corresponding to their several distances from the planet. This theory is now one of the accepted facts of science.

Photometric investigations have confirmed the satellite theory. Prof. Seeliger says that "the unvarying brilliancy of the outer rings under all angles of illumination from 0 to 30 degrees can be explained from no other point of view." Some found it difficult to accept this theory because the obscure inner ring shows as a dense dark shading on the body of Saturn. The brightest parts of the ring system are more lustrous than the planet, and the constitution of the inner obscure ring is doubtless the same as that of the brighter ring, only the little bodies are much more thinly strewn and consequently reflect less light. The scanty distribution of the supposed particles in the inner ring would not, however, cause them to appear dark against the globe of Saturn. Prof. Seeliger shows that the darkening is due to the never-ending swarms of their separate shadows transiting the planet's disc. The dusky ring being transparent, sunlight is not wholly excluded from the planet, which shows through as if veiled with a piece of crape.

The meteoric constitution of the rings was abundantly confirmed by means of spectographs taken by Prof. Keeler in 1895. From these he determined the comparative radial velocities of its parts. If the rings were solid the swiftest rate of rotation would naturally be at the outer edges where the largest circles were described, but if the rings were composed of particles the inverse would hold good. Prof. Keeler found the latter to be the case. The speed was greatest at the inner edge and gradually diminished outward, each part moving with the speed at which a satellite would travel if it were placed at the same distance from the planet. This fact was immediately confirmed by Campbell, Deslandres and Belopolsky.

Prof. G. H. Darwin suggests that the rings of Saturn " replace an abortive satellite, scattered by tidal action into annular form, as they lie closer to Saturn than is consistent with the integrity of a revolving body of reasonable bulk." Roche, of Montpelier, in 1848 determined that the limit of possible existence for such a body is 2.38 radii of Saturn from its centre. Miss Agnes Clerke says: " The virtual discovery of its pulverulent condition dates, then, according to Prof. Darwin from 1848. He conjectures that the appendage will eventually disappear, partly through the dispersal of its constituent particles inward, and their subsidence upon the planet's surface, partly by their dispersal outward, to a region beyond 'Roche's limit,' where coalescence might proceed unhindered by the strain of unequal attractions. One modest satellite, revolving inside Mimas, would then be all that was left of the singular appurtenances we now contemplate with admiration." The early measurements of the rings would give definite support to this theory, but the later ones would contradict it. There may, however, be such a development in progress, but of so slow a nature that the consummation of the prediction may not occur in the lifetime of man.

In a paper read before the British Astronomical Association in 1915. Mr. C. E. Stromeyer sought to improve on Clerk Maxwell's finding by advancing the theory that the meteoric particles of which the rings of Saturn are composed may be fluid drops.

or at least "sticky." He argues that the gaps in the rings could only have been formed if the particles were sticky, by the sweeping up of particles into one or more satellites too small even for the largest telescopes. If left to themselves there would be no tendency for the ring particles to combine, but under the perturbing influences of Saturn's satellites certain circular orbits would frequently change into elliptical ones, and these would cross the adjoining circular ones. The particles found there, if of a fluid or sticky nature, would be swept up, a gap or division would appear in Saturn's ring, and one or more satellites would be formed in the gap, too small of course even for the largest telescopes. He says: "This sweeping-up process could not have been of a permanent nature if the ring particles had not been fluid drops, or at least of a sticky nature, for otherwise no building-up would have been possible—only collisions and renewed scatterings." This "sticky" theory found no acceptance at that meeting. It was pointed out by one of the speakers that at the distance of Saturn "the sun's heat and light were reduced to the one-hundredth part of what they are on the earth, and unless the planet radiated a considerable amount of heat, the temperature of the ring must be very low. The ring had no atmosphere, hence the loss of heat by its particles must be very rapid. At very low temperatures substances tended to be brittle rather than sticky; thus a golf ball dipped into liquid air and then dropped a few feet broke into fragments."

Prof. Lowell explains the accepted theory of how the gaps are formed in the rings by the influence of the planet's satellites. The orbits of the particles which compose the ring would not in general be much disturbed by the attraction of a satellite; but those particles whose periods are equal to a simple fraction, such as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc., of the period of the satellite would be drawn out of their original paths, and these would be left dark and empty. If the ring were originally continuous it would be in this way broken up into a series of bright concentric rings separated by dark spaces. Mimas being the nearest satellite to the rings has the most effect in causing these divisions and making them permanent. The Cassini division corresponds to the orbit of a satellite which would have one-half the period of Mimas; the inner boundary of Ring B corresponds to the orbit of a satellite with one-third, and the inner boundary of the Crape Ring to the orbit of a satellite with one-fourth the same period. A body revolving round Saturn at any of these distances would always be in conjunction with Mimas at the same part of its orbit and the cumulative effect of the gravitational pull of the satellite would eventually draw the body into an orbit where these disturbing influences would not occur.

Another result of the gravitational influence of the satellites of Saturn is seen in certain swellings which are observed on the rings when they are presented edgeways to us. It is then evident that the rings are not of the same thickness throughout; the outer edge of each ring has a considerably greater thickness than the inner edge. Prof. Lowell suggested that this formation is due to collision taking place between the crowded particles because of the disturbing influence of the satellites driving many of them out of the proper plane of the ring. These conglomerations, according to Lowell, appear "exactly inside the points where the satellites' disturbing action is greatest, or, in other words, in precisely their theoretic place." These appearances, sometimes called knots or beads, are swellings extending all round the outer edge of each ring. They have this appearance to us, because we see them in cross section when the rings are turned edgeways to us. The shadow of the planet thrown on the ring also demonstrates the existence of this thickening of the ring towards the outer edge.

A new theory regarding the construction of the rings was advanced by Birkeland in 1911. He says that from experiments made by him it would appear that the rings are formed by an electro-magnetic force. He claims that this force emanating from Saturn can account for all the observed phenomena of the rings. We have no evidence that this theory has been taken seriously by the astronomical world, and in the absence of anything in the nature of proof of it we are satisfied that the meteoric theory expounded by Clerk Maxwell, and afterwards confirmed by observations, visual, photometric, and spectroscopic, is the true one.

Mr. P. H. Hepburn wrote a paper to the British Astronomical Association in 1914, in which he stated that close examination of a photo of Saturn by Prof. Barnard shows Ring A to be transparent. The globe of the planet is clearly visible through it, both limbs being sharply defined. The combined effect of ring and ball is one of brightness; that is to say, the region where the one is superimposed above the other is brighter than the adjacent parts of the ring, and very much brighter than the north limb of the ball which projects beyond the ring. The question of the transparency of Ring A caused a considerable amount of discussion, but the point was definitely settled in 1917. On the night of February 9th, Naval Instructor Ainslie and Mr. J. Knight observed an occultation of a small star by Saturn's ring. The star when first seen appeared to be projected on the extreme edge of Ring B. It passed along the Cassini division, and appeared during its passage to be as bright as when clear of the planet. It was afterwards *easily seen through Ring A*, but greatly reduced in brightness. There was no variation in brightness as it passed behind Ring A, except for two sudden brightenings, the first lasting 10 to 15 seconds, and the second for only about 5 seconds. Mr. Ainslie took these to correspond with Encke's division and another exterior to it. The star was not so bright when passing behind these gaps as when clear of the ring, but was estimated to be twice as bright as when seen through the ring. This was a most interesting and unique observation, for, as far as is known, no observer had previously seen Ring A pass over a star. It gave further proof of the accuracy of Clerk Maxwell's conclusion that the ring is composed of very minute particles. Mr. Ainslie drew attention to the smallness of the particles which composed the ring. This was supplemented by Dr. Crommelin, who stated that as the diameter of the star was hardly likely to be as much as one ten-thousandth of a second of arc, the particles were probably at the most not more than 200 yards in diameter, because there was no perceptible flickering or momentary obscuration during the passage of the star behind the ring.

Another point touched on as being suggested by the observation is that there are only two divisions in the Ring A, and not six or eight as represented in a drawing by Prof. Lowell. With regard to this, however, Rev. T. E. R. Phillips, then President of the B.A.A., suggested that possibly on that night there were only two divisions, but, he said, " was it not conceivable that if the ring consisted of streams of minute particles, perturbations in the particles might cause divisions in the ring to appear from time to time and close up again."

This theory of Mr. Phillips seems to be a reasonable one, as notwithstanding all the extra divisions depicted by Lowell, there was still another seen in Ring B by M. Mentore Maggini, of the Royal Observatory, Arcetri, in October, 1913. This division was observed in the bright ring at the side of Cassini's. It had been seen in 1910, and also in 1912, but was then considered an illusion.

The observation of Messrs. Ainslie and Knight also disposes of the idea that Encke's division had ceased to exist. The Henry Bros. at the Paris Observatory in 1884, using a refractor of 15 inches aperture, and a power of 1,000, satisfied themselves that Encke's division had completely disappeared. Other observers in America afterwards came to the same conclusion. If this conclusion was justified, and we have no reason to assume that it was not, it points to variability, as without doubt the division is again visible, and the unique observation of Messrs. Ainslie and Knight demonstrates that Encke's division has still a real existence. Observations by Maginni and others show changes in both Cassini's and Encke's divisions.

Changes in the dusky ring have also been observed. It is said that even from night to night the colour and brightness of the dark ring changes in a marked degree, and occasionally irregularities can be seen in its outline.

The figure of Saturn is that of an oblate spheroid. The polar compression is larger than that of any other planet. Saturn may not appear to the eye to be so compressed as Jupiter, but that is because the rings distract the eye. Telescopic observers might find it interesting to compare the planets in this respect. The values given for Jupiter's compression average about 1/17th, whereas Sir William Herschel's and Bessel's value for Saturn is about 1-10th, and that of Main and Hind about 1-9th. The difference between the polar and equatorial diameters of Saturn is probably equal to the diameter of the earth.

The apparent diameter of Saturn varies according to its distance from the earth, being at minimum 15 seconds of arc, and at maximum 20 seconds of arc. Its real (equatorial) diameter is estimated to be about 76,000 miles. Saturn's volume is estimated to be 3/5ths that of the giant Jupiter. It is impossible to adequately comprehend the vast bulk of Saturn until we bring it into comparison with that of our own earth.

Let us imagine the mighty globe of Saturn to be cut up into earths, of which it will make about 720. If these earths be placed in a line, touching each other, they would stretch out into space for nearly six million miles, or about twenty-four times the distance between the earth and the moon. To inspect this immense line of earths would occupy a period of nearly seven years if we travelled day and night without ceasing at the rate of a hundred miles an hour. Or, if these earths were arranged round us at a distance of one million miles they would touch each other, making a continuous belt round the heavens having a diameter equal to the apparent diameter of the moon. If we compare it with the moon, we find there is enough material in Saturn to construct 35,000 of our moons, and if these moons were placed in a line they would make a causeway that would reach more than three-quarters of the way from the earth to the sun.

Saturn is in an earlier state of development than any of the other planets. Its mass is very small in comparison with its volume, its density being only 64 per cent. that of water. It would therefore float in water. Miss Agnes Clerke says: "Since his density is shown by the amount of superficial bulging to increase centrally, it follows that his superficial materials must be of a specific gravity so low as to be inconsistent, on any probable supposition, with the solid or liquid state. Moreover, the chief arguments in favour of the high temperature of Jupiter apply, with increased force, to Saturn; so it may be concluded, without much risk of error, that a large proportion of his bulky globe, 76,000 miles in diameter, is composed of heated vapours kept in active and agitated circulation by the process of cooling."

Prof. G. H. Darwin has demonstrated from the movements of the satellite Titan that the density of Saturn gains greatly with descent into the interior, so that its surface materials must be lighter than any known solid or liquid.

When sufficiently cooled and solidified to support life as we conceive it, what a wonderful sky Saturnians will have to revel in. After sunset the rings will appear as large luminous arches stretching right across the heavens from east to west, their altitude on the meridian depending on the latitude of the observer. The hours between sunset and sunrise will be marked by the passage of the shadow of the planet along the brilliantly illuminated arches from east to west. Additional light will be cast on the planet when the Sun is below the horizon by its ten satellites, which will be seen to traverse the sky at various speeds. Three of these moons will appear larger though not so luminous as our moon, the others varying in size down to the tiny Phœbe, which will just be visible as a point of light.

There are markings on Saturn similar to those on Jupiter. They are, however, not so easily distinguishable, and instead of being always seen straight, they are usually arranged in curves. Very superior instruments are needed to examine the irregularities in these belts which provide a means for estimating the rotation of the planet. In this way Sir William Herschel in 1793 estimated the rotation period to be 10 hours 16 minutes. Professor Hall discovered a brilliant white spot on the equator of Saturn in 1876, which he believed to be an immense eruption of white matter from the interior of the planet. He invited a large number of astronomers to observe the phenomenon, and from all the observations taken he deduced a rotation period of 10 hours 14 minutes 24 seconds, which differs very slightly from that obtained by Herschel nearly a century earlier. Mr. W. F. Denning made a series of observations of certain markings in Saturn's north temperate zone, which extended over six months. From these he deduced a mean rotation period of 10 hours 37 minutes 56.4 seconds. The extreme difference in the individual rates amounted to 13.8 seconds. The rotation period determined by Mr. Denning is 23½ minutes in excess of Prof. Hall's value. Mr. Denning suggests that "possibly this apparent discordance may represent the normal difference between the rates of the equatorial and north temperate currents on Saturn." Prof. Lowell came to the conclusion that Saturn is actually rotating in layers with different velocities, the inside one turning the faster.

The shadow which Saturn throws on the rings is very often shown in drawings as it is supposed to be from the spheroidal form of the planet, but it is seldom seen as a regular curve. Proctor says: "The way in which the shadow narrows where the rings are brightest may be fairly regarded as due to irradiation, and we may even thus come to regard the figure of the shadow as affording a neat photometric test of the brightness for different parts of the ring. But the irregularities of figure cannot all be thus explained. Nor can they be at all explained in the contour of the rings themselves. It has been suggested that they may indicate differences in the transparency of the deep atmospheric surroundings of the planet itself which are made evident by the transmission of direct sunlight, though they are not recognisable by means of the fainter dispersed sunlight which we receive from the planet's limb."

Saturn is more richly endowed with satellites than any of the other planets. When Huygens, with a twelve foot telescope in 1655, discovered the satellite Titan, it was believed that the whole solar system had been explored. There were six planets and the same number of satellites: one to the earth, four to Jupiter, and one to Saturn. It was maintained that it would be wasting time to look for more satellites. This foolish method (ten) of reasoning was soon upset by Cassini, who, six years later, that is, in 1671, discovered the satellite Iapetus. A year later he picked up the satellite Rhea, and after an interval of twelve years he discovered two others, Tethys and Dione.

No more satellites were discovered for more than a century. In 1787 Sir W. Herschel suspected the existence of a satellite within the orbit of Tethys, but it was not until two years later, on account of its nearness to the planet, that he succeeded in assuring himself that the object was really a satellite. While studying the movements of this new satellite, named Enceladus, he soon discovered another, Mimas, still nearer to the planet. The eighth satellite was discovered independently in 1848 by Lassel at Liverpool, and by Bond at Cambridge, Mass. The ninth and tenth satellites were first detected on photographic plates by Prof. Pickering.

The satellites seem to form into three groups. The five inner are comparatively close to the planet, their distances ranging from 115,000 to 330,000 miles. These moons increase in size outwards, the first, Mimas, being about 600 miles in diameter, and the fifth, Rhea, 1,500 miles. Separated from this group by a gap of 430,000 miles is the second group, consisting of Titan, Hyperion and Themis, whose distances range from 760,000 to 930,000 miles. These three satellites, which are the first, eighth and tenth in order of discovery, vary greatly in size. Titan is larger than the planet Mercury, exceeding 3,000 miles in diameter; Hyperion has a diameter of only 500 miles, while Themis is very minute. Far beyond these lie the orbits of the third group, Iapetus and Phœbe, whose distances from Saturn are 2½ and 8 million miles respectively. These two satellites form a great contrast. Iapetus is about the size of our moon, whereas Phœbe is less than 100 miles in diameter.

Four or five of Saturn's satellites may be observed under good conditions in small telescopes on moonless nights. The periods of these vary from two to eighty days, and the constant changes which are taking place in their positions with regard to one another and the parent planet are of considerable interest.

Titan is conspicuously visible. Its orbit, which is nearly circular, is traversed in 16 days, but being in the same plane as Saturn's rings, and therefore greatly inclined to the ecliptic, it appears to us when not seen edge on as an eclipse. Hyperion is the third smallest satellite, and is visible only in large telescopes. It travels round Saturn in an eccentric orbit once in 21 days. There is an intimate connection between the orbits of Titan and Hyperion, as a result of which the conjunction of these two satellites always takes place where the distance between the two orbits is greatest. Proctor says: "It appears not improbable that Hyperion is the largest of a ring of small bodies travelling between the giant satellites, Titan and Iapetus."

Iapetus is of special interest on account of its marked variability. It is the second largest of the satellites, and shines almost as brightly as Titan when west of the planet, but is scarcely discernible when east. Sir William Herschel concluded that this variation indicated that the satellite rotated once only in the course of its revolution, and so, as is the case with our moon, always turns the same face toward the primary. In 1792 he wrote: "From changes in this body we may conclude that some part of its surface, and this by far the largest, reflects much less light than the rest; and that neither the darkest nor the brightest side is turned towards the planet, but partly the one and partly the other, though probably less of the bright side." No better explanation of this phenomenon has since been put forward.

Saturn journeys round its mighty orbit, which has a mean radius of 886 million miles, in about 29½ of our years. The rotation period being a little over ten hours, the Saturnian year, therefore, consists of more than twenty-five thousand days, each of these days having approximately 5 hours of daylight and 5 hours of night.

The axis of rotation of Saturn is inclined to the plane of its orbit at an angle of 64 deg. 18 min. The obliquity of the ecliptic is therefore 25 degs. 42 minutes, which is not very different from that of the earth—23 deg. 27 min. The seasons of Saturn, in their contrast between summer and winter, are therefore somewhat similar to ours. But what a difference in duration; more than seven years of summer, and an equal amount of winter. Each polar region and each side of the ring will have 14 years and 8 months of sunlight, and will be plunged in darkness for a similar period. Owing to the enormous distance of Saturn from the sun—ten times that of the earth—the sun's diameter as seen from Saturn is only 1/10th that which is seen by us, and the area of the disc only 1/90th of that which warms and invigorates the earth.

Proctor does not seem to have the same conception of Saturn as that which we have quoted from Miss Agnes Clerke. In his book, "Saturn and its System," he devotes a chapter to the question of the habitability of Saturn, in which he argues that it may be peopled with "creatures admirably adapted to the conditions that surround them." He concludes the chapter by saying: "The result of the examination of the probable physical conditions and phenomena subsisting on Saturn does not appear to favour the supposition that the planet is a suitable habitation for beings constituted like the inhabitants of our globe. The variation of gravity, the length of the Saturnian year, and the long-protracted eclipses caused by the ring, are the circumstances that seem to militate most strongly against such a supposition. Over a zone near the Saturnian equator these circumstances have less effect, however, and it is not impossible that arrangements unknown to us prevail on Saturn which may render other parts of his surface habitable as we should understand the term."

Sir John Herschel, speaking of the sun being visible below the ring at some seasons at rising and setting, although eclipsed during the greater part of the day, says: "This will not prevent, however, some considerable regions of Saturn from suffering very long total interception of the solar beams, affording, to our ideas, but an inhospitable asylum to animated beings, ill compensated by the feeble light of the satellites. But we shall do wrong to judge of the fitness or unfitness of their condition from what we see around us, when perhaps the very combinations which convey to our minds only images of horror, may be in reality theatres of the most striking and glorious displays of beneficent contrivance."