BOOK IV - THE SATELLITES

—

FOREWORD[1]

Rotation of the Planets

THE oblate form of several of the planets indicates rotatory motion. This has been confirmed in most cases by tracing spots on their surface, by which their poles and times of rotation have been determined. The rotation of Mercury is still doubtful, but Schröter believes that by examining daily the cusps of the crescent he has discovered a rotation of $24^h\ 5^m\ 28^s$; that of the new planets has not yet been ascertained. The sun revolves in twenty-five days seven hours and forty-eight minutes about an axis which is directed towards a point half-way between the pole-star and of alpha of Lyra,[2] the plane of rotation being inclined by $7^\circ\ 30'$, or a little more than seven degrees, to the plane of the ecliptic: it may therefore be concluded that the sun's mass is a spheroid, flattened at the poles. From the rotation of the sun, there was every reason to believe that he has a progressive motion in space, a circumstance which is confirmed by observation. But, in consequence of the reaction of the planets, he describes a small irregular orbit about the centre of gravity of the system, never deviating from his position by more than twice his own diameter, or a little more than seven times the distance of the moon from the earth. The sun and all his attendants rotate from west to east, on axes that remain nearly parallel to themselves in every point of their orbit, and with angular velocities that are sensibly uniform. Although the uniformity in the direction of their rotation is a circumstance hitherto unaccounted for in the economy of nature, yet, from the design and adaptation of every other part to the perfection of the whole, a coincidence so remarkable cannot be accidental. And, as the revolutions of the planets and satellites are also from west to east, it is evident that both must have arisen from the primitive cause which determined the planetary motions. Indeed, Laplace has computed the probability to be as four millions to one that all the motions of the planets, both of rotation and revolution, were at once imparted by an original common cause, but of which we know neither the nature nor the epoch.

The larger planets rotate in shorter periods than the smaller planets and the earth. Their compression is consequently greater, and the action of the sun and of their satellites occasions a nutation in their axes and a precession of their equinoxes similar to that which obtains in the terrestrial spheroid, from the attraction of the sun and moon on the prominent matter at the equator. Jupiter revolves in less than ten hours round an axis at right angles to certain dark belts or bands, which always cross his equator. This rapid rotation occasions a very great compression in his form. His equatorial axis exceeds his polar axis by 6,000 miles, whereas the difference in the axes of the earth is only about twenty-six and a half [miles]. It is an evident consequence of Kepler's law of the squares of the periodic times of the planets being as the cubes of the major axes of their orbits, that the heavenly bodies move slower the farther they are from the sun. In comparing the periods of the revolutions of Jupiter and Saturn with the times of their rotation, it

---

[1] The material in this and the forewords to Books I, II and III is extracted from the 10th and last edition of Mary Somerville's *On the Connexion of the Physical Sciences*, (corrected and revised by Arabella B. Buckley), p. 4-106, London : John Murray, 1877.

[2] Alpha Lyra or alpha Lyr is the fifth brightest star, called Vega, situated in the bright northern constellation of Lyra.

appears that a year of Jupiter contains 10,484 of his days, and that of Saturn 24,620 Saturnian days.

The appearance of Saturn is unparalleled in the system of the world. He is a spheroid nearly 700 times larger than the earth, surrounded by a ring even brighter than himself, which always remains suspended in the plane of his equator: and, viewed with a very good telescope, it is found to consist of two concentric rings, divided by a dark band. The exterior ring, as seen through Mr. Lassell's[3] great equatorial at Malta, has a dark-striped band through the centre, which may possibly be another division: it is altogether less bright than the interior ring, one half of which is extremely brilliant; while the interior half is shaded in rings like the seats in an amphitheatre. In 1850 Mr. Dawes in England, and Professor Bond[4] in America, made the remarkable discovery of a dark transparent ring, whose edge coincides with the inner edge of the interior rim, and which occupies about half the space between it and Saturn. The transparency of this ring was better ascertained in 1852 by Mr. Lassell, who compares it to a band of dark-coloured crape drawn across a portion of the disc of the planet, and the part projected upon the blue sky is also transparent. At the time these observations were made at Malta, Captain Jacob also discovered the transparent ring at Madras. None of these rings can be very dense, since the density of Saturn himself is known to be less than the eighth part of that of the earth and there are strong reasons given by Professor Clerk-Maxwell[5] for believing that they are composed of myriads of minute satellites revolving around the globe of the planet, as was originally suggested by Cassini[6] in the eighteenth century. A transit of the sun across a star might reveal something concerning this wonderful object. The ball of Saturn is striped by belts of different colours. At the time of these observations, the part above the ring was bright white; at his equator there was a ruddy belt divided in two, above which were belts of a bluish green, alternately dark and light, while at the pole there was a circular space of a pale colour. The mean distance of the interior part of the double ring from the surface of the planet is about 18,846 miles, it is no less than 28,384 miles broad, but by the estimation of Sir John Herschel[7], its thickness does not much exceed 250 miles, so that it appears like a plane. By the laws of mechanics, it is impossible that this body can retain its position by the adhesion of its particles alone. It must necessarily revolve with a velocity that will generate a centrifugal force sufficient to balance the attraction of Saturn. Observation confirms the truth of these principles, showing that the rings rotate from west to east about the planet in ten hours and a half, which is nearly the time a satellite would take to revolve about Saturn at the same distance. Their plane is inclined to the ecliptic, at an angle of $28^\circ\ 10'\ 44''.7$; in consequence of this obliquity of position, they always appear elliptical to us, but with an eccentricity so variable as even to be occasionally like a straight line drawn across

---

[3] Lassell, William, (1799-1880), astronomer, born in Bolton, England. Lassell discovered several planetary satellites including Triton, Ariel, Umbriel and Hyperion (independently of W. C. Bond [see next note] who made his discovery the same night).

[4] Bond, William Cranch, (1789-1859), astronomer, born in Portland, Maine, USA. Bond was a pioneer in celestial photography (he made the first daguerreotype of the moon in 1850) and discovered Hyperion the seventh satellite of Saturn (independently of W. Lassell [see previous note] who made his discovery the same night).

[5] Maxwell, James Clerk, (1831-1879), physicist, born in Edinburgh, Scotland. His greatest work was the theory of electromagnetic radiation outlined in his *Treatise on Electricity and Magnetism* (1873). He is ranked with Isaac Newton and Albert Einstein for the importance of his fundamental contributions to science which paved the way for both the quantum theory of Planck and Einstein's theory of relativity. Maxwell read and publicly admired the works of Mary Somerville (see *Foreword to the Second Edition*).

[6] see note 53, *Bk. II, Chap. XIV.*

[7] see note 64, *Preliminary Dissertation.*

the planet. In the beginning of October 1832, the plane of the ring passed through the centre of the earth; in that position they are only visible with very superior instruments, and appear like a fine line across the disc of Saturn. About the middle of December, in the same year, the rings became invisible, with ordinary instruments, on account of their plane passing through the sun. In the end of April, 1883, the rings vanished a second time, and reappeared in June of that year. Similar phenomena will occur as often as Saturn has the same longitude with either node of his rings. Each side of these rings has alternately fifteen years of sunshine and fifteen years of darkness.

It has been proved theoretically, that the rings could not maintain their stability of rotation if they were everywhere of uniform thickness; for the smallest disturbance would destroy the equilibrium, which would become more and more deranged, till, at last, they would be precipitated on the surface of the planet. But if some parts of the rings were enormously thicker than others, it could not escape observation, therefore Professor Clerk-Maxwell concludes that they cannot be irregular solids, and the only other theory which will account for their stability is, that they are composed of an immense number of unconnected particles revolving round the planet with different velocities. Professor Struve has shown that the centre of the rings is not concentric with the centre of Saturn.[8] The interval between the outer edge of the globe of the planet and the outer edge of the rings on one side is $11''.390$, consequently there is an eccentricity of the globe in the rings of $0''.215$. If the rings obeyed different forces, they would not remain in the same plane, but the powerful attraction of Saturn always maintains them and his satellites in the plane of his equator. The rings, by their mutual action, and that of the sun and satellites, must oscillate about the centre of Saturn, and produce phenomena of light and shadow whose periods extend to many years. According to M. Bessel[9] the mass of Saturn's ring is equal to the $\frac{1}{118}$ part of that of the planet.

The distance and minuteness of Jupiter's satellites render it extremely difficult to ascertain their rotation. It was, however, attempted by Sir William Herschel[10] by ascertaining their relative brightness. He observed that they alternately exceed each other in brilliancy, and, by comparing the maxima and minima of their illumination with their positions relatively to the sun and to their primary, he found reason to believe that, like the moon, the time of their rotation was equal to the period of their revolution about Jupiter. Later observations, however, render this conclusion doubtful. The eighth satellite of Saturn, Iapetus, is the only one whose period of rotation has been fairly ascertained. This was done first by Cassini and afterwards by Sir W. Herschel, who concluded that the time of its rotation on its axis must agree very nearly with the period of its revolution round Saturn.

Jupiter's Satellites

The changes which take place in the planetary system are exhibited on a smaller scale by Jupiter and his satellites; and, as the period requisite for the development of the inequalities of these moons only extends to a few centuries, it may be regarded as an epitome of that grand cycle which will be accomplished by the planets in myriads of ages. The revolutions of the

[8] see note 29, *Preliminary Dissertation.*
[9] see note 37, *Bk. II, Chap. XIV*
[10] See note 52, *Preliminary Dissertation.*

satellites about Jupiter are precisely similar to those of the planets about the sun; it is true they are disturbed by the sun, but his distance is so great, that their motions are nearly the same as if they were not under his influence. The satellites, like the planets, were probably projected in elliptical orbits: but, as the masses of the satellites are nearly 100,000 times less than that of Jupiter and as the compression of Jupiter's spheroid is so great, in consequence of his rapid rotation, that his equatorial diameter exceeds his polar diameter by no less than 6000 miles; the immense quantity of prominent matter at his equator must soon have given the circular form observed in the orbits of the first and second satellites, which its superior attraction will always maintain. The third and fourth satellites, being farther removed from its influence, revolve in orbits with a very small eccentricity. And, although the first two sensibly move in circles, their origins acquire a small ellipticity, from the disturbances they experience.

It has been stated, that the attraction of a sphere on an exterior body is the same as if its mass were united in one particle in its centre of gravity, and therefore inversely as the square of the distance. In a spheroid, however, there is an additional force arising from the bulging mass at its equator, which acts as a disturbing force. One effect of this disturbing force in the spheroid of Jupiter is to occasion a direct motion in the greater axes of the orbits of all his satellites, which is more rapid the nearer the satellite is to the planet, and very much greater than that part of their motion which arises from the disturbing action of the sun. The same cause occasions the orbits of the satellites to remain nearly in the plane of Jupiter's equator,[11] on account of which the satellites are always seen nearly in the same line; and the powerful action of that quantity of prominent matter is the reason why the motions of the nodes of these small bodies are so much more rapid than those of the planet. The nodes of the fourth satellite accomplish a tropical revolution in 531 years, while those of Jupiter's orbit require no less than 36,261 years;–a proof of the reciprocal attraction between each particle of Jupiter's equator and of the satellites. In fact, if the satellites moved exactly in the plane of Jupiter's equator, they would not be pulled out of that plane, because his attraction would be equal on both sides of it. But, as their orbits have a small inclination to the plane of the planet's equator, there is a want of symmetry, and the action of the protuberant matter tends to make the nodes regress by pulling the satellites above or below the planes of their orbits; an action which is so great on the interior satellites, that the motions of their nodes are nearly the same as if no other disturbing force existed.

The orbits of the satellites do not retain a permanent inclination either to the plane of Jupiter's equator, or to that of his orbit, but to certain planes passing between the two, and through their intersection. These have a greater inclination to his equator the farther the satellite is removed, owing to the influence of Jupiter's compression; and they have a slow motion corresponding to secular variations in the planes of Jupiter's orbit and equator.

The satellites are not only subject to periodic and secular inequalities from their mutual attraction, similar to those which affect the motions and orbits of the planets, but also to others peculiar to themselves. Of the periodic inequalities arising from their mutual attraction the most remarkable take place in the angular motions[12] of the three nearest to Jupiter, the second of which receives from the first a perturbation similar to that which it produces in the third and it experiences from the third a perturbation similar to that which it communicates to the first. In the eclipses these two inequalities are combined into one, whose period is 437.659 days. The

[11] The plane of Jupiter's equator is the imaginary plane passing through his centre at right angles to his axis of rotation. (Somerville's note.)

[12] *Angular motion or velocity* is the swiftness with which a body revolves–a sling, for example; or the speed with which the surface of the earth performs its daily motion about its axis. (Somerville's note.)

variations peculiar to the satellites arise from the secular inequalities occasioned by the action of the planets in the form and position of Jupiter's orbit, and from the displacement of his equator. It is obvious that whatever alters the relative positions of the sun, Jupiter, and his satellites, must occasion a change in the directions and intensities of the forces, which will affect the motions and orbits of the satellites. For this reason the secular variations in the eccentricity of Jupiter's orbit occasion secular inequalities in the mean motions of the satellites, and in the motions of the nodes and apsides of their orbits. The displacement of the orbit of Jupiter, and the variation in the position of his equator, also affect these small bodies. The plane of Jupiter's equator is inclined to the plane of his orbit at an angle of $3^\circ 5' 30''$, so that the action of the sun and of the satellites themselves produces a nutation and precession in his equator, precisely similar to that which takes place in the rotation of the earth, from the action of the sun and moon. Hence the protuberant matter at Jupiter's equator is continually changing its position with regard to the satellites, and produces corresponding nutations in their motions. And, as the cause must be proportional to the effect, these inequalities afford the means, not only of ascertaining the compression of Jupiter's spheroid, but they prove that his mass is not homogeneous. Although the apparent diameters of the satellites are so small that they can scarcely be measured, yet their perturbations give the values of their masses with considerable accuracy—a striking proof of the power of analysis.

A singular law obtains among the mean motions and mean longitudes of the first three satellites. It appears from observation that the mean motion of the first satellite, plus twice that of the third, is equal to three times that of the second; and that the mean longitude of the first satellite, minus three times that of the second, plus twice that of the third, is always equal to two right angles. It is proved by theory, that, if these relations had only been approximate when the satellites were first launched into space, their mutual attractions would have established and maintained them, notwithstanding the secular inequalities to which they are liable. These extend to the synodic motions[13] of the satellites: consequently they affect their eclipses, and have a very great influence on their whole theory. The satellites move so nearly in the plane of Jupiter's equator, which has a very small inclination to his orbit, that the first three are eclipsed at each revolution by the shadow of the planet, which is much larger than the shadow of the moon: the fourth satellite is not eclipsed so frequently as the others. The eclipses take place close to the disc of Jupiter when he is near opposition;[14] but at times his shadow is so projected with regard to the earth, that the third and fourth satellites vanish and reappear on the same side of the disc. These eclipses are in all respects similar to those of the moon: but, occasionally, the satellites eclipse Jupiter, sometimes passing like obscure spots across his surface, resembling annular eclipses of the sun, sometimes like a bright spot traversing one of his dark belts, and even sometimes as a dark spot upon the belt. This last fact, observed by Schröeter and Harding, has led to the conclusion that some of the satellites have occasionally obscure spots on their own bodies, or in their atmospheres. Before opposition, the shadow of the satellite, like a round black spot, precedes its passage over the disc of the planet; and, after opposition, the shadow follows the satellite.

In consequence of the relations already mentioned in the mean motions and mean longitudes of the first three satellites, they never can be all eclipsed at the same time: for, when

[13] *Synodic motion of a satellite.* Its motion during the interval between two of its consecutive eclipses. (Somerville's note.)

[14] *Opposition.* A body is said to be in opposition when its longitude differs from that of the sun by 180°. (Somerville's note.)

the second and third are in one direction, the first is in the opposite direction; consequently, when the first is eclipsed, the other two must be between the sun and Jupiter. The instant of the beginning or end of an eclipse of a satellite marks the same instant of absolute time to all the inhabitants of the earth; therefore, the time of these eclipses observed by a traveler, when compared with the time of the eclipse computed for Greenwich, or any other fixed meridian, gives the difference of the meridians in time, and, consequently, the longitude of the place of observation.[15] The longitude is determined with extreme precision wherever it is possible to convey the time instantaneously by means of electricity from one place to another, since it obviates the errors of clocks and chronometers.

Satellites of Saturn, Uranus and Neptune

The little that is known of the theories of the satellites of Saturn and Uranus is, in all respects, similar to that of Jupiter. Saturn is accompanied by eight satellites. There has been much confusion about their nomenclature owing to some astronomers numbering them in the order of their discovery, and others according to their distances from Saturn. At the suggestion of Sir J. Herschel they are now called after the heathen deities Iapetus, Hyperion, Titan, Rhea, Dione, Tethys, Enceladus, and Mimas; Iapetus being the most distant and Mimas the nearest to Saturn. The size of these satellites is not accurately known. Titan, which is the largest, is about the size of Mars. Hyperion was simultaneously discovered in 1848 by Mr. Bond[16] in America, and the distinguished astronomer Mr. Lassell,[17] of Liverpool. The orbit of the most distant satellite is inclined about $12^\circ\, 14'$ to the plane of the ring; but the great compression of Saturn occasions the other satellites to move nearly in the plane of his equator. So many circumstances must concur to render the two interior satellites visible, that they are only seen with difficulty. They move exactly at the edge of the ring and their orbits never deviate from its plane. When Sir William Herschel discovered them in 1789, he saw them like beads, threading the slender line of light which the ring is reduced to when seen edgewise from the earth. And for a short time he perceived them advancing off it at each end, when turning round in their orbits. The eclipses of the exterior satellites only take place when the ring is in this position, and even then, owing to the great distance of Saturn, these eclipses cannot be used, like those of Jupiter, for the determination of longitudes. Of the situation of the equator of Uranus we know nothing, nor of his compression; but the orbits of his satellites are nearly perpendicular to the plane of the ecliptic; and by analogy, they ought to be in the plane of his equator. Uranus is so remote that he has more the appearance of a planetary nebula than a planet, which renders it extremely difficult to distinguish the satellites at all; and quite hopeless without such a telescope as is rarely to be met with even in observatories. Sir William Herschel discovered the two that are farthest from the planet, and ascertained their approximate periods, which his son [Sir John Herschel]

---

[15] The meridian passing through the Observatory of Greenwich (see note 22, *Preliminary Dissertation*) is assumed by the British as a fixed origin from whence terrestrial longitudes are measured. And as each point on the surface of the earth passes through 360°, or a complete circle in twenty-four hours, at the rate of 15° in an hour, time becomes a representative of angular motion. Hence, if the eclipse of a satellite happens at any place at eight o'clock in the evening, and the *Nautical Almanac* shows that the same phenomena will take place at Greenwich at nine, the place of observation will be in the 15th degree of west longitude. (Somerville's note.)

[16] See note 4.

[17] See note 3.

afterwards determined to be $13^{d}\ 11^{h}\ 7^{m}\ 12^{s}.6$ and $8^{d}\ 16^{h}\ 56^{m}\ 31^{s}.30$ respectively. The orbits of both have an inclination of $78^{\circ}\ 58'$ to the plane of the ecliptic. The two interior satellites are so faint and small, and so near the edge of the planet, that they can with difficulty be seen even under the most favourable circumstances: however, Mr. Lassell has ascertained that the most distant of the two revolves about Uranus in $4^{d}\ 3^{h}\ 28^{m}\ 8^{s}.0$ days and that nearest to the planet is $2^{d}\ 12^{h}\ 29^{m}\ 20^{s}.7$ days, and from a long and minute examination he is convinced that the system only consists of four satellites. Soon after Neptune was seen Mr. Lassell (see note 6) discovered the only satellite known certainly to belong to that planet, although he believes he has discovered a second. The elements of the first satellite have been determined by M. Otto Struve,[18] and Mr. Lassell has determined its period to be $5^{d}\ 21^{h}\ 2^{m}\ 7^{s}$. The satellites of Uranus offer the singular and only instance of a revolution from east to west, while all the planets and all the other satellites revolve from west to east. Retrograde motion is occasionally met with in the comets and double stars, and the known satellite of Neptune may possibly also have a retrograde motion,[19] but this is not yet clearly ascertained.

---

[18] See note 29, *Preliminary Dissertation.*

[19] *retrograde motion.* Somerville was correct. Triton, Neptune's largest satellite (six others have since been discovered) is indeed retrograde and the only "large" moon in the solar system to orbit "backwards." The other moons with retrograde orbits are Jupiter's Ananke, Carme, Pasiphae and Sinope and Saturn's Phoebe, all of which are less than one tenth the diameter of Triton. *Bill Arnett's "nine planets" web site*.